This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

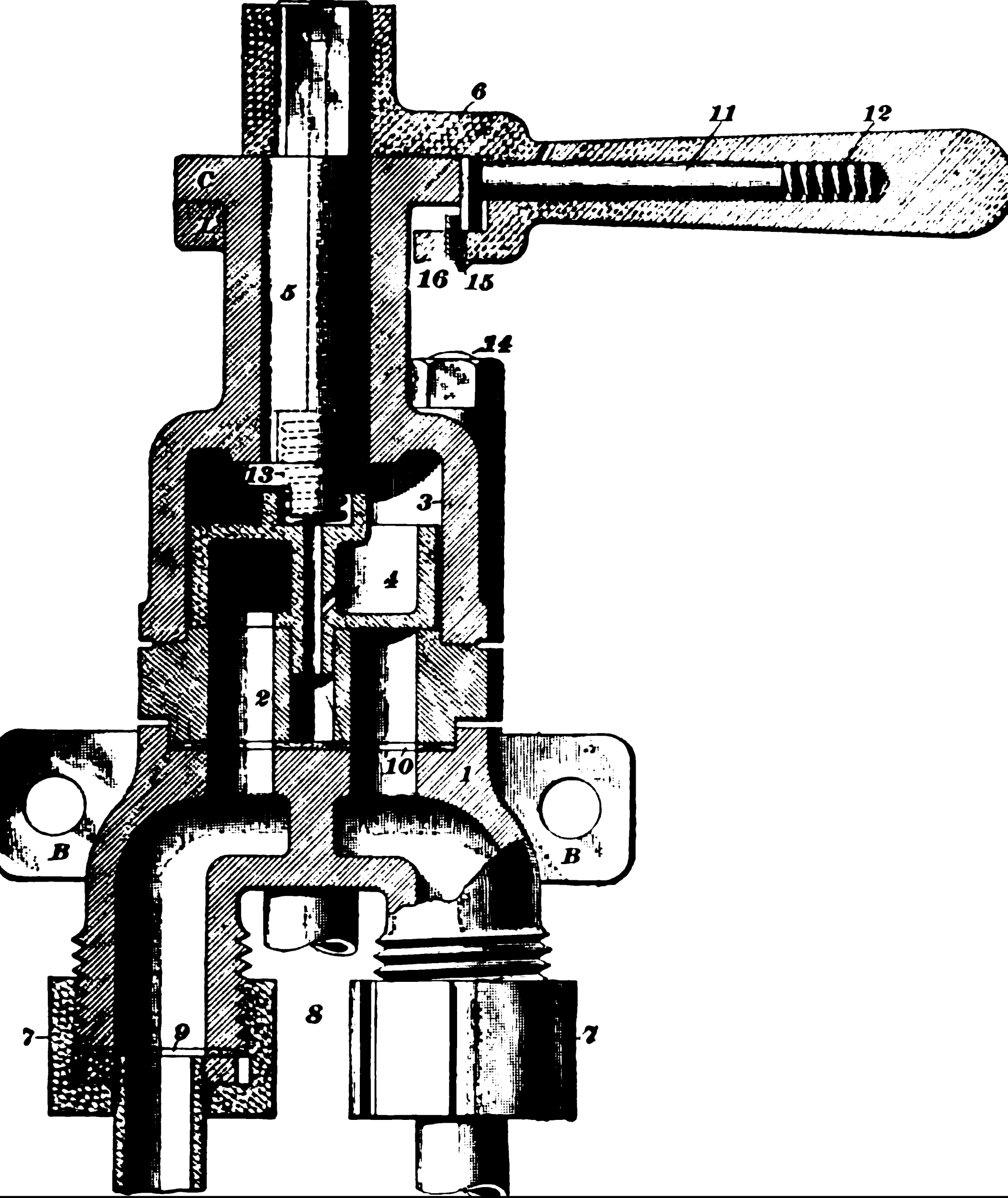
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



Straight air brakes, automatic air brakes, electric brakes and ...

International Textbook Company,
International Correspondence Schools

INTERNATIONAL
LIBRARY OF TECHNOLOGY

A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING
PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE
INFORMATION CONCERNING THEM. FULLY ILLUSTRATED
AND CONTAINING NUMEROUS PRACTICAL
EXAMPLES AND THEIR SOLUTIONS

STRAIGHT AIR BRAKES
AUTOMATIC AIR BRAKES
ELECTRIC BRAKES AND SIGNALS
MECHANICAL INSTRUCTIONS
OPERATING INSTRUCTIONS
TRIAL EQUIPMENT
ARMATURE REPAIR WORK
MAINTENANCE OF EQUIPMENT
ELECTRICAL MEASUREMENTS AND TESTS

SCRANTON:
INTERNATIONAL TEXTBOOK COMPANY
92

92

Printed in the United States.

PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one select the proper formula, method, or process and in teaching him how and when it should be used.

The first portion of this volume contains a comprehensive treatise on straight-air, automatic-air, and electric systems of braking electric cars. Sectional views of the braking devices are shown, indicating the air passages and chambers. Carefully prepared instruction is provided relating to the operation, care, and inspection of the apparatus. The operation of manual and automatic block signal systems is clearly explained. The sections relating to mechanical and operating instructions, repair work, and general maintenance of equipment are of great value to car crews, inspectors, and car-barn men. The information is thoroughly practical and is based on the result of years of experience of some of the largest electric-railway systems. The three sections on armature repair work constitute a practical treatise on the repair of railway-motor armatures; numerous armature-winding diagrams are provided. Methods are explained for making electrical measurements and important tests that can be carried out conveniently without the use of complicated apparatus.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

INTERNATIONAL TEXTBOOK COMPANY

CONTENTS

STRAIGHT AIR BRAKES

ELECTRIC BRAKES AND SIGNALS *Section* *Page*

MECHANICAL INSTRUCTIONS

OPERATING INSTRUCTIONS

TRIAL EQUIPMENT

ARMATURE REPAIR WORK

ELECTRICAL MEASUREMENTS AND TESTS

Continued

STRAIGHT AIR BRAKES

INTRODUCTION

FIELD OF STRAIGHT AIR BRAKES

1. The levers and rods constituting the foundation rigging considered in *Hand-Brakes* are applicable to any system of brakes, either as part of the braking system itself or as part of the auxiliary hand-brake rigging provided in case the main braking system should become disordered.

2. No power-brake system can safely dispense with the hand-brake, and a hand-brake requires foundation rigging. Wherever braking force is applied through shoes, rods and levers must be used. On cars of moderate weight and speed, the hand-brake suffices, because it can be given leverage sufficient to lock and slide the wheels, and, in good hands, a prompt stop can be made with little labor. Heavy high-speed cars, however, require great leverage, and in order to obtain this the power arms must be much longer than their respective weight arms, and the power must move through a comparatively great distance in order to move the weight through a comparatively small distance. For example, on an ordinary hand-brake rigging, the head of the brake handle is the point of application of the power, and the brake shoes are the points of application of the weight. When the brake is released, all shoes clear the wheels by an amount called the *clearance*, which is provided to prevent the shoes from hugging the wheels and impeding their motion while the motive power is on. Motion of the brake handle is transmitted, through the foundation rigging to the shoes, which move toward their respective wheels, but do not exert useful pressure on them until all shoe clearance has been taken up by further movement of the brake handle.

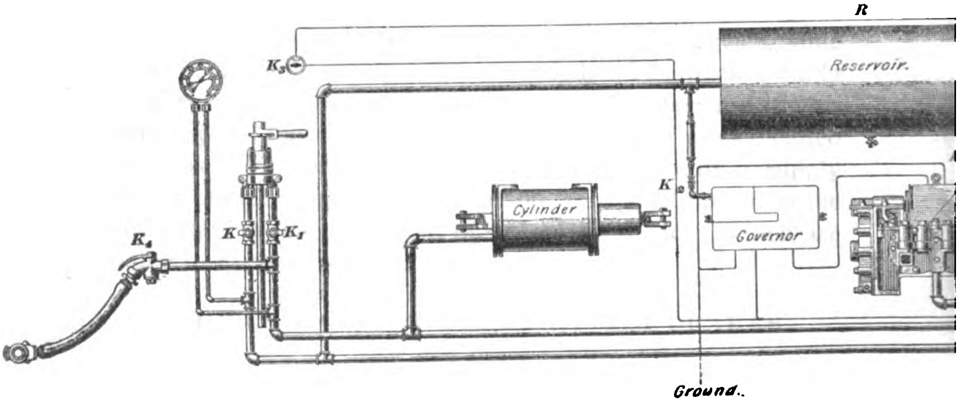
The more powerful the brake rigging is—that is, the greater its leverage—the greater is the distance through which the motorman's arm must move before the shoes appreciably retard the motion of the wheels. Excessive wear of shoes, wheels, and other devices increases the number of turns of the handle necessary to stop the car, thereby increasing the time and distance of an emergency stop, both of which should be a minimum. Accordingly, on heavy or high-speed cars, and even in a double-truck city service, some form of power brake is recommended. The form usually adopted is the **straight air brake,** so called because the air that applies the brakes passes straight into a device called the brake cylinder, from a reservoir that contains a supply of air under pressure. The action of a straight air-brake equipment is not dependent on automatic devices, which are liable to cause trouble.

ADVANTAGES OF STRAIGHT AIR BRAKES

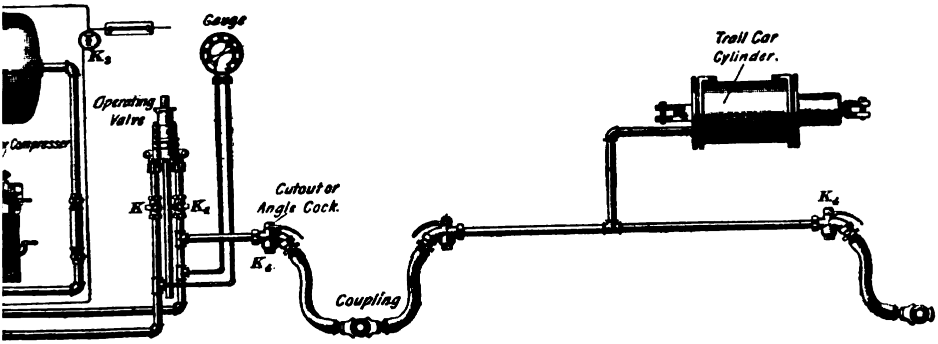
APPLICATION OF BRAKES

3. Greater Safety.—With compressed air, the brakes, in an emergency, can be almost instantly applied at maximum pressure. With hand-brakes, considerable time is spent in taking up the clearance. The maximum braking force can be applied at the maximum speed. When this is done, the tendency to wheel-skidding is reduced to a minimum. With both time and distance of stop at their minimum, the liability to accident is necessarily at a minimum also. In addition, there are no chains to snap.

4. Economy of Labor.—A powerful braking effect is secured without great physical effort, thereby keeping the motorman physically fresh and alert in judgment and action.



Fi


Gauge
K_3
Operating Valve
Compressor
K
K_2
Cutout or Angle Cock.
K_4.
Coupling
Trail Car Cylinder.
K_4

1

19

5. **Simplicity.**—It is easier to acquire proficiency in handling straight air brakes than ordinary hand-brakes. Operation, inspection, and maintenance are easily mastered by any one qualified for the duties of motorman.

6. **Faster Schedules Practicable.**—Stronger release springs are permissible, making the shoes less liable to cling to the wheels. On account of the quickness of stops and promptness of release, less time is consumed in slowing down and starting the car. The certainty of being able to stop almost instantly, if necessary, makes higher maximum speeds safe.

7. **Time of Power Consumption Lessened.**—Higher speeds, in conjunction with coasting, effect a direct reduction in the length of time during which the motive power is applied through a round trip.

PARTS OF STRAIGHT AIR BRAKE

8. The principal parts of a straight air-brake equipment are: the *air compressor*, the *compressor motor*, the *governor*, the *reservoir*, the *gauge*, the *valve*, and the *brake cylinder*. Fig. 1 is a sketch showing the connections of the several parts. The actual disposition of each device depends on the amount and disposal of available space.

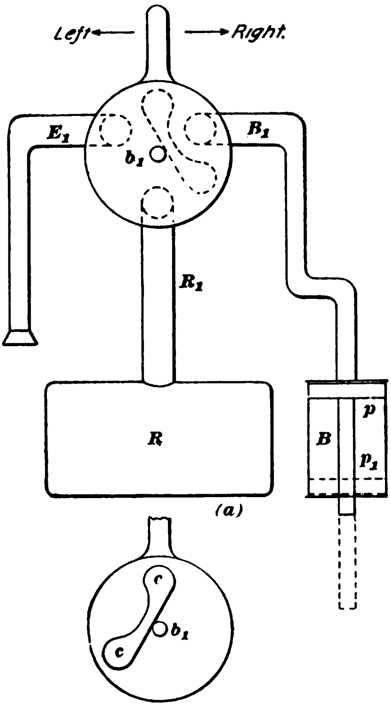
In Fig. 1, K, K are cut-out cocks in the reservoir pipe; K_1, K_1 are cut-out cocks in the brake-cylinder pipe, called the *train line;* K_2 is a cut-out cock in the pipe leading from the reservoir to the governor; K_3, K_3 are snap switches in the motor circuit.

THE BRAKE VALVE

9. The **brake valve**, generally called the **engineer's valve**, is the device by which the motorman applies and releases the brake; it is located on the platform between the hand-brake and controller. The brake valve has three duties to perform. In one position of the handle, the reservoir and brake cylinder are connected, thereby

setting the brakes. In a second position, the brake cylinder and atmosphere are connected, thereby releasing the brakes. In a third position, all air passages are blanked, so that there can be no movement of air.

Fig. 2 shows the nature of the operations that the brake valve performs. B_1, E_1, and R_1 are three pipes leading from the brake cylinder B, atmosphere, and reservoir R, respectively, to the brake valve; on top of the valve body is a cap, Fig. 2 (*b*), that turns around b_1 as a center and has in it a slot cc. In (*b*), the inside of the bottom part of the cap is shown. When the cap is turned over and placed in position on the valve, the slot cc will be in the position shown by the dotted lines in (*a*). In the position shown in the diagram, the handle points front and the ports to which E_1 and R_1 lead are covered by the under side of the valve cap and therefore do not communicate with each other or with the port leading to pipe B_1. If, however, the valve handle is moved to the right, the slot in the cap connects ports B_1 and R_1 and air passes from the reservoir to the brake cylinder and forces piston p toward the dotted position p_1, thereby pushing on the system of levers that set the brakes. If the cap handle is moved back to the vertical position, all the ports are again blocked and the air in the brake cylinder must remain there and keep the brakes set. By moving the valve handle to the left, ports B_1 and E_1 are connected,



(a)

(b)

FIG. 2

thereby allowing the air in the brake cylinder to escape to the atmosphere and permitting the release springs to pull the piston back to its normal position.

THE GOVERNOR

10. When a motor-driven compressor is used, a **governor** must be employed to start and stop the motor between certain predetermined limits of main-reservoir pressure. This can be done by hand, by opening and closing a switch in the motor circuit, but, as a rule, motormen have all they can attend to without having to regulate the air pressure. The automatic governor was introduced for safety and convenience.

The general principles that underlie all governors of this type are the following: The governor must be actuated primarily by the air pressure that it is to control. This air pressure can be made to operate a switch that opens and closes the motor circuit, as indicated in Fig. 3. A switch blade is pivoted at *F* and is connected to a piston stem at *F'*. The trolley wire connects to the blade, and when it touches block *K*, current from the trolley wire can flow through the motor that runs the compressor. Ordinarily, spring *S* keeps the piston *P* pushed over to the right, so that the switch blade touches *K* and the motor runs and compresses the air in the reservoir *R*. As soon as the pressure in *R* gets above the standard pressure, it pushes the piston to the left, thus overcoming the resistance of the spring *S* and forcing the switch blade away from *K*, thereby opening the motor circuit

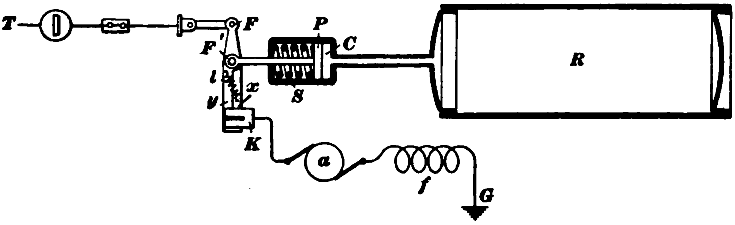


FIG. 3

and stopping the motor. When, from leakage or an application of the brake, the pressure in R gets so weak that the spring S can overcome its pressure on the piston P, the piston moves to the right, closes the switch, and again starts the pump.

The lower end of the blade is in two parts, x and y, one part being hinged to the other. The two parts are attached also by a spring l, whose object is to secure a quick break and avoid an injurious arc when the switch is opened. Part y first moves out of contact with K; then part x is pulled out by the action of spring l.

THE COMPRESSOR

11. The reservoir or train pipe of every air-braked car must be provided with compressed air by an **air compressor,** or **air pump,** located on the car itself, on a car coupled to it, or at designated places along the line. In the latter case, the reservoir on the car must be large enough to store sufficient air to operate the brakes until the next storage plant is reached. Such an arrangement constitutes the *storage air-brake system*. Only *compressor air-brake equipments*, that is, those that are provided with a compressor, will be considered here.

Air compressors or pumps are driven in either of two ways: (1) By being geared to the car axle, in which case they are called *axle-driven compressors;* (2) by means of gearing or direct connection to the shaft of an independently operated electric motor provided for that purpose, in which case they are known as *motor-driven compressors*.

12. Axle-Driven Compressor.—There are several bad features of **axle-driven compressors** that have caused them to lose favor among electric-railway men. Being permanently attached to the axles, they must be disconnected before a set of wheels can be changed. Changing of wheels, on account of flat spots in them, is frequently necessary on electric railways, and especially so on cars equipped with air brakes; and this changing is rendered laborious where compressors are attached to the axles. Again, an axle-driven compressor must run whenever the car is in motion, and it cannot run except when the car is in motion. This feature has two disadvantages: Since the motion of the compressor depends on that of the car axle, there is no simple way of governing the motion of the compressor without affecting that of the car. If the compressor must run whenever the car does, unless means are taken to prevent such a condition, the reservoir may be stored up to its bursting point. This condition is avoided in either of two ways, neither of which is economical. The first way consists in short-circuiting, as it were, the intake and outlet valves of the compressor. The intake, or suction, valve is the opening through which the pump draws its supply of air from the atmosphere into the cylinder; the outlet, or discharge, valve is the opening through which the pump discharges the air into the reservoir after having been compressed.

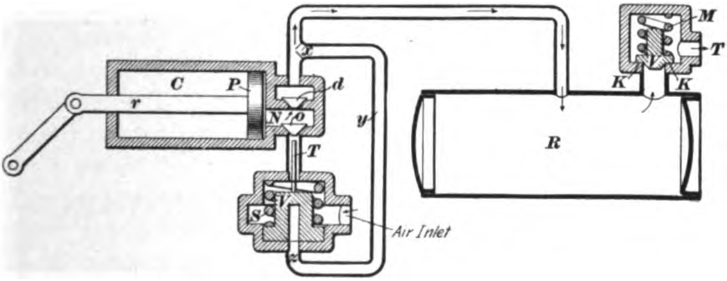


FIG. 4

Fig. 4 shows the short-circuiting plan spoken of above. Suppose that the piston *P* makes a stroke to the left; as it does a vacuum is created on the right-hand side of it, and there being no pressure on top of valve *o*, the air under valve *o* lifts it from its seat and fills all the space on the right-hand side of the piston. When the piston gets as far to the left as it will go, the cylinder is full of air that has come in at *o*. The piston now starts to make a stroke to the right; as it does so, it presses on the air in cylinder *C* and valve chamber *N* and raises its pressure; this closes valve *o*, and as soon as the pressure in the cylinder exceeds that in the reservoir *R*, it lifts valve *d* and the compressed air passes into the reservoir *R*. As the piston continues to move back and forth, each time taking in a cylinder full of air through valve *o* and forcing compressed air into the reservoir through valve *d*, the pressure in the reservoir rises, and it keeps on rising until it becomes great enough to burst the reservoir or some of its connecting pipes, unless a safety valve or other device is provided to render such a result impossible.

In Fig. 4, pipe *x y z* always contains air at reservoir pressure, because one end of it is connected to the reservoir pipe at *x*; also, the air in this pipe presses up under the piston *V*, and tries to raise it against the resistance of spring *S*. Ordinarily, spring *S* is strong enough to keep piston *V* down, so that the stem *T* does not touch valve *o*, and therefore cannot raise it. But whenever the air in the reservoir gets to a certain pressure, it overcomes the resistance of *S* and forces *V* up, so that *T* raises valve *o* and keeps it open so long as the pressure in the reservoir is able to overcome spring *S*. Under this condition, the pump simply draws air into the cylinder through valve *o* and blows it out again through the same valve. In this way no air is wasted, as none is compressed so long as the pressure in the reservoir is up to normal value. When, through leakage or an application of the brakes, the pressure in *R* reduces sufficiently, spring *S* pushes down piston *V* and the pump begins to compress air again.

13. The other method of preventing an excess of pressure is also shown in Fig. 4, on the right-hand end of the reservoir. The method consists in using an ordinary pop, or safety, valve attached to the reservoir or to one of its pipes. In Fig. 4, *M* is a spring, which at all ordinary pressures keeps the valve *V* on its seat, so that no reservoir air can get past the valve. If the pressure in the reservoir gets up to the safe limit, it raises the valve and allows reservoir air to escape through opening *T*. The valve has a shoulder *K*; its object is to expose a larger area to the action of the air when the valve is once off its seat, thereby causing the valve to lift higher than it otherwise would. When the valve acts, it allows enough air to escape to bring the reservoir pressure below the standard.

When the car stands still, the compressor cannot work. This means that if the car stands idle in the shed for some time and all of the air in the reservoir is let out or leaks out, the air brake cannot be used until the car has been run far enough to pump enough air into the reservoir to apply the brake. In the meanwhile the motorman must rely on the hand-brake.

14. Motor-Driven Compressor.—The main objection to the **motor-driven compressor** is its first cost. Nevertheless, it is being almost universally adopted, as it is the most flexible system of brake control in use on surface street cars and gives caretakers an experience that will qualify them to take care of any axle-driven equipment now on the market. The greater part of the present subject, therefore, will be devoted to a consideration of the method of operating the controlling devices on an air car supplied by an independent motor compressor.

CHRISTENSEN STRAIGHT AIR BRAKE

THE ENGINEER'S VALVE

DESCRIPTION

15. Valve Seat, Base, and Seat Gasket.—Fig. 5 is a general view of the **Christensen straight air engineer's valve.** Fig. 6 is a top view of the valve **body,** or **base,** and its connections. Fig. 6 (*a*) is a top view of the base. This position of the base corresponds to section *A*, Fig. 5. Ports B_1, E_1, R_1, lead to the pipes B_1, E_1, R_1; the valve base is countersunk, as indicated at *c*, and on the bottom of the countersunk part is a thin leather gasket *g*, Fig. 6 (*b*), called the **seat gasket.** The middle section, or **valve seat** *B*, Fig. 5, seats on this gasket, which has holes to correspond to those in the seat and base. Fig. 7 is a top view of the middle section. The holes B_1, E_1, R_1 are a continuation of those in the valve base and gasket, when the seat is in the proper position. The valve, which will be considered later, rotates on the upper surface of *B*.

16. Valve Disk, Stem, and Spring.—In Fig. 8, (*a*) shows the **valve disk** proper looked at from above and from the side, and (*b*) shows the two ports and passage in the bottom of the valve. In (*a*), *o* is an oil hole extending through the valve disk and valve-handle stem shown in Fig. 9. In Fig. 8 (*a*), *a*, *a* are two shoulders cast on top of the valve disk and machined to form slot *K*, in which tongues *l*, *l*, Fig. 9, on the valve-handle stem fall in place, thereby enabling the handle to turn the valve. The handle fits on the stem at *H*, Fig. 9; *T*, Fig. 8 (*a*), is a pinhole that receives the pin *p*, Fig. 9; the pin and hole

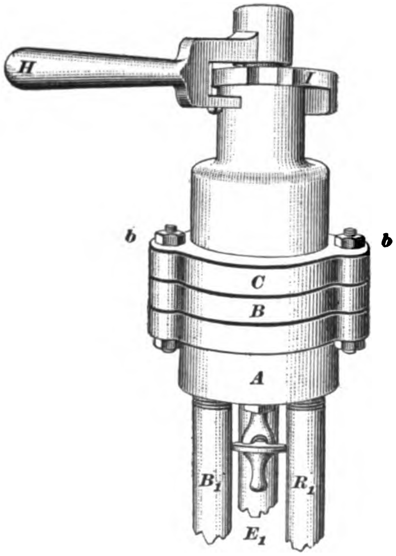
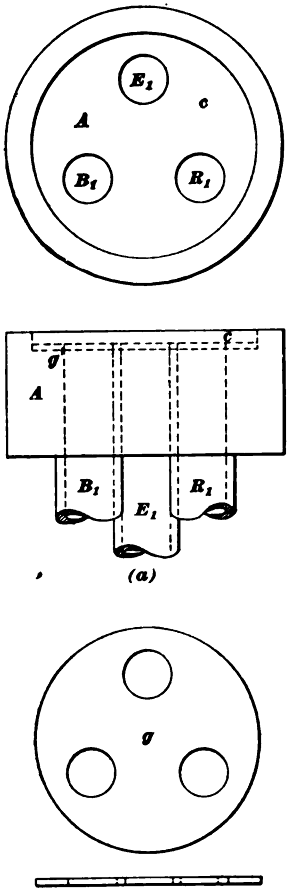


FIG. 5



(a)

(b)

FIG. 6

act as guides to prevent the stems being put in end for end, thereby having the valve handle point in the wrong direction, when in lap position. In Fig. 8 (*b*), the dotted line indicates that the two holes, or ports, *p*, *p* connect by means of a cavity cored in the valve disk. The surface of the disk *x* between the two ports *p*, *p* is a machined surface that blanks any port that it may cover.

Fig. 10 shows a spiral spring, one end of which sets in a countersunk space in the valve disk; the other end extends into space *s*, Fig. 9, of the stem,

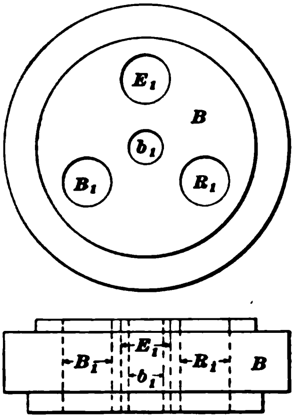
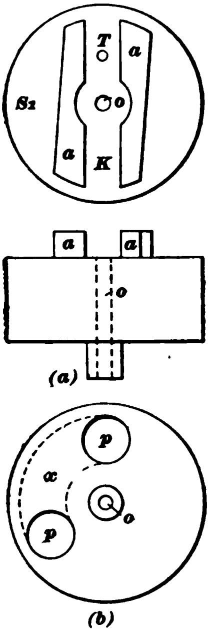


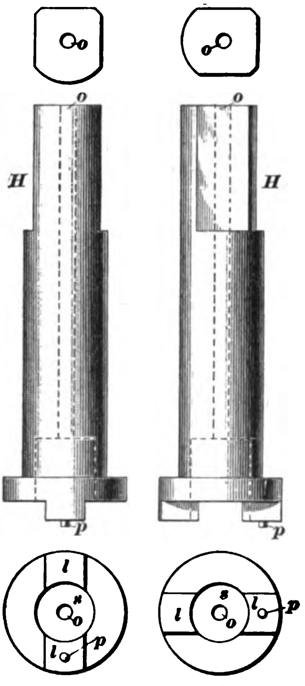
FIG. 7



(a)

(b)

FIG. 8



(a) (b)

FIG. 9

so that the stem must be forced down into its position against this spring, thereby pressing the valve against its seat.

17. Assembly, Valve Handle.—Fig. 11 shows the

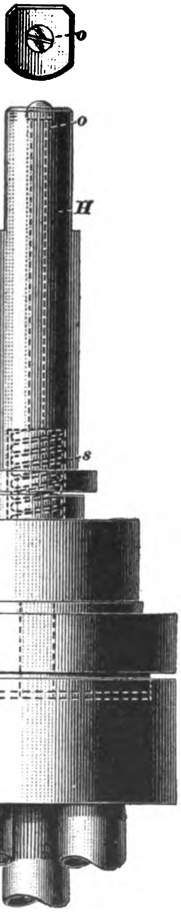


Fig. 11

Fig. 10

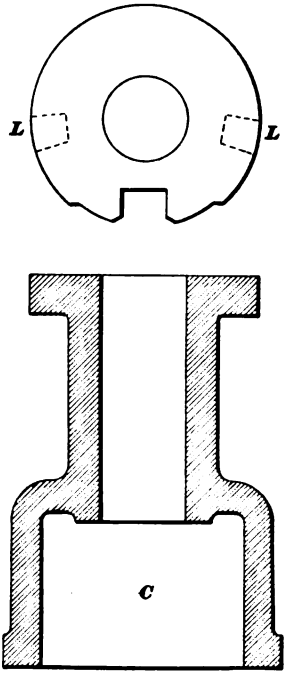


Fig. 12

parts assembled and Fig. 12 shows the valve cap *C*. Fig. 13 shows the valve handle recessed to receive spring *s* that presses on the pawl *p* and gives decision to the notches. Fig. 14 is a section through a Christensen brake valve; *1* is

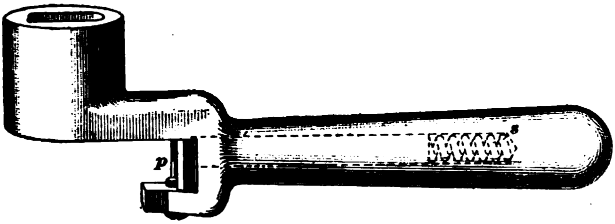

s
p

Fig. 13

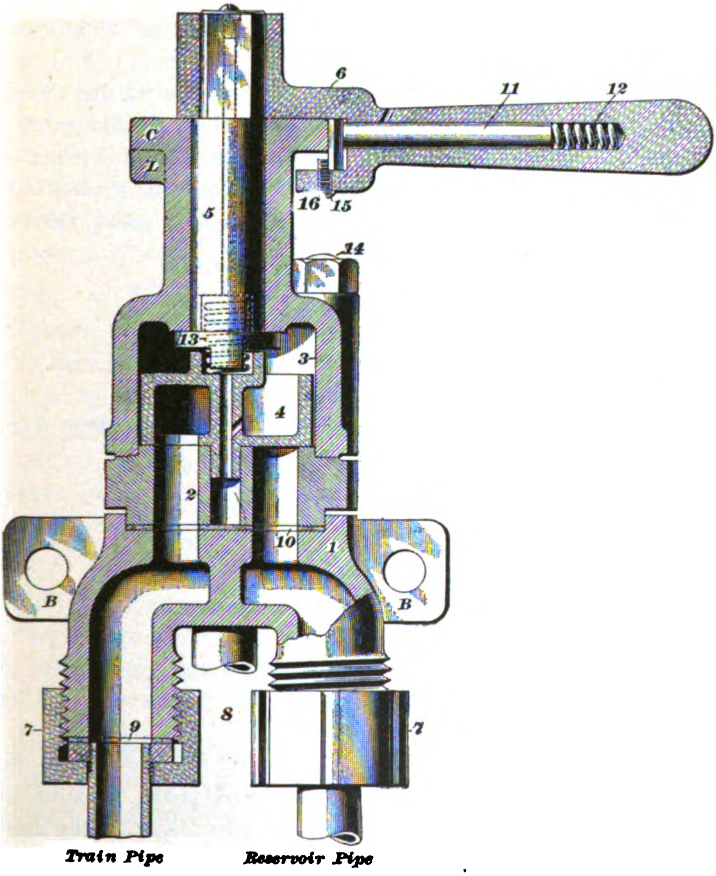

6
11
12
C
L
5
16
15
14
13
3
4
2
10
1
B
B
7
9
8
7
Train Pipe
Reservoir Pipe

Fig. 14

the valve base provided with a bracket *B*, by means of which the device can be anchored to the dash iron; *2* is the valve seat or middle section; *3*, the cap; *4*, the valve disk; *5*, the stem; *6*, the handle; *7*, *7*, union nuts that connect the train-line and reservoir pipes to the base; *8*, the exhaust pipe; *9*, a gasket; *10*, the valve-seat gasket; *11* and *12* are the latch and spring that give decision to the notches; *13*, the stem spring; *14*, one of the bolts that secure the parts of the valve in place; *15*, a screw to limit the amount of motion of latch *11*.

POSITIONS

18. Designation.—Fig. 15 is a top view of the Christensen valve, as it appears on a car. The dotted circles indicate the exhaust, reservoir, and train-pipe connections as marked. There are five positions; namely, *lap*, *service stop*, *emergency stop*, *slow release and running*, and *quick release*.

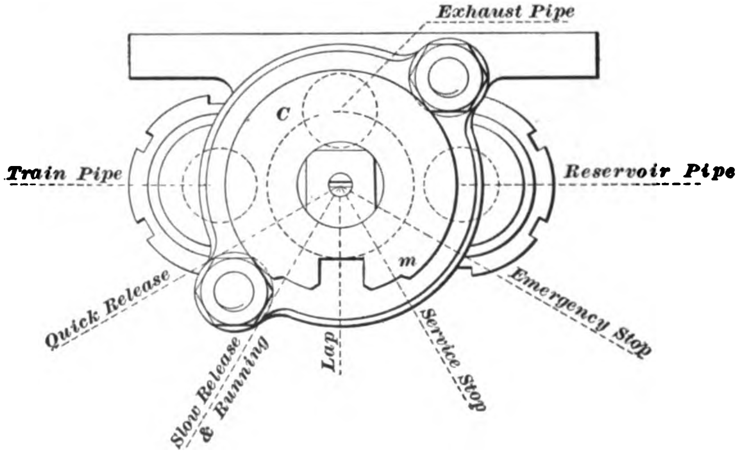


FIG. 15

19. Lap Position.—The brake-valve handle can be removed or installed only at the **lap position**, because in all other positions lug *16*, Fig. 14, interferes with the cap-crown *C*. In the lap position, the handle points toward the motorman; all ports are blanked so that none of the three pipes can communicate with each other. If there is any air in the brake cylinder, it is held there.

20. **Service Position.**—To make a service stop, the operating handle is moved to the right into the **service position.** In Fig. 14, it will be noticed that latch *11* presses against the crown *C*; by this means, it is easy to tell when the handle reaches the service position, because the latch interferes with the shoulder *m*, Fig. 15, to pass which force must be used. In the service position, a small opening is created between the reservoir and brake cylinder, so that compressed air passes from the reservoir into the cylinder. The flow of air is gradual, and the degree to which the brakes set depends on how long the valve is allowed to rest in the service position. If, in making a service application, the motorman finds that the car is going to stop too soon, he eases off the brakes by letting a little air out of the brake cylinder; this is done by throwing the handle to the slow-release position.

21. **Slow-Release Position.**—In the **slow-release position** a small opening is created between the brake cylinder and exhaust pipe, thereby letting brake-cylinder air escape to the atmosphere; this lowers the pressure in the brake cylinder and tends to release the brakes. If the handle is left on the slow-release position too long, the brakes will release entirely, because all the brake-cylinder air escapes to the atmosphere.

22. **Quick-Release Position.**—When the handle is moved to the **quick-release position,** the brake-cylinder air escapes to the atmosphere in a single puff; this gives the release springs a chance to pull the brake piston, levers, and shoes promptly to the release position.

23. **Emergency Position.**—If the handle is moved to the right as far as it will go, a full and unobstructed passage is opened between the reservoir and brake cylinder, thereby allowing the full reservoir pressure to act on the brake piston, setting the brakes with full force immediately;

this position is known as the **emergency position.** On the under side of the cap crown, in both the full-release and emergency positions, is a lug that stops the handle at the proper place. One of these lugs is indicated at *L*, Fig. 14.

OPERATION

24. Under Headway.—It is customary to run with the operating handle in the slow-release, or running, position, where the brake cylinder connects with the atmosphere, so that there is no danger of compressed air accumulating in the cylinder and slowly setting the brake. The same is true of the full-release position, as far as creeping of the brakes is concerned. As the slow-release position serves every purpose, as there is no advantage in using quick release, and as it is more convenient, on account of its nearness to the lap position, to use the slow-release position, that position is used for running and is designated as the **running position.** The lap position can be used for running, but such practice has two disadvantages:

1. Failure to release all the air used in a previous application is liable to cause the car to run with the brake partially set, because all the ports are blanked in lap position.
2. If there happens to be any leakage between the reservoir and train-pipe ports in the brake valve, air will get into the brake cylinder and the brakes will slowly creep on unknown to the motorman.

There is only one valve handle to a car, so that since the handle can be removed only on the lap position, when the handle is not in place, both valves must be in the lap position, unless one of them has been turned by hand or with a wrench. As a rule, when the device leaves the factory, the fit between the valve stem and cap is such that the stem cannot be moved by hand; there have, however, been cases where valves installed in service have been made to work so easily that they could be turned by hand to the service or release position. If the valve on the rear end of the car is turned to the release position, there will be a constant loss of air through the valve, so that although the motorman may apply the brakes they will not hold; if the rear valve is turned to service position, the brakes will apply without the motorman's knowledge of the cause.

On some types of brake valves an open hood is cast on the valve crown, as indicated in Fig. 16, thereby permitting easy instalment of the handle between the stem and hood, but rendering it impossible to turn the valve stem by hand.

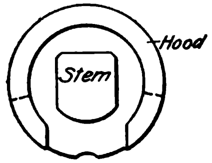


FIG. 16

25. Starting.—The first thing a motorman must do after installing his handle, is to throw it to full release to insure that the car may not be started with the brake partially set. He must also be certain that the hand-brake is not set on either end. The quick release is provided to "kick off" the brakes; it lets air out of the brake cylinder with a rush, and the release springs, being allowed to act with an impulse, are more certain to act reliably. Some brake valves do not have a marked slow-release position; in such cases a slow release is obtained by quickly snapping the valve to the release position and back to lap again.

26. Stopping.—The emergency position is provided to effect a very sudden stop in time of danger. The emergency position enables the brakes to set much more quickly, but does not set them any harder. If the operating handle is left on the service stop long enough, just as much air will get into the brake cylinder as in an emergency application. When communication between the reservoir and cylinder is maintained long enough for the two to acquire the same pressure, the reservoir pressure and brake-cylinder pressure are said to have equalized.

Ordinarily, in service stops, equalization does not take place; the motorman puts the valve in the service position, but throws it into the lap position before the brake piston reaches the end of its stroke. He allows the valve to rest on the service position long enough to let a little air into the cylinder and its connecting pipes; this air expands, forces the brake piston out a certain distance, and partially sets the brake. If this partial setting is not sufficient to make the required stop, the valve is once more thrown to service position, letting in a little more air, which sets the brake harder. The operation is repeated as often as is necessary. Usually, after a service application, the reservoir pressure exceeds that in the cylinder, as is evidenced by the fact that if the valve is placed in the service position after the car is stopped, the gauge hand shows a further reduction in the reservoir. A service application does not reduce the reservoir pressure as much as an emergency application, which allows the cylinder and reservoir to equalize almost immediately.

27. Precautions.—Each application of the brake reduces the pressure available for making the next stop. There must be a limit below which the reservoir pressure should not be allowed to fall, as an occasion for an emergency stop might arise when the full reservoir pressure would be needed. It is equally important that the reservoir pressure should not exceed a certain value, because such a condition invites leaks, may stop or injure the compressor motor, or burst the reservoir. Ordinarily, the regulating devices are so adjusted that the reservoir pressure cannot exceed 60 or 65 pounds per square inch nor become less than 45 or 50 pounds per square inch. The present tendency is toward the use of greater pressures—80 to 90 pounds. As the reservoirs are tested to a pressure of 200 pounds per square inch, the chances of explosion are small. The gauge shows the pressure in the reservoir, and no excuse should be accepted for a motorman letting the pressure get below the allowable amount. There is a margin of 10 or 15 pounds between which limits the reservoir pressure can vary with no bad results. In order to reduce a reservoir pressure from 60 or 65 pounds to 45 or 50 pounds, at least three emergency applications are necessary; how many service applications can be made within this margin depends on how much air the motorman wastes and on local conditions. It takes less air to stop on an up grade than on a level, less on a level than on a down grade, and it should take less to stop on a slippery rail than on a good one, because on a slippery rail an ordinary application of the brake may grip the wheels so hard as to stop them from rotating and cause them to slide on the rail until the car is brought to a stop.

Different valves vary in construction, but all operate to the same end. The neutral or off-position is always the lap position, and the handle must occupy this position before it can be removed. The reason for this is that when the motorman must go from one end of the car to the other, air will be held in the brake cylinder while he is changing ends; but too much reliance must not be placed in the ability of the lap position to hold the air in the brake cylinder for any length of time. Air under a pressure of 60 or 75 pounds is very active, and if there is the least crack for it to leak through, it will do so. In case of a leak in the brake cylinder or between the valve, exhaust, and cylinder ports, or in any of the pipes or couplings involved in their connection, the brakes are likely to leak off. Therefore, under no circumstances should a car that is provided with air brakes be left unattended unless the hand-brakes have been set. This rule holds good on the service position as well as on the lap position. If the valve is left on service position, the brake cylinder being in communication with the reservoir, all air must leak out of both before the brakes can release entirely.

28. Effect of Equalization.—If after equalization due to an emergency or an excessively long service application, the valve is thrown to the lap position, the cylinder is cut off from the reservoir, but each continues to hold the pressure that existed just before the valve was lapped. The pressure holding the brake is then the same as if the reservoir and cylinder were still connected. This pressure is not, however, the same as the pressure that existed in the reservoir before the brakes were applied.

Before the brake is applied, the pressure in the reservoir is due to the pressure of a certain amount of air there; an application of the brake causes this air to expand in the cylinder and its connecting pipes, thereby practically increasing the capacity of the reservoir, so that the given amount of air is not confined in as small a space as before. How much the pressure drops through equalization depends on the relative sizes of the reservoir and cylinder. Assuming their capacities to be the same and the reservoir pressure to be 60 pounds per square inch, the pressure in both, after equalization, will be 30 pounds per square inch. The capacity of the connecting pipes is not considered in this case.

INSPECTION

29. The engineer's valve should be taken apart at regular intervals and dipped in gasoline. The valve and seat should then be served with a light coat of valve grease and the valve reassembled before dust can collect. Never try to take the valve apart without exhausting the air. The first symptom that the valve is in bad order is a leakage, which may cause the brake to leak on or off. A leak between the main reservoir and the train-pipe ports will cause the brake to creep on if the valve is held on lap position for any length of time. A leak between the train pipe and exhaust ports in the valve will cause the brake to leak off when applied, making it necessary to apply more air to hold the car. Any kind of a leak in any of the devices on an air-braked car increases the work that the compressor must do, because all wasted air must be replaced.

THE PRESSURE GAUGE

INTRODUCTORY REMARKS

30. The **air gauge**, or **pressure gauge**, shows the pressure in the device to which it connects. Some gauges have one hand, others two; in the latter case they are called *duplex gauges*. Single cars require but one gauge hand, because only reservoir pressure need be indicated. Where

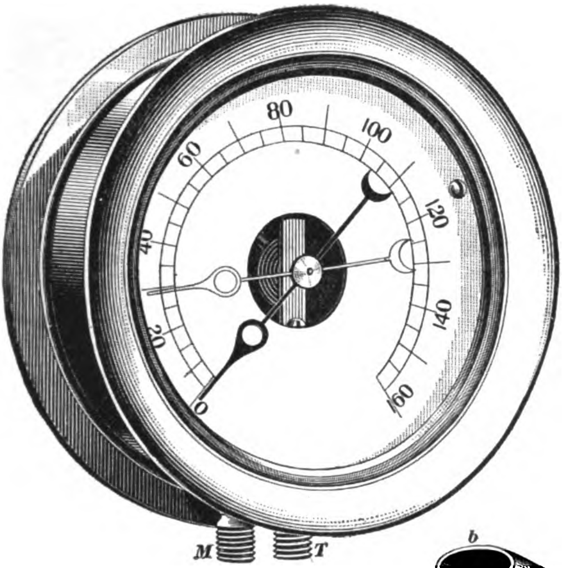
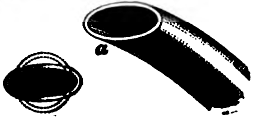


FIG. 17



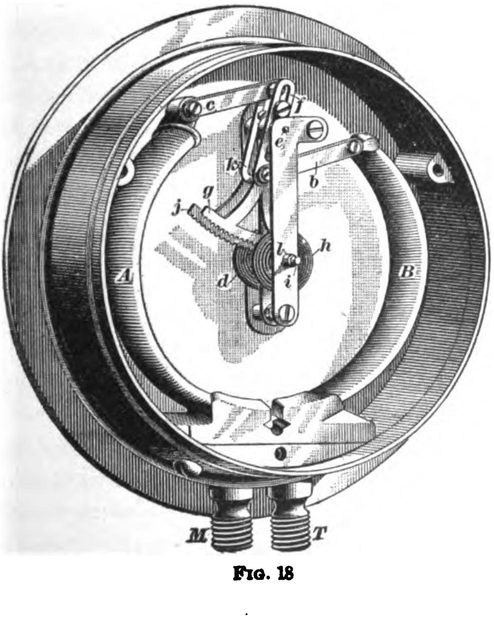


FIG. 18

two or more air-braked cars are coupled, a duplex gauge is used, the red hand showing reservoir pressure and the black hand showing brake-cylinder or train-pipe pressure.

DESCRIPTION

31. A duplex air gauge is shown in Figs. 17 and 18. It really consists of two gauges combined in one case, the same scale serving for both hands. The right-hand gauge which connects with *T*, Fig. 18, operates the black hand. This gauge is piped to the train-line pipe beyond all cut-out cocks that may be used on the platform, and it shows, at all times, the air pressure in the train line. The other connection *M*, a part of the left-hand gauge, is piped to the reservoir and indicates reservoir pressure under all service conditions. This gauge operates the red hand.

An inside view of the air gauge is given in Fig. 18. *A* and *B* are two bent metal tubes of elliptic shape, as shown in the separate views. The tube *B* is connected to fitting *T* and tube *A* to fitting *M*. The bottom ends of the tubes are held fast, but the top ends are free. The action of the gauge may be explained as follows: If a tube of elliptic section is bent as shown in Fig. 18 and then subjected to an internal pressure (of either a gas or a liquid), the force exerted will tend to straighten the tube. This is due to the fact that the force exerted within the tube tends to make it assume a circular form. In assuming the circular form, the concave side *a* of the bent tube tends to lengthen, and the convex side *b* to shorten; these two effects conspire to straighten the tube, and in this way impart a movement to the free end. Tube *A* is connected to one end of the lever *kj* by means of the rod *c*. This lever is pivoted at *e*, and the end *j* forms a toothed sector that gears into a pinion on the spindle *i*. The spindle *i* carries the red hand of the gauge, and works within a hollow spindle *l*, which carries the black hand. Tube *B* is connected by rod *b* to the lever *fg*, at a point below the fulcrum or pivot, so that the black hand will be turned in the same direction as the red hand. The lower end of the lever *fg* takes the form of a toothed sector that gears into a pinion on the hollow spindle *l* and operates the black, or brake cylinder, hand.

OPERATION

32. Since the reservoir connects with *M*, reservoir air enters tube *A* under pressure and tends to straighten it. This causes the free end of *A* to move to the left, drawing the rod *c* with it, thus moving the toothed sector *j* to the right. As this sector engages with the spindle *i*, the latter is made to move in a clockwise direction, thereby giving the red hand a similar motion. Train-line pressure enters *B* through fitting *T* and tends to straighten it, thus moving its free end to the right. As bar *b* is connected below the fulcrum of lever *fg*, the movement of the free end of *B* will cause the toothed sector *g* to move to the right and turn the black hand also in a clockwise direction. The greater the pressures within the tubes, the more will they straighten and the farther around the scale will the gauge hands move. Coiled springs *d* and *h* take up the lost motion in the sector and pinion teeth. By means of the adjusting screws and slotted levers shown in Fig. 18, the gauge lobes *A* and *B* are so adjusted that when they are not acted on by pressure, their respective hands point to zero.

LOCATION

33. The pressure gauge should be placed within the motorman's range of vision when he is looking straight ahead; that is, he should be able to see it without withdrawing his attention from the road ahead. On most systems, the gauge is supported by its pipes, or by a bracket, in front and to the right or left of the motorman's head. On many roads, it is the custom to curtain or paint the end glasses on vestibuled cars, so that the light from the car lamps cannot blind the motorman; in such cases a clear space should be left so that light may fall on the gauge.

Any irregularity in the indication or condition of the gauge should be reported, so that the trouble may be located and removed before it causes more serious troubles.

GAUGE TESTS

34. Duplex Gauge.—Indirectly, the air gauge indicates many things about the condition of the air equipment. Suppose, for example, that there is a leak in the reservoir or in one of its pipe connections, or that its bleed cock has been left partly open: in this case there is a constant loss of air from the reservoir, and the red hand will be observed to fall back slowly, regardless of the position of the brake valve, showing that the reservoir pressure is diminishing through a leak. When the brake valve is thrown to service or emergency position, the brake cylinder and reservoir are connected, so that a leak in either will cause both hands to drop back slowly if the valve remains in that position long enough for the brake cylinder and reservoir to equalize. When the application is first made, the red hand drops suddenly, due to the reservoir air expanding into the brake cylinder, and the black hand rises, due to the air let into the brake cylinder. When, however, the valve is put back on lap position, after an application, both of the gauge hands should remain steady; if the red hand falls slowly, it indicates a leak in the reservoir or its pipe line; if the black hand falls, the leak is in a brake cylinder or in the train pipe.

In an ordinary service application, the brake valve is not left on the service position long enough for the reservoir and brake-cylinder pressures to equalize and become the same, so that when the valve is returned to the lap position the red hand may register a great deal more than the black hand. If, after a service application, and with the brake valve on the lap position, the red hand creeps down and the black hand creeps up, it shows that the reservoir and brake cylinder are equalizing through a leak in the brake valve. When the brake valve is in the release position, the black hand should register zero, because the brake cylinder is open to the atmosphere. To find out if there is a leak in the brake system, pump the reservoir up to full pressure, place the operating valve on lap position, and watch the gauges. If the red hand creeps down, there is a leak; if the black hand creeps up at the same time, the leak is in the valve itself between the reservoir and train-pipe chambers.

On a single car provided with only one gauge hand, the motorman has no direct way of telling if there is any air in the brake cylinder, so that his only safeguard is to be certain and release fully after each application. For this reason, it would be well to use a duplex gauge, even on a single car. Next, throw the operating valve to the service or emergency position long enough for the reservoir and brake cylinder to equalize, and then return it to the lap position. If the black hand now remains stationary, but the red hand creeps down, the leak is in the reservoir line; but if the red hand remains stationary, and the black hand creeps down, the leak is in the train line. If there are two or more cars, the train-line leak can be located as follows: Referring to Fig. 1, cut out the brake valves by means of stop-cocks K, K_1 on both ends of the car; if this stops the leak, the trouble is in one of the valves. To find out which valve, cut them out one at a time. If the cutting out of the valve does not cut out the leak, it must be in some brake cylinder, train-line pipe, or coupling. To find the faulty car, begin at the last car and turn, one after the other, the angle cocks K_4; as soon as the cock that cuts out the leak is turned, it may be known that the leak lies between that cock and the one behind it.

35. Single-Hand Gauge.—On a single car, the train pipe being short and there being few cocks and no couplings and but one brake cylinder, there is much less liability of having train-pipe leaks, and when they do occur, they are in most cases due to faulty packing on the brake piston. A single car generally has a single gauge, which is piped to the reservoir pipe; in case of a leak in the reservoir or its pipes, the hand will creep down. To find out if there is a leak in the train pipe, cylinder, or any of their connections, pump the reservoir up to full pressure with the valve in the release position; then throw the valve to the lap position. If the gauge hand holds its own in both of these positions, it is safe to assume that the reservoir connections are free from leaks. This being the case, throw the valve to service or emergency position. The gauge hand will drop several pounds due to the expansion; but after equalization has taken place, the hand should remain stationary at the reduced pressure. If it creeps down, there is a train-pipe leak.

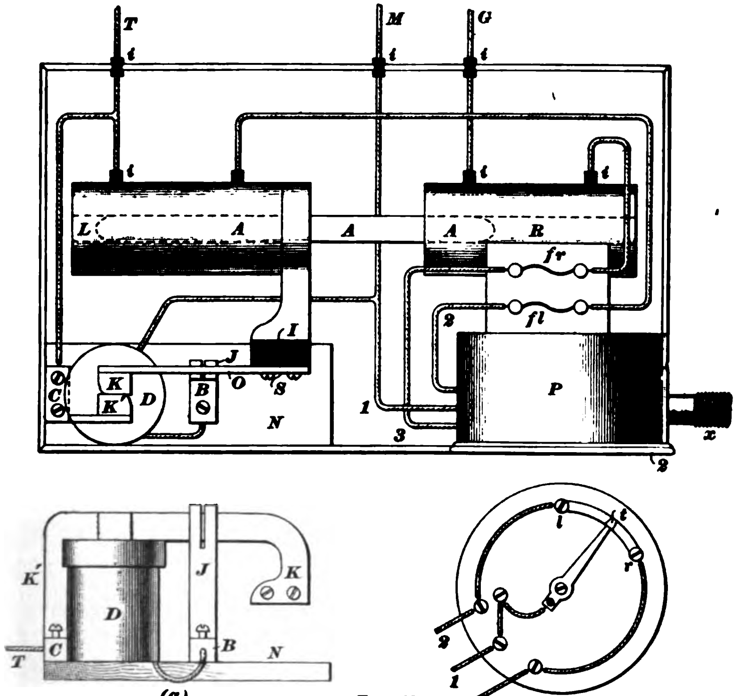
GAUGE FAULTS

36. Occasionally, an apparent leak in the brake system is due to a leak in the gauge. An inside fitting may be loose, or the gauge tube may have minute holes in it; in either case, the gauge will not indicate correctly, because some of the air that should act on it escapes at the point of leakage. As there are always two gauges on a car, one on each end, a defective gauge is readily detected by the discrepancy in their readings. The easiest way to locate a leak exactly, is to bring air pressure to bear on the leak and then listen for the noise of escaping air.

THE GOVERNOR

DESCRIPTION

37. The Armature and Magnets.—A top view of the automatic governor, or **the automatic**, used on Christensen air-brake equipments is shown in Fig. 19. *L* and *R* are electromagnets. The armature, or plunger, *A A* can slide back and forth between the magnets, and it carries an arm to which is fastened finger *K*, insulated from the plunger block *I*. When the current passes through magnet *L*, the armature *A A* is pulled to its extreme left-hand position. Finger *K* makes contact with finger *K'*. When the current passes through magnet *R*, the armature is pulled to the right and the motor circuit, of which *K* and *K′* are a part, is opened. The total current taken by the compressor motor passes through *D*, which acts as a blow coil to extinguish any arc that may form between *K* and *K′*. When fingers *K* and *K′* touch each other, the current coming in on trolley wire *T* takes path *T–C–K′–K–J–B–D* through the blow coil over to wire *M* that leads to the compressor motor circuit. Whenever *K* and *K′* touch each other, the compressor motor starts and runs until current excites coil *R*, which pulls apart fingers *K* and *K′*, thus opening the motor circuit.



(a) FIG. 19 (b)

38. The Regulator.—Whether *R* or *L* will get current depends on the action of the **regulator.** The action of this device *P* is similar to that of the gauge just considered.

The gauge hand, instead of being used to indicate pressure on a scale, carries on its end a carbon knob *t*, Fig. 19 (*b*) or Fig. 20 (*a*), that plays between contact buttons. On some governors, the movable hand is connected to an extension of the pin, instead of being screwed to it, as indicated in Fig. 19 (*b*).

The contact buttons are lettered *l* and *r* because when *t* touches button *l*, magnet *L* gets current, when *t* touches *r*, magnet *R* gets current. Pipe connection *x*, Fig. 19, goes to the reservoir or to one of its pipes, as shown in Fig. 1. In Fig. 19, f_r is a fuse in circuit with magnet *R*, and f_l is a fuse in circuit with magnet *L*. One end of the fuse f_r leads to connection *3* in the rear of the regulator and from there to contact button *r*. The other end goes to magnet *R*. One end of fuse f_l goes to post *2* on the rear of the regulator, and thence to contact button *l*; its other end connects to magnet *L*. Middle contact post *1* on the rear of the regulator connects to the hand that carries carbon knob *t*; as the hand moves, the connection is kept complete by means of a flexible wire. Post *1* also connects on the outside to the wire that runs from the blow coil *D* to the motor circuit. All shaded parts marked *I* or *i* are made of hard-rubber insulating material. Wires *T*, *M*, and *G* are the main governor wires leading to the car trolley wire, the pump motor, and the car ground wire, respectively.

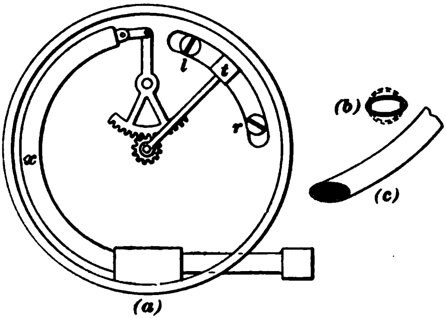


FIG. 20

CONNECTIONS

39. Fig. 21 shows the connections of the governor. The trolley wire comes in at the left-hand bushing near *T*, after passing through switch *K* and fuse *F*. The governor trolley wire taps to the car trolley wire on the negative side of one or both motor switches or breakers, so that if one or both of the motor switches are open, the governor and hence the pump motor cannot get current. The current for the governor passes through either of two snap switches, Fig. 1, one of which is on either end of the car. Assuming that the pump-motor trolley wire is tapped to the car trolley wire on the negative side of both motor switches, both these switches and one pump-circuit snap switch must be closed before the motor can start; also, if either of the main switches is opened, the motor can get no current. On ground-return cars employing breakers connected in parallel, as in Fig. 22, if the pump trolley taps on the negative side of the breakers, both must be open to kill the pump circuit.

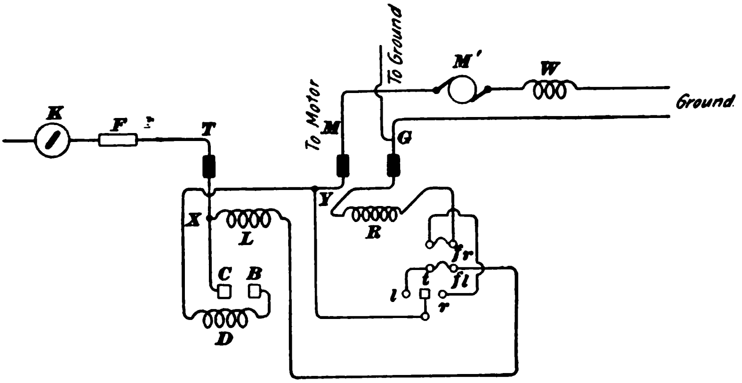


FIG. 21

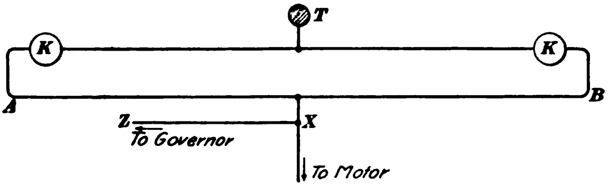


FIG. 22

On ground-return systems using ordinary overhead switches, or on metallic-return systems using breakers, the devices are connected in series, as shown at *K*, *K*, Fig. 23.

In Fig. 23, if the governor trolley wire be tapped on at *P*, as indicated by the dotted line, the pump motor can get current, even if the two motor switches are open, because it is tapped to the positive side of both. If the governor trolley wire be tapped at *Z*, the opening of either motor switch or breaker will stop the pump, because its trolley wire is on the negative side of both. The best place, perhaps, to tap the pump wire is at *X*, between the two motor switches or breakers. In this case, the pump tap is on the positive side of the No. 2 switch, but on the negative side of the No. 1 switch. If the No. 1 switch be opened, both the car-motor and pump-motor circuits are interrupted; if the No. 2 switch be opened, only the car-motor circuit is broken.

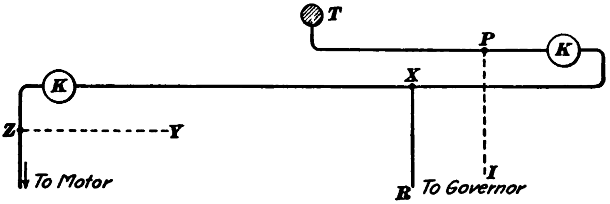


FIG. 23

40. Object of Snap Switches.—The object of the two snap switches, Fig. 1, in the pump-motor circuit, is to provide means for the motorman to stop the pump motor, in case the governor fails to do so, when the gauge shows reservoir pressure to be too high. With two switches, he can start and stop the motor from either end of the car. In case the governor gets out of order, the motorman can use one of the snap switches to control the reservoir pressure. Always keeping his eye on the pressure gauge, he can open the switch when the pressure gets high enough and close it when the pressure is too low. In order to control from one snap switch, the other must be open.

OPERATION

41. The regulator hand *t*, Fig. 19 (*b*) and Fig. 21, is so adjusted that with no pressure in the reservoir, and therefore no force within the air lobe that operates the hand, a spring forces knob *t* against contact post *l*. Suppose that the reservoir is empty and that it is necessary to start the pump to get up pressure; the carbon knob *t* touches the contact *l*. Current comes in at *T* to point *X*, Fig. 21; if magnet *L* was the last one to operate, armature *A A*, Fig. 19, in its extreme left-hand position and fingers *K* and *K'*, make contact, so that the current splits at *X*, Fig. 21, part of it taking the path $X-C-B-D-Y-M-M'-W-G$ and starting the pump motor, and part of it taking the path $X-L-f_1-l-t-Y-M-M'-W-G$ through the left-hand magnet coil *L*, exciting it. In this particular case, where the armature *A A*, Fig. 19, and the finger *K* are already at the left-hand end of their travel, magnet *L* does nothing. Suppose that at the time the pump switches were closed, the armature *A A* happened to be so far to the right that fingers *K* and *K'* failed to touch each other. In this case, when the current gets to *X*, Fig. 21, it cannot go through the pump motor because the circuit is open between *B* and *C*, Fig. 21. But it does take the path $X-L-f_1-l-t-Y-M-M'-W-G$ through the left-hand magnet, which then pulls the armature to the left, causing *K* and *K'*, Fig. 19, to touch each other and start the pump. The current that passes through magnet *L* to pull *A A* to the left must pass through the pump motor to reach the ground at *G*; but on account of the resistance of magnet *L*, this current is too small to start the motor.

42. As the pressure in regulator lobe *x*, Fig. 20, increases, in response to increase in the reservoir pressure, the lobe straightens out, and its free end pulls contact knob *t* away from contact post *l* and interrupts the flow of current through magnet *L*, Fig. 21. Armature *A A* still remains at the left-hand end of its travel, and the pump motor still works, for there is, as yet, no influence brought to bear to pull the armature to the right. As the pressure in the reservoir, hence in the valve lobe, increases, the valve lobe straightens out still more and carbon knob *t* moves slowly from contact *l* toward contact *r*. As soon as knob *t* touches contact *r*, the trolley current takes path *T–X–C–B* (remember that fingers *K* and K' on contact blocks *C* and *B* still touch each other) $D–Y–t–r–f_r–R–G$ along the ground wire to the ground. Magnet *R*, being thus excited, pulls armature *A A*, Fig. 19, quickly to the right, pulls fingers *K* and K' apart, and stops the pump motor. At the same time, since coil *R* gets its current from the motor-circuit trolley wire at point *Y*, which is on the negative side of the contact breaker KK', magnet *R* can no longer get current and can exert no pull on *A A* after contact is broken between *C* and *B*, Fig. 21. The armature, however, lies in the right-hand position until a fall in the pressure causes knob *t* to drop back on contact *l*, once more pulling *A A* to the left to start the pump motor.

ADJUSTMENT

43. Connecting posts *r* and *l* can be slid back and forth in a circular slot shown in Fig. 19 (*b*). By adjusting these posts in the slot, the governor can be made to stop the pump motor at one given pressure and start it at another. Suppose, for example, that it is desired to have the motor stop when reservoir pressure gets up to 60 pounds and start when the pressure falls to 45 pounds. The best way to make this adjustment for the first time is as follows: Push the posts as far apart as they will go and, if necessary, start the pump by pulling the armature to the left by hand. The carbon knob *t* will occupy a position between the two contact posts, or will bear against *l*. After the pump gets to work, watch the pressure gauge; as soon as it registers 60 pounds, stop the pump, by hand, and move the post *r* nearly to the position occupied by the knob *t*. Next, let the air out of the reservoir by throwing the operating handle alternately into the emergency and full-release positions, or by installing the brake handle upside down (so that the valve may be turned to other than its normal positions), and then turning the valve until its cavity covers the valve-seat reservoir and exhaust ports. If, with switches in, the pump fails to start when the pressure gauge shows the reservoir pressure to be 45 pounds, move the post *l* farther toward the position occupied by the carbon knob *t* when the pressure was 45 pounds. Let the pump raise the pressure again.

If the governor stops the motor before the gauge shows 60 pounds, post *r* was moved in too far the last time and must be moved out a little. If, however, the pump does not stop until 65 or 70 pounds is registered, post *r* must be moved a little farther in; letting the air once more out of the reservoir, if the pump starts at 50 pounds, post *l* must be moved to the left a little; but if the pump does not start until the pressure is reduced to 40 pounds, post *l* must be moved in a little. Posts *l* and *r* can be loosened by turning to the left a little screw that is in the end of each. By moving these posts back and forth, the governor can be made to start the pump at exactly 45 pounds and stop it at exactly 60 pounds. After adjusting a post, be certain that its end screw is well secured.

TESTS

44. Motor Fails to Start.—If on closing one of the snap switches K_3, K_3, Fig. 1, the motor fails to start, the trouble may be due to the governor; one of the switches K_3 may be out of order, or the main fuse *F*, Fig. 21, may be blown. The first thing to do is to see that fuse *F* is all right. If it is blown, put in another just like it. If the pump still fails to start, lift the governor cover and inspect and test the governor as follows: If armature *AA*, Fig. 19 (*a*), is to the right, pull it to the left, by hand, until *K* and *K'* touch, and see that there is good contact between *K* and *K'*. If the pump still refuses to start, the trouble may be due to an open circuit in the pump motor itself, or in some wire leading to or from it. If on pushing the armature *AA* to the left, by hand, the pump starts, it goes to prove that there is no open circuit in the motor. If the governor will start the motor when moved over by hand, but refuses to start it automatically, it proves that there is an open circuit in the magnet L or in some part of its circuit, because it is magnet L that pulls the arm to the left, causing K and K' to touch and automatically start the motor.

An open circuit in the L magnet circuit may be due to any of four causes: magnet L may be burned out; one of its connecting wires may be loose or broken; fuse f_l may be blown; carbon knob t may fail to make contact with post l; there may be some wrong connection made. Wrong connections will be considered later. In most cases, failure to start automatically will be due to the blowing of fuse f_l or to the failure of the knob t to make contact. If fuse f_l is blown, put in another just like it, but open both snap switches before doing so, and push AA to the right. After the new fuse is in, and if, on closing the snap switch, magnet L pulls AA to the left and starts the motor, the apparatus is in order; but if the new fuse blows, there is probably a short circuit in magnet L, and the only thing to do is to cut out the governor and govern by hand. If failure to start is due to knob t failing to make contact with post l, the governor should operate to start the motor when t is pushed against post l by hand. If it does, post l must be readjusted and fixed securely in its place. When armature AA is to the right, K and K' are apart and the motor cannot get a starting current. There may be a little current through L, but not enough to start the motor. To start the motor, AA must be drawn to the left, either automatically or by hand.

45. Motor Fails to Stop.—Suppose that the pump starts automatically, but fails to stop when the pressure reaches standard value. In this case, there is something the matter with the circuit of magnet R; knob t may fail to touch post r, fuse f_r may be blown, magnet R or one of its wires may have an open circuit in it, or the ground wire may be loose or broken. The first thing to do when the pressure gets too high and the governor fails to stop the pump, is to stop the pump by means of switch K_3, Fig. 1. Then look at fuse f_r to see if it is blown; press *t* against post *r* by hand; follow the pump ground wire coming out of the governor at *G* and see if it makes good connection with the car ground wire.

If the fuse wire f_r is gone, put in another; if on closing the snap switch, opened to stop the motor, the armature *A A* moves to the right and stops the motor, this shows that the connections are in good order; if *A A* does not move to the right, see if the pressure is up to or above standard value, and if it is not, allow the pump to raise it. If the trouble is due solely to the blowing of the fuse, the motor will stop at or near standard pressure. If, however, the new fuse blows as soon as the current goes through it, there is a ground or short circuit in the magnet *R*, and the governor must be cut out. If the pump fails to stop until the pressure is 5 or 10 pounds above the standard, the chances are, as a rule, that post *r* needs adjusting. If inspection proves the fuse to be all right and knob *t* to be touching post *r*, the trouble is a bad ground connection or a burnt-out magnet coil. If the trouble is with the ground wire, inspection will disclose it; if the trouble is with the magnet coil, renew the coil.

CUTTING OUT THE GOVERNOR

46. If the governor develops disorder that the motorman cannot remove, cut out the governor and regulate by hand, closing the snap switch when the pressure is too low, and opening the switch when the pressure is too high. To cut out the automatic governor, turn the stop-cock K_1, Fig. 1, and move armature *A A*, Fig. 19, by hand, to the left until fingers *K* and K' touch each other. It is seldom that this governor has a disorder that this method of cutting out is not effective in removing. The only fault that this operation will not remove is a ground on blow coil *D*, Fig. 21, on magnet *L*, or on the motor itself. A ground on the motor is outside of the governor and cannot be cut out by it. A ground on magnet *L*, Fig. 21, or blow coil *D* can be removed by disconnecting wires *T* and *M* from the governor and connecting them together. A ground on any of these parts is apt to cause fuse *F* to blow. Wherever there is a ground there is always more or less burning, which usually can be located by the smoke and the smell of burning insulation. The chances of a ground occurring on the governor are slight, because the iron parts of the governor are set on wood and the iron pipe leading to the regulator has a rubber coupling in it. The same is true of the motor compressor; it is held in a wooden cage and the reservoir pipe has a rubber coupling. If for any reason the pump motor gets so much out of order that it cannot run, the only thing to do is to open both of the snap switches and use the hand-brake. The necessity of closely watching the air gauge when controlling the air by hand cannot be too forcibly impressed on the mind of the motorman, so that in time of an accident, he may have plenty of air for an emergency stop.

WRONG CONNECTIONS

47. When an automatic governor is installed, its wires should be plainly and indelibly marked, so that in the future, if the automatic is disconnected, there may be no confusion of wires in reconnecting it. If the wires are not tagged or marked on both the car and governor, confusion is apt to result, as on different roads the terminals are brought out differently. The only certain way to get any device properly connected is to understand the device and follow all wires to their destination.

CIRCUITS WHEN STARTING AND STOPPING

48. Fig. 24 shows the parts of the governor that operate to start the motor, and Fig. 25 shows the parts that operate to stop it. In Fig. 24, coil *L* gets its current from point *X*, which is on the positive side of the gap between *C* and *B*; so that when gap *CB* is open, as it always is after the governor has operated to stop the motor, coil *L* can get current with which to draw the armature to the left and start the motor, as soon as the pressure gets low enough to allow knob *t* to touch post *l*. As soon as the armature connects contacts *C* and *B*, coil *L* is relieved of practically all current and remains so as long as this connection is intact, because *L* is short-circuited by the short stretch of circuit *X–C–B–D–Y* that the pump-motor current travels through to get to the motor. Coil *L* never being in action, except for a moment at a time, has no tendency to heat. Also, when knob *t* leaves post *l*, it causes no arc between *t* and *l*, because knob *t* leaves post *l* as soon as the pressure becomes over 45 pounds; but *t* does not get to post *r*, and therefore the armature does not break contact between *B* and *C* until the pressure reaches the high-pressure limit—for instance, 60 pounds. Knob *t*, therefore, breaks the circuit through magnet *L* while it has the low-resistance wire *X–C–B–D–Y* in parallel with it and cannot therefore cause much of an arc.

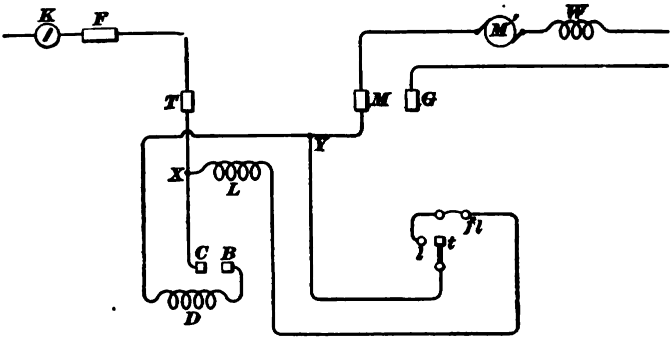


FIG. 24

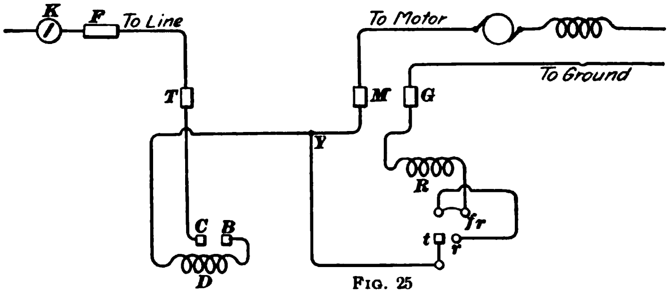


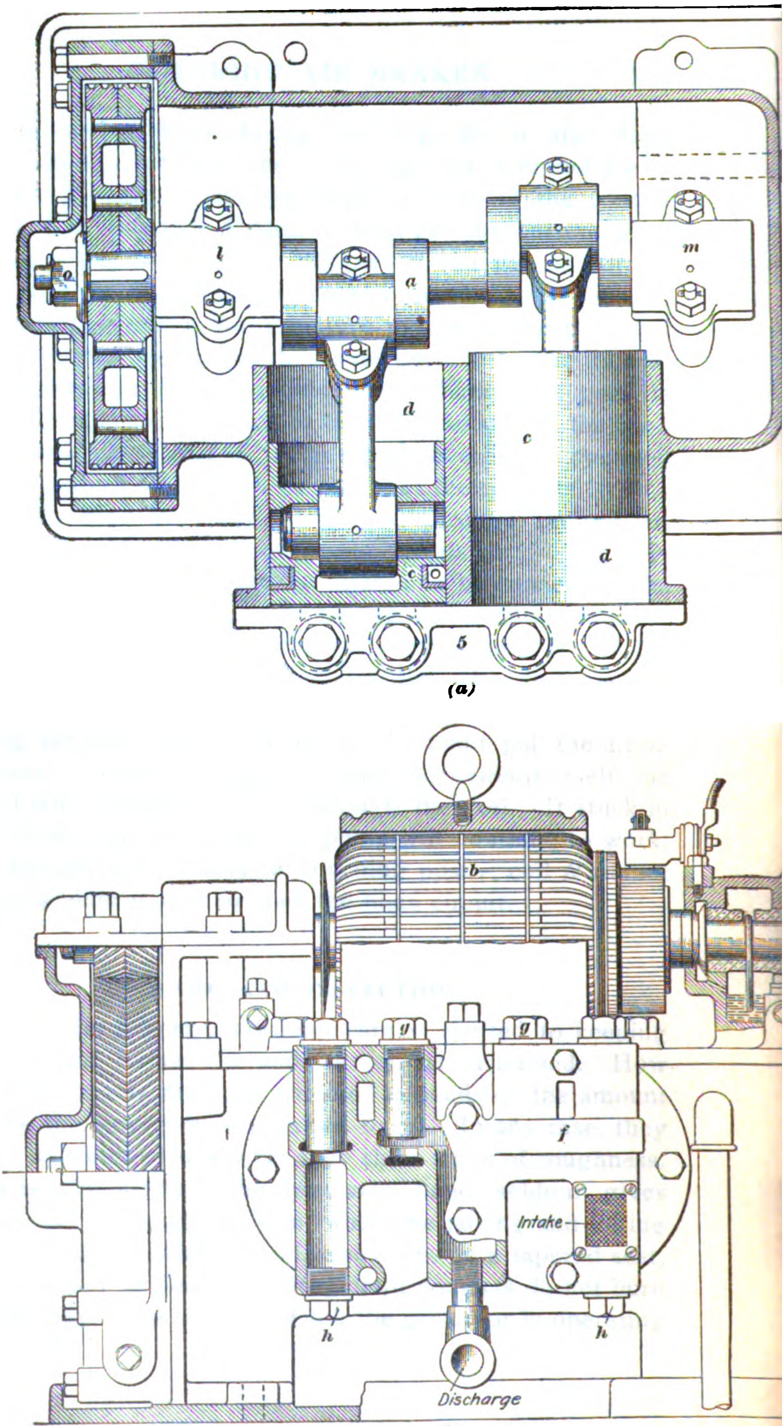
FIG. 25

When current flows through *R*, Fig. 25, it also flows through knob *t*, which connects through the arm and a wire to point *Y*, which is on the negative side of the contact breaker *CB*. Magnet *R* cannot, then, get any current when there is a gap across *CB*. Magnet *R* can get no current unless *CB* is closed and *t* touches post *r*. As soon as knob *t* touches post *r*, the armature moves to the right and stops the pump motor; at the same time, it breaks its own circuit, although *t* still touches post *r*, because it gets its current from point *Y*, which is on the dead side of the open circuit between *C* and *B*. Thus the governor is operated without heating of the coils or arcing at the contacts.

Coil *L*, Fig. 24, gets its ground through the motor, while *R*, Fig. 25, has a direct ground of its own. The only way that coils *L* and *R* can be injured is by connecting the governor wires wrongly, or by having the armature stick so that it cannot move when the coils try to pull it. If the armature sticks in its right-hand position, when the pressure gets low and knob *t* touches post *l*, Fig. 24, the current is passing through coil *L*, but as coil *L* cannot pull the armature over to close the gap *CB* and short-circuit itself, the current will continue to flow through the coil. If stuck in its left-hand end of travel, the pump will continue to work, and although knob *t* may be touching post *r*, coil *R* cannot pull the armature over to open the main circuit.

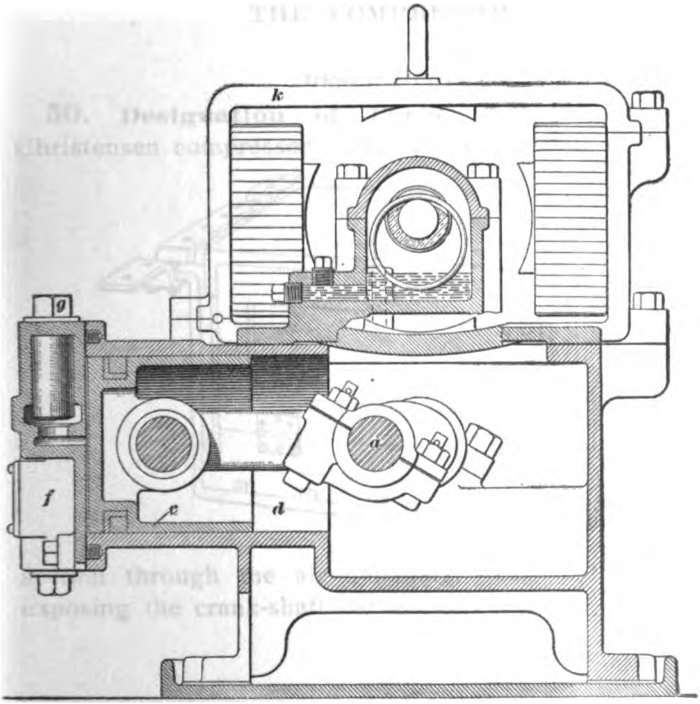
CARE AND INSPECTION

49. Under proper conditions, care is limited to keeping the governor blown out and its contacts trimmed. How often the contacts must be trimmed depends on the amount of work the governor is required to do. In any case, they should be trimmed whenever they show signs of roughness. In passenger service, the regulator hand seldom gives trouble; but in freight service, when the jarring and jolting are severe, the regulator hand, which fits on a tapered seat, has a tendency to shake off. Regulator contacts do not burn because they break no arcs when the governor is operating



(a)

(b)



(c)

properly; so that, if the regulator contacts do show a tendency to burn, trouble must be sought in the governor connections.

Very often, when a governor is changed from one car to another, its adjustment must be changed in order to make it cut in and cut out at the proper pressures. In many cases, a readjustment is made when the governor is not really at fault, but is only apparently so, due to a difference in the gauges on the two cars. When governors are abused and overheated, they sometimes refuse to cut out. In such a case, unless the fault is located and removed, the cut-out operating coil will, in course of time, roast, necessitating its renewal. In renewing an operating coil, care must be taken, before screwing it down, to see that the two coils are perfectly in line, otherwise the sliding armature may bind and fail to throw over. It is seldom that any part of the governor grounds, and when it does, inspection will show that the governor frame is in contact with some grounded part of the car.

THE COMPRESSOR

DESCRIPTION

50. Designation of Parts.—Fig. 26 shows the Christensen compressor. Fig. 26 (*a*) presents a horizontal section through the air cylinders, gear, and pump case, exposing the crank-shaft connections to view. Fig. 26 (*b*)

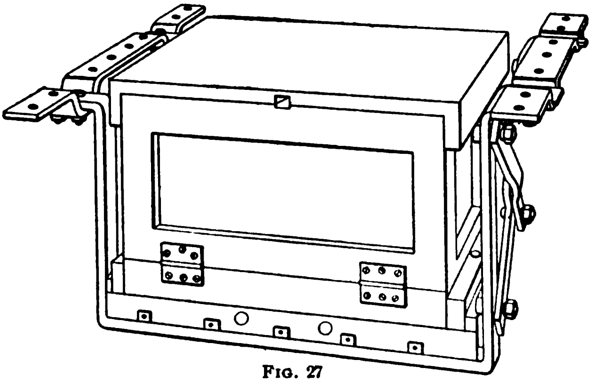


Fig. 27

shows a partial vertical section through the commutator end bearing, the cylinder head, and motor frame, exposing

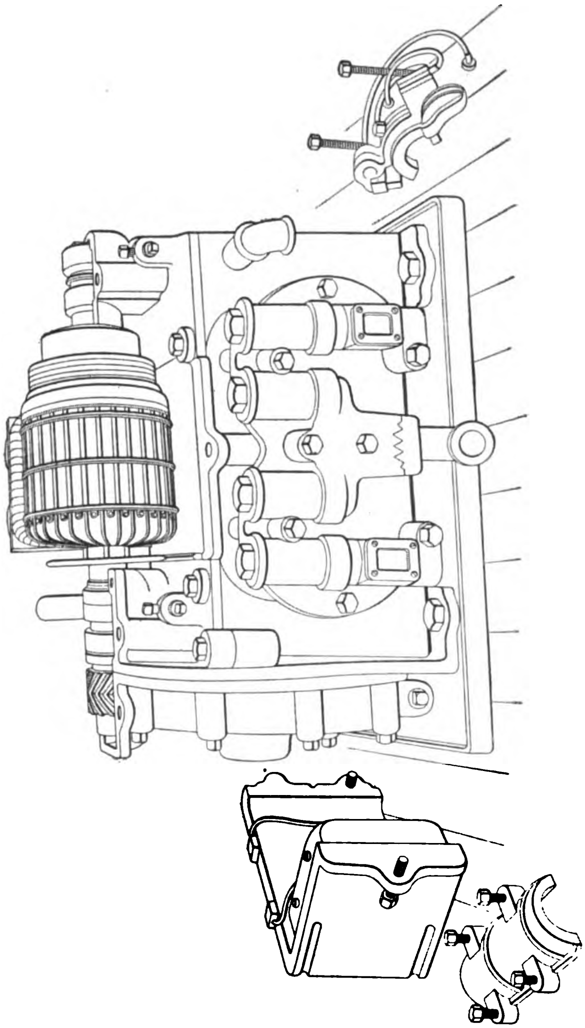


FIG. 28

armature *b* and the valves to view. Fig. 26 (*c*) shows a vertical section at right angles to the armature and crankshaft.

51. In Fig. 26 (*a*), rotation of the crank-shaft *a*, geared at one end to the shaft of the armature *b* shown in Fig. 26 (*b*), moves pistons *c* in cylinders *d*, Fig. 26 (*a*). The pistons are so connected to the crank-shaft that they move at all times in opposite directions; when one is moving up, the other is moving down, thereby minimizing vibration. The two cylinders, with valves at but one end, constitute a double-cylinder single-acting pump. The gear-case and crank-shaft chamber communicate, and are kept partly filled with oil, poured in through elbow *e*, shown in (*b*), which also gauges the level of the oil. The motor case forms the pump-body cover, a gasket separating them. Cylinder head *f* contains all valves, and its removal exposes the cylinders and pistons to view. Screens, or strainers, prevent dust from entering the suction valves. All valves are interchangeable, except in so far as their seats may be worn differently, and can be withdrawn by removing caps *g*. To clean the valve chambers, plugs *h* must be taken out. To remove an armature, disconnect and lift off the top of field frame *k*, shown in Fig. 26 (*c*), and remove the armature bearing caps. To change a gear, draw off the oil and remove nut *o*, Fig. 26 (*a*), and the

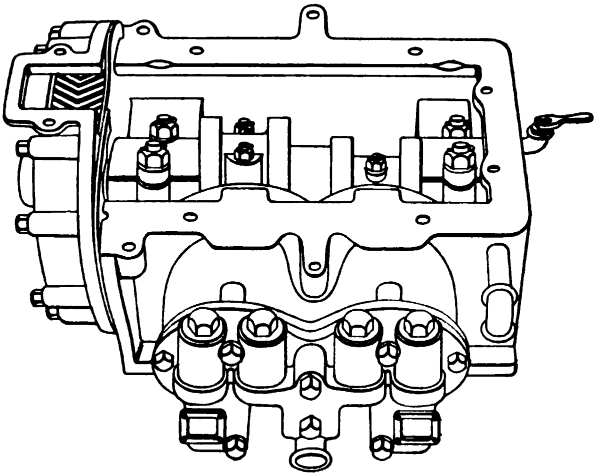


FIG. 29

gear-case. To take out the crank-shaft and pistons, remove the motor frame, caps *l* and *m*, and the cylinder head.

52. Relation of Parts.—Fig. 27 shows an enclosed motor compressor ready to be installed; Fig. 28 shows the compressor with the upper half of the motor removed; Fig. 29 shows it with the whole motor removed, exposing the crank-shaft to view.

OPERATION

53. Fig. 30 shows the principle on which the valves operate. Only one cylinder is considered, but the action of both sets of valves is the same. Normally, the weight of the valves *a* and *b* keeps them seated, as in the diagram. Chamber *c*, under suction valve *b*, opens to the atmosphere through screen *d*. Chamber *e*, above the valve seat, connects to pump cylinder *f*, as does also chamber *g*, under discharge valve *a*. Chamber *h*, above the discharge-valve seat, connects to reservoir *i*, which is to be charged. Movement of piston *j* to the right tends to create a vacuum to its left, and hence also in chambers *g* and *e*; main-reservoir pressure in *i* and in the space above valve *a* keeps valve *a* seated. The vacuum above valve *b* allows atmospheric pressure to raise it, thereby allowing air to rush into the cylinder through path *d*–*c*–*e*–

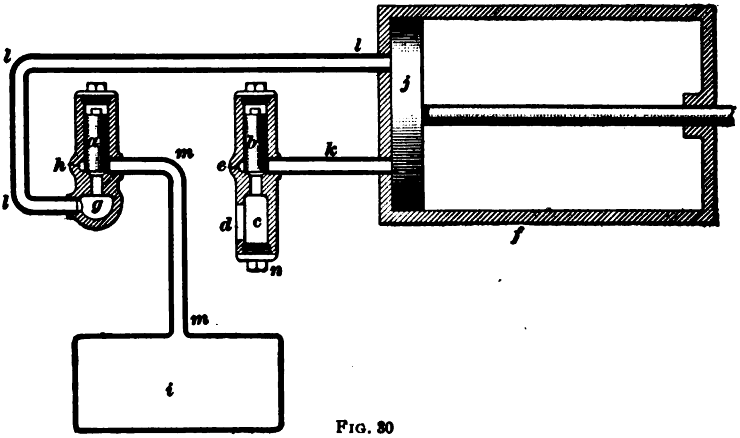


Fig. 30

pipe *k*; when piston *j* completes its stroke to the right, the space behind it is full of air at atmospheric pressure, and valve *b*, having the same pressure above and below it, seats from its own weight. As the piston begins a stroke to the left, it compresses the air in front of it, causing valve *b* to seat harder, preventing any escape of air to the atmosphere. Compressed air passes through pipe *l*, and as soon as the pressure in chamber *g* exceeds that in reservoir *i*, valve *a* lifts, allowing the compressed air under it to flow into reservoir *i* through pipe *m*. Each stroke of the piston repeats this cycle of operation. In the actual pump, pipes *k* and *l l* are absent, chambers *e* and *g* opening directly into the cylinder behind them. Plug *n* closes the lower portion of chamber *c*.

CARE AND INSPECTION

54. Lubrication.—The following instructions, properly observed, will aid in the successful operation of the combined motor and air pump:

A good grade of mineral oil with a low freezing test should be used. Oil should be poured into the filling elbow *e*, Fig. 26 (*b*), until almost level with the top. Inspection should be made every other day, and more oil poured in if necessary. At least once every 2 months the drain plug should be opened and the oil drawn off and filtered. The gear and commutator-end armature bearing are oiled through plugs in the bearing casings. As the crank-shaft and connections run in a path of oil, the only care necessary is to keep the oil clean and free from grit. Oil to be used in the compressor or in any other part of the equipment should not be allowed to stand exposed in open vessels because of the danger of gritty substances getting into the oil. Caretakers should be familiar with the location and purpose of all elbows and drain plugs. The frequency with which oil should be renewed depends on its quality, on the climate, and on the work to be done. A newly installed compressor should be carefully watched for several trips.

55. Gear and Pinion.—Gears and pinions should be handled with care. A bruised or burred tooth in either is liable to bend the armature shaft. In removing a gear from the crank-shaft, use a hammer on the rough part of the gear. In removing a pinion from the armature shaft, use the pinion puller provided for the purpose. This device is shown in Fig. 31. Clamp *a* is placed over the pinion. Turning bolt *b* in a clockwise direction forces the clamp *a* toward the right and draws the pinion from the armature shaft.

Two keyways, one-quarter of the circumference of the armature shaft apart, are provided, so that the gear can be shifted and its life prolonged, the tendency being to wear the teeth at the two points corresponding to the dead centers of the crank-shaft. Care should be taken to have the gear and pinion mesh properly; they should be in line, and should have a clearance of about $\frac{1}{64}$ inch. A defective gear-tooth can be heard to click once for every revolution of the gear. A defective pinion tooth clicks once for every revolution of the pinion. Want of alinement, irregularity of the teeth, or a gear bored out of center will cause a grinding noise. Excessive wear in the teeth will cause a loud click when starting.

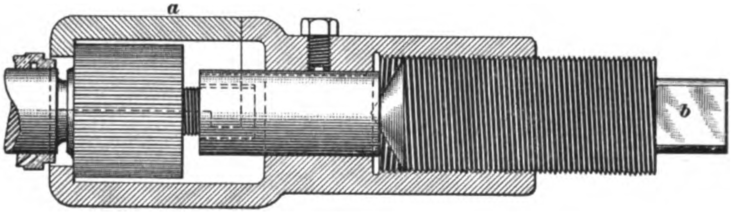


FIG. 31

56. The Valves.—The valves should be periodically removed, and they and their seats and chambers cleaned with gasoline applied with lintless cloth. Neither oil nor waste must be used on the valves, the tendency of both being to impair their action. Where a pump is slow in raising the air pressure, inspect the valve action and see that the screens are not clogged. Other factors that influence the time required to raise the pressure to standard value are low voltage, leaky pipes or couplings, a deranged motor, a leaky piston, or some stop-cock or drain cock left open. Be certain that the pressure gauge is correct, and that no unnatural sounds are allowed to persist uninvestigated.

57. The Motor.—A series-wound motor is used, so designed as to start on a full-line voltage without a starting coil. It is liable to the same troubles as a car motor, except that since its frame is insulated from the ground, it is not so liable to ground troubles. The brushes must be set the right distance apart, must have a backward lead, and must make good contact with the commutator. In case an armature is removed for repair, the new armature must be made to run in the same direction as the old one. The commutator must be kept smooth with a piece of rough canvas; a little vaseline applied occasionally through the pores of a piece of cloth will do the commutator good. Always be sure that the brush-holder springs make good contact.

A motor that runs well has a shiny chocolate-colored commutator, and the brushes screech when the motor slows down. The brushes must not spark. If the motor is too light for the work, the brushes will spark and roughen the commutator, notwithstanding anything that may be done to prevent it. The commutator may wear rapidly where neglected leaks in the piping and couplings allow air to escape to the atmosphere, thereby compelling the compressor motor to work continuously. No compressor of a size proportioned to an equipment running under proper conditions can long operate under improper conditions.

58. Persistent sparking may be due to any or several of the following conditions: (1) a loose brush holder; (2) a tight brush; (3) a weak brush-holder spring; (4) a brush too loose in its holder; (5) a brush hammer resting on the brush holder instead of on the brush; (6) brushes set incorrectly—either the wrong distance apart or both too far over in the direction of rotation; (7) a brush holder down on the commutator; (8) a brush holder too far from the commutator; (9) grease or brush paraffin on the commutator;

(10) excessive armature end play, allowing the brush holder to rub the head of the commutator; (11) a bad quality of carbon in the brushes; (12) a loose armature core; (13) a loose commutator; (14) loose commutator bars; (15) loose commutator connections; (16) flat, rough, grooved, or eccentric commutator; (17) commutator mica bodies too hard or too thick, or bars too soft; (18) a commutator that is not of uniform hardness; (19) high or low bars in the commutator; (20) short-circuited, open-circuited, or wrongly connected armature coils; (21) two grounds on armature or field, or one ground on each; (22) roasted armature or field insulation; (23) armature rubbing against the pole pieces; (24) armature shaft bent; (25) wet fields or wet armature; (26) armature overloaded; (27) field coil short-circuited or wrongly connected; (28) motor shell partly open, thereby introducing an air gap in the magnetic circuit.

Most of these faults can be detected by inspection; others must be located by test.

Blowing of the pump-motor fuse may be due to the following conditions: (1) If the fuse persists in blowing, the fuse may be too small or its connections may be loose, or otherwise making a poor contact, occasioning heating; (2) the motor may be working against excessive pressure that a faulty gauge fails to indicate; (3) there may be a hot or tight bearing, or a band wire may have broken and become lodged between pole pieces and armature; (4) flashing over due to carbon dust on the brush yoke. A motor should be blown out with air once or twice a week or oftener. Commutator bars should be beveled on the end to avoid crumbling mica segments. Care should be taken not to nick or dent a commutator band wire, as trouble will follow. The foregoing faults are not confined to Christensen compressors, but are common to all electric compressors engaged in similar work.

THE RESERVOIR

CONNECTIONS

59. The reservoir *R*, Fig. 1, is a tank of sheet steel, usually supported underneath the car by iron hangers attached to the car sills; in some cases it has been located inside the car, under the seats, and even on top of the car. In cases where space is limited, two smaller reservoirs can be used instead of one large one of the same capacity. Where two small reservoirs are used, they should be piped in series, as in Fig. 32 (*a*), and not in parallel, as in Fig. 32 (*b*). The capacity of the two reservoirs is the same in both cases, but the series-connection has the advantage that most of the condensation of moisture takes place in the first reservoir, leaving comparatively dry air to be used from the second one. Fig. 33 shows an actual reservoir ready to be installed.

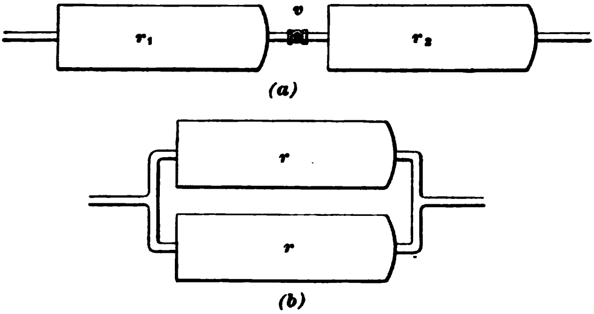


FIG. 32


FIG. 33

60. The series-connection of two reservoirs of different sizes has been used to improve the efficiency of the axle-compressor equipment. Less time is required to store a small reservoir to a given pressure than a large one. In Fig. 32 (*a*), suppose that r_1 is smaller than r_2, the pump stores r_1 to full pressure, and as soon as the pressure in r_1 exceeds normal, valve *v* opens and lets air into r_2. The result of this arrangement is to greatly decrease the time that must elapse before a car coming out of the shed can store air enough to apply the brake, because very few strokes of the axle compressor suffice to raise the small reservoir to standard pressure. Should it be necessary to make a stop, the air for doing so is drawn from the small reservoir. A small reservoir cannot equalize with a given brake cylinder at as high a pressure as the larger one, and therefore cannot produce as quick an emergency stop; but it suffices for all normal purposes.

CAPACITY

61. The air pump is supposed to keep the reservoir pressure up to standard, and since the reservoir has a certain capacity, it will hold a certain amount of air at normal pressure. Ordinarily, the capacity of any vessel is measured by its inside dimensions; in one sense this idea is correct, for if a tank is 20 inches long and the area of its end is 78½ square inches, the contents of the tank will be 20 inches × 78½ square inches = 1,570 cubic inches. However, to say that a tank will hold 1,570 cubic inches of air or any other compressible matter without stating the pressure, will give no information as to the usefulness of the tank for storing air. Suppose the capacity of the tank to be 1,570 cubic inches of air at atmospheric pressure. If more air is compressed into the tank, the useful capacity of the tank is increased, although the dimensions are not, because there is more air, by weight, than there was before. If air is forced in until the pressure is doubled, there will be twice as much air in the reservoir as before. If the final pressure is ten times the initial pressure, the tank will contain ten times as much air. A given volume of air at 60 pounds pressure will do twice as much work as at 30 pounds pressure. For example, it will force a piston to overcome twice the resistance.

Experienced motormen know that in making a platform stop, the existing air pressure must be considered. To convey an intelligent idea of how much air a tank of given dimensions will hold, it is necessary to know what pressure it will safely stand. The greater the capacity of the reservoir or an air-brake equipment and the less the capacity of the brake cylinder, the greater will be the pressure at which they will equalize in emergency applications. On modern straight air equipments, the reservoir capacity is from three to five times that of the brake cylinder.

DIMENSIONS

62. Air-brake reservoir dimensions are limited to a few standard sizes. Table I shows the dimensions of Christensen reservoirs to be used on cars of specified weights (empty weight of cars being considered); also, the dimensions of the brake cylinder to be used with each reservoir. The row of figures on the left shows how many times greater the capacity of the reservoir is than that of the brake cylinder to be used with it. It is, however, an advantage to have the reservoir as large as possible, so as to keep the pump motor idle the greater part of the time.

TABLE I

SIZES OF BRAKE CYLINDERS AND RESERVOIRS

Ratio	Brake Cylinder Inches	Reservoir Inches	Weight of Empty Car Pounds
4.1	12 × 14	14 × 43	50,000 to 70,000
3.4	10 × 14	12 × 33	30,000 to 50,000
2.7	8 × 14	10 × 24	20,000 to 30,000
2.8	7 × 14	10 × 19	15,000 to 20,000
2.5	6 × 14	8 × 20	10,000 to 15,000
2.6	5 × 14	8 × 14	5,000 to 10,000

CARE AND INSPECTION

63. The reservoir demands little attention beyond that necessary to keep its fastenings from becoming loose, and to prevent water accumulating in it. The compression of air in the reservoir necessarily liberates a certain amount of water, the quantity of which depends on the humidity of the air taken in. The reservoir, therefore, must be drained regularly by means of the drain cock underneath it.

THE BRAKE CYLINDER

DESCRIPTION

64. Fig. 34 is a section through a brake cylinder; *1* is the cylinder body; *2*, the back head; *3*, the front head; *4*, the piston; *6*, *7*, the front and back forks through which pass bolts *15* and *16* around which turn the cylinder levers of the foundation rigging; *8*, the release spring; *11*, the piston packing bolts; *12*, the head-bolts; *13*, the hollow piston stem, or rod. The hole near *11* is threaded to receive the pipe leading to the engineer's valve. *P* is the piston push rod.

OPERATION

65. Fork *6* is stationary; fork *7* moves back and forth with the push rod *P*, which moves the brake levers. When air is let in at the right-hand end of the cylinder, piston *4* is forced to the left, carrying with it push rod *P*, which moves the lever connected to pin *16* and sets the brakes. In moving to the left, piston *4* compresses spring *8*, so that when the brake valve is put on release position, letting all the air in the brake cylinder pass to the atmosphere, spring *8* returns piston *4* and piston rod *13* to normal position. Since fork *7* and push rod *P* are independent of piston rod *13*, the push rod must be returned to normal position by the release springs on the brake rigging. The object of having *P* and *13* independent of each other is that, when the hand-brake is used and push rod *P* must be pulled out, it will not be necessary to pull out *4* and *13* against the tension spring *8*. The brake-piston travel should be kept within the limit prescribed by the brake manufacturer. After this limit is passed, the push rod *P* may bend or it may split the hollow stem *13*.

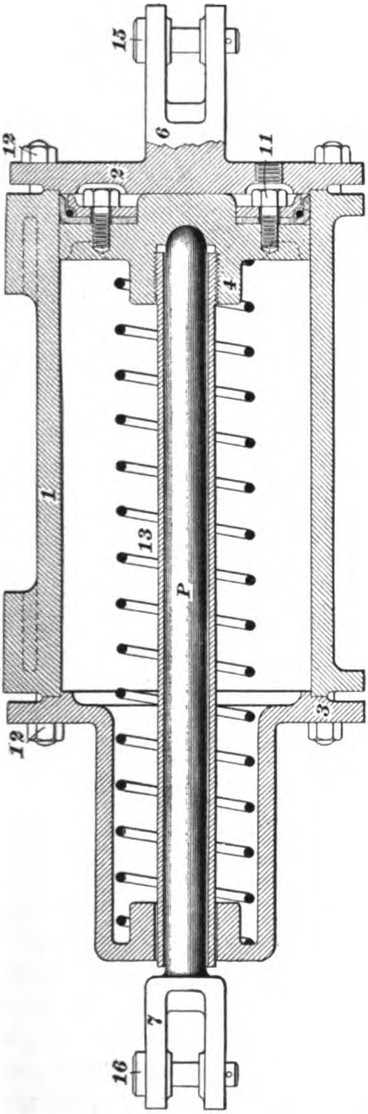


FIG. 34

BRAKING FORCE

66. For a given pressure, the total force that the push rod can exert depends on the area of the piston *4*; the total force, expressed in pounds, equals the number of square inches of the face of the piston multiplied by the air pressure per square inch. The area of the piston, in square inches, can be found by multiplying the diameter of the piston, in inches, by itself, and multiplying this by .7854; or by multiplying the radius of the piston, in inches, by itself and multiplying this by 3.1416.

EXAMPLE.—What force will a 6-inch piston exert at a pressure of 60 pounds per square inch?

SOLUTION.—Area piston = 6 × 6 × .7854 = 28.27 sq. in. Force exerted is 60 × 28.27 = 1,696.2 lb. Ans.

In all brake problems, the calculations are based on the assumption that the pressure in the brake cylinder is that of equalization—usually from 50 to 60 pounds—and that the brake levers are all in their positions of best action.

CARE AND INSPECTION

67. There is nothing in a brake cylinder to demand care except the leather packing ring. When the packing ring becomes worn, it must be renewed. But long before it is excessively worn it is likely to become dry. In either case, air can leak past the piston, with the result that, although the brake will apply, it will not hold, but will leak off, in consequence of the escape of air past the piston. The packing leather should be oiled at intervals to keep it soft and pliable. In the back head of the cylinder, a pipe plug is provided for oiling purposes.

Should it be necessary to remove the piston head for inspection or renewal, first force out the piston stem by an application of air; in the piston-rod pipe is a small hole, into which a nail can be inserted to prevent the release spring forcing the piston out when the cylinder head is removed. It is sometimes customary to use a special preparation instead of oil for lubricating the brake cylinder.

INSULATION COUPLINGS

68. In Fig. 1, two **insulation couplings** are shown—one in the pipe leading from the governor to the reservoir, and the other in the pipe leading from the compressor to the reservoir. The object of these insulation couplings is to insulate the governor and compressor frames from the grounded parts of the car. Without the couplings, the compressor and governor frames are in metallic connection with the track rails through the reservoir, reservoir pipe, engineer's valve, train pipe, brake cylinder, and brake rigging to the shoes and car wheels. The insulation couplings are made of heavy rubber tubing provided with suitable pipe fittings. They must not only insulate, but must be strong enough to withstand the full reservoir pressure.

On metallic-return systems, the insulation couplings are not necessary, as, under normal conditions, there is no other ground that, in conjunction with a ground fault, can create a short circuit. On a ground-return system, however, should any current-carrying part of the governor or compressor get into metallic connection with the surrounding frame, there would, were the insulation couplings omitted or defective, be a short circuit. The insulation couplings are not absolutely necessary to the successful operation and maintenance of the equipment, because the governor and compressor motor are no more liable to fault grounds than are the car motors; but they are desirable in so far as they prevent a fault ground on either of those devices from doing any harm, and at the same time greatly decrease the tendency for such grounds to occur. Insulation couplings should be installed in an inclined or a vertical position, and preferably housed so that accumulation of water, either on the inside or outside, will not detract from their insulating properties.

PIPING

69. All joints should be as good as tinning and perfect threads can make them, and should be well secured against vibrations that tend to impair the whole pipe system. Most of the troubles traced to the compressor are due, more or less, to leaks that keep it working two-thirds of the time instead of one-third, which is all that should be necessary on a brake system that is in good order. Long pipe bends are preferable to fittings, as every fitting introduces a field for leaks. There should be as few bends and fittings as possible. The pipe system should be so installed that all pipes incline toward drain cups provided to catch accumulations of water. Pockets and trap bends are to be avoided, and strainers should be kept clear. Accumulations of water will freeze in cold weather and impair the action of the brakes, if, indeed, they are not rendered entirely inoperative.

THE LEVER SYSTEM

DESCRIPTION

70. Air-Brake Connections.—Fig. 35 shows a system of air-brake levers, the braking power of which is supplied by compressed air let into the brake cylinder from the reservoir. The diameter of the brake piston is, in this case, 6 inches, and its area, in round numbers, is 28 square inches. Assuming the reservoir and cylinder to equalize at 10 pounds per square inch, the piston in an emergency application presses against the push rod with a force of $28 \times 60 = 1,680$ pounds. One end of lever *A* is jointed to the back head of the cylinder, the other end of this lever is attached to tension rod *X*. One end of lever *B* connects with the push rod, and the other end with tension rod *Y*. Levers *A* and *B* are also connected through tension rod *C*. Air admitted to the cylinder causes the push rod to move to the right, carrying with it the lower end of lever *B*. Using rod *C* as a fulcrum, lever *B* pulls on rod *Y*; using rod *Y* as a fulcrum, lever *B* pulls on rod *C*. The pull on *Y* sets the brakes on the one truck, and the pull on *C* sets those on the other truck.

The amount of pressure transmitted to rods *X* and *Y* depends on the force applied and on the leverage of levers *A* and *B*. (The leverages are given in the figure.) Lever *B*'s power arm is 7 inches, its weight arm 9 inches; the leverage $9 \div 7 = 1.286$, opposes the power; therefore, the force with which the upper end of the lever acts on rod *Y* is $1,680 \div 1.286 = 1,306$ pounds, which is the braking pull applied to the right, or forward, end of the car. The pull on rod *C* is the stress acting on the fulcrum of a first-class lever whose power is 1,680 pounds and whose weight is 1,306

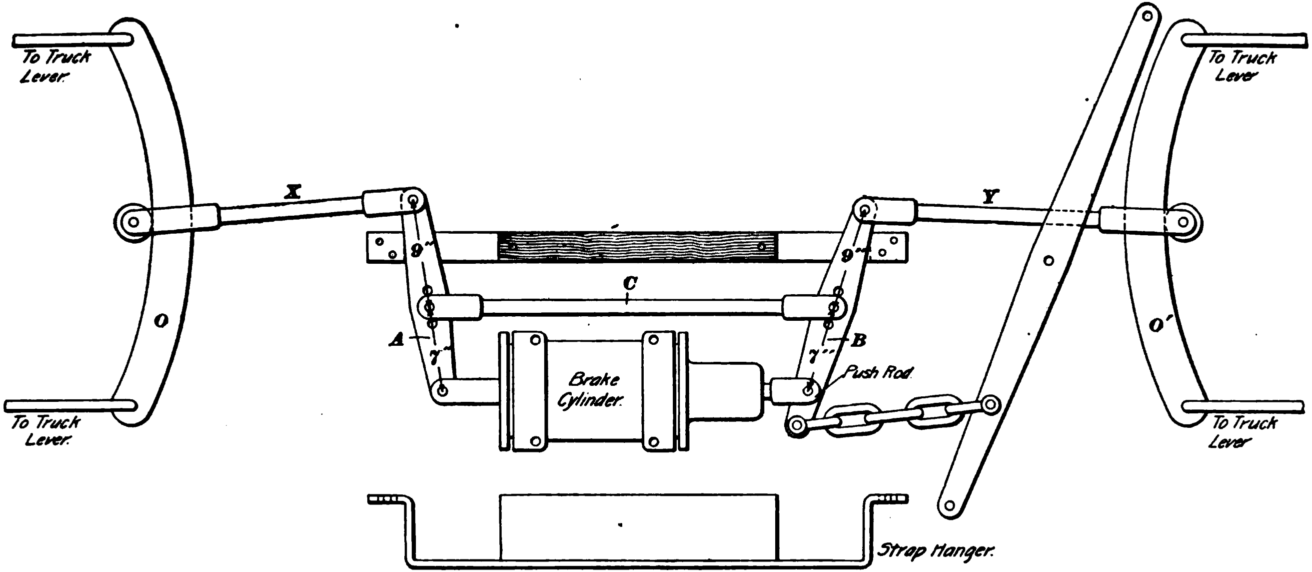

To Truck Lever.
To Truck Lever.
To Truck Lever
To Truck Lever
O
O'
X
Y
C
A
B
9"
9"
7"
7"
Brake Cylinder.
Push Rod
Strap Hanger.

FIG. 35

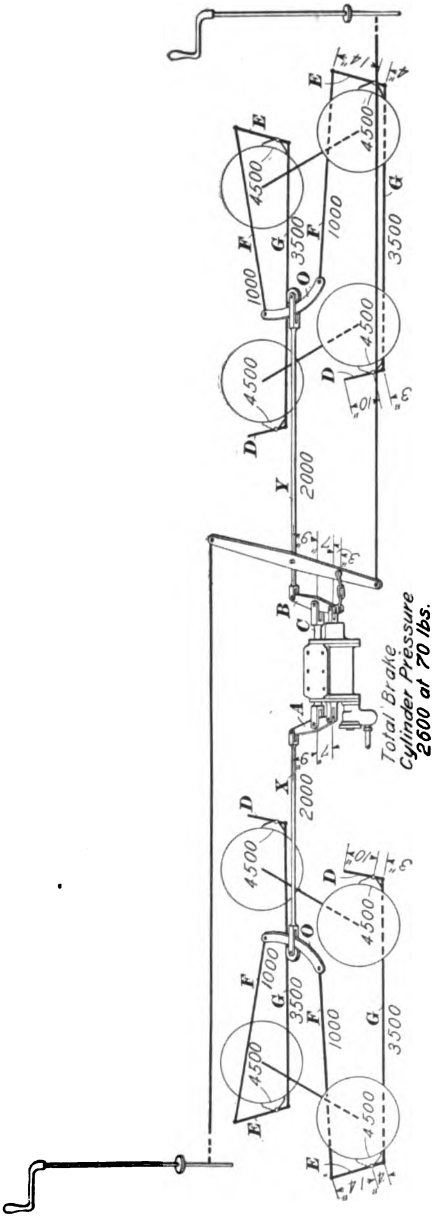
pounds; therefore, the force acting on the tension rod *C* and applied as power to the third-class lever *A* (whose fulcrum is the back-cylinder fork, whose power arm is 7 inches, and whose weight arm is 16 inches; that is, 7 inches + 9 inches) is 1,680 pounds + 1,306 pounds = 2,986 pounds. As the leverage of lever *A* is 16 ÷ 7 = 2.286 and is opposed to the power, the force acting on the upper end of the lever and the pull on rod *X* is 2,986 ÷ 2.286 = 1,306 pounds. The pull on rods *X* and *Y* being the same, the front brakes get the same pressure as the rear ones. The final pressure applied to the brake shoes depends on the leverage of the truck rigging.

The use of chains in the air part of the brake rigging is dispensed with, and the pressure on all long rods and levers that are liable to break is kept as low as possible, it being left to the truck levers, which are short and stout, to raise the final shoe pressure to the required degree.

71. The lower sketch in Fig. 35 shows the carrier used, whereby the air brake is not rendered inoperative, even though a tension rod or circle bar gives way on one end of the car. For example, suppose tension rod *Y* to be disconnected or broken; on admitting air to the brake cylinder, the push rod and the lower end of lever *B* would move to the right as usual, the upper end of lever *B* moving to the left. The amount of movement of the upper end of lever *B* to the left is limited by the wooden block set in the carrier. As soon as the lever touches this block, it can go no farther; using the block as a fulcrum, lever *B* begins to pull on tension rod *X*, setting the brake on the opposite end of the car. Under the conditions, the brake cannot be set as hard as it could were rod *Y* intact, because when the upper end of lever *B* comes against the wooden block the push rod has passed its position of best leverage.

In some types of Christensen brake riggings, the wooden-block device has been discarded as unnecessary.

72. Hand-Brake Connections.—The long lever with its center fixed to the car body is used to set the hand-brake.



Total Brake Cylinder Pressure 2600 at 70 lbs.

FIG. 36

It is attached to the 3-inch extension on the end of lever *B* by means of a chain. A pull on the lower end of the long lever will cause a pull on the chain, thereby operating lever *B* in the same way as the push rod. When the hand-brake is used, the push rod is pulled in and out of the hollow piston that holds it. It will be noticed that the air brake and hand-brake operate in the same direction, so that if the air brake were applied with the hand-brake already partially set, there could be no danger to the motorman or the brake rigging. Figs. 35 and 36 show that, in order to operate the hand-brake, the pull applied to the hand-brake lever must, through the short chain, move all the air-brake connections. Movement of these parts consumes pressure that should be expended on the

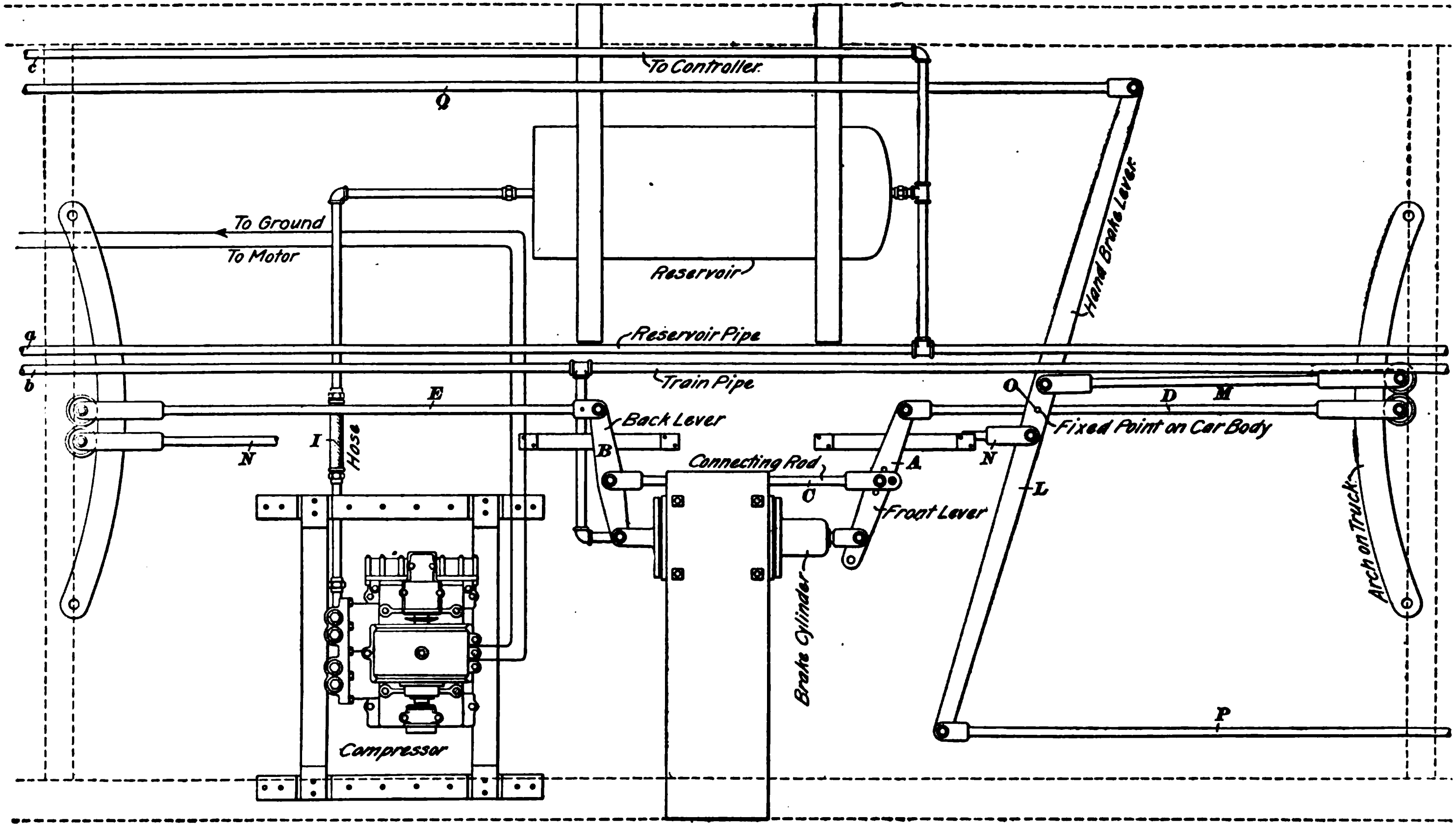

c
To Controller
Q
To Ground
To Motor
Reservoir
Hand Brake Lever
a
Reservoir Pipe
b
Train Pipe
E
O
D
M
Back Lever
I
Hose
N
B
Connecting Rod
A
N
Fixed Point on Car Body
C
L
Front Lever
Arch on Truck
Brake Cylinder
Compressor
P

FIG. 87

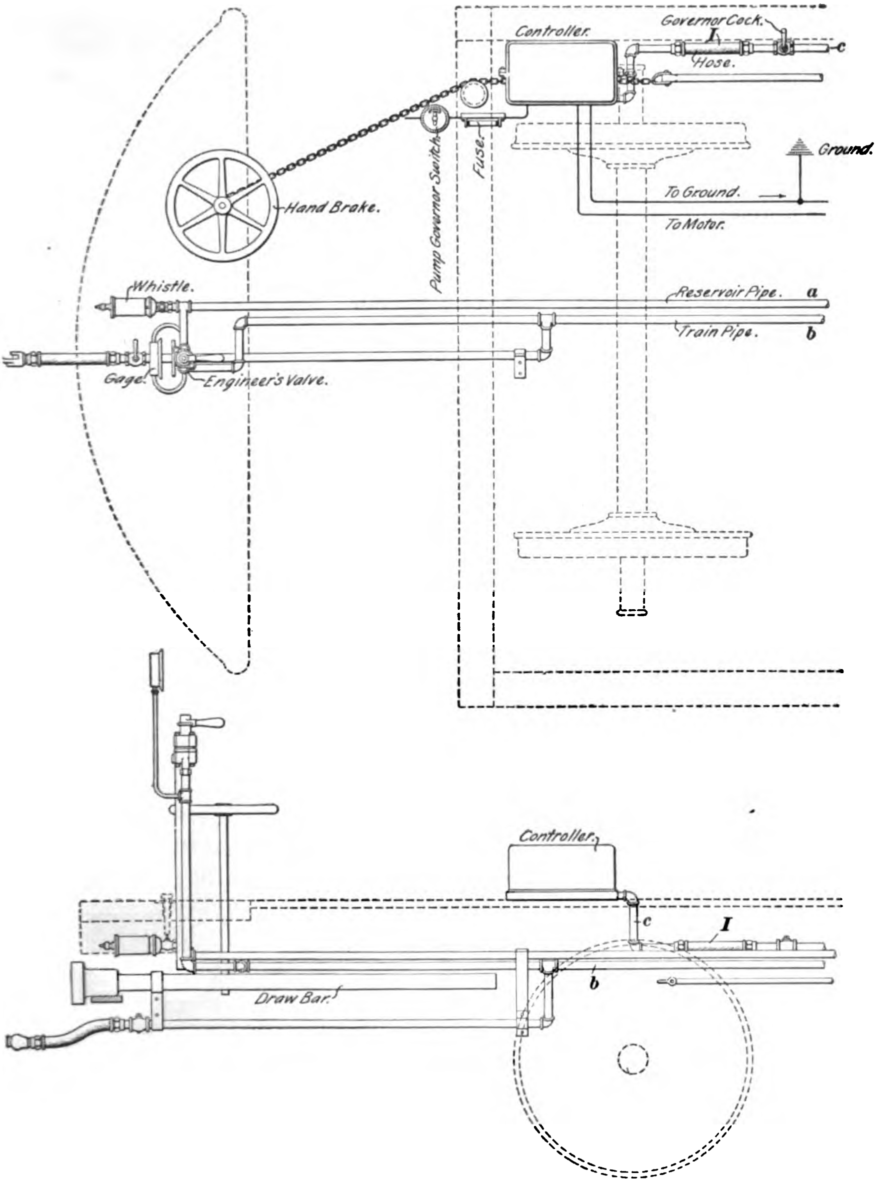

Governor Cock.
I
Hose.
c
Controller.
Ground.
To Ground.
To Motor.
Fuse.
Pump Governor Switch
Hand Brake.
Whistle.
Reservoir Pipe.
a
Train Pipe.
b
Gage.
Engineer's Valve.
Controller.
c
I
b
Draw Bar.

FIG. 38

brake shoes, with the result that the efficiency of the hand-brake or its ability to effect a prompt stop is much impaired. This weakness accompanies most of the hand-brake riggings used as auxiliaries to the air-brake system, and has been the source of much complaint.

Figs. 37 and 38 show a layout of the Christensen straight air-brake equipment and indicate the location and interconnection of devices. If the two drawings are conceived to be held together, so that points *a*, *b* on the one register with the same points on the other, the result is a complete equipment for a single-end car; and if an extension similar to Fig. 38 is added to the right-hand end of Fig. 37 also, the complete layout for a double-end car is the result.

In this arrangement of air brakes and hand-brakes, the loss of efficiency just referred to does not occur. In this rigging the hand-brake and air brake are independent of each other as far as the arches on the trucks. In fact, the entire removal of one does not interfere with the operation of the other. The hand-brake lever is fulcrumed at its center to the car body, as in Figs. 35 and 36, but it has two independent roller brake rods running to the arches or circle bars.

OPERATION

73. Movement of Parts.—Fig. 36 is a standard Christensen brake-rigging diagram. In connection with this diagram, it is assumed that all wheels on an eight-wheel car weighing, with its four motors, 40,000 pounds, are to be braked by air. The letters *A*, *B*, *C*, *X*, and *Y* have the same meaning as in Fig. 35. Levers *D* are called *dead levers* because they have one end fixed to the truck frame. Levers *E* are called *live levers*. Collectively, both are known as *truck levers*. Rods *F* are called the *truck-pull rods*, and rods *G* are called *bottom rods*.

Now take the right-hand end of the rigging. A pull to the left on brake-rod *Y* divides equally between truck-pull rods *F*, thereby forcing the upper ends of the live levers to the left around their brake shoes as centers. The lower ends move to the right, pulling bottom rods *G* to the right and thereby forcing the shoes on that end of the truck against the wheels. The shoes on the other end of the truck will then be set against their wheels.

A pull to the right on brake rod *X* produces a similar transmission of motion to the brake shoes on the left-hand truck. The dimensions of all levers are given. As the levers on the two sides of a truck are the same, the measurements are given on one side only.

74. Braking Stresses.—As the total weight on the rails is 40,000 pounds, and the total allowable shoe pressure is nine-tenths of this, or 36,000 pounds, the allowable pressure per shoe is 36,000 ÷ 8 = 4,500 pounds. Take the shoe operated by the dead lever on the observer's side of the right-hand truck. The power arm is 13 inches and the weight arm 10 inches, and therefore the leverage $\frac{13}{10} = 1\frac{3}{10}$ favors the power; the pull on bottom rod *G* need be but $\frac{4,500}{1\frac{3}{10}} = 3,462$ pounds, or, say, 3,500 pounds, as marked in the diagram. A pull of 3,500 pounds applied to the lower end of the live lever *E*, whose upper end, supported by truck pull rod *F*, acts as its fulcrum, forces the right-hand shoe against the wheel. The power arm of lever *E* is 18 inches, the weight arm 14 inches, and the leverage (which favors the power) 18 ÷ 14 = 1.285. Therefore, the force acting on the shoe, which is the weight, is 1.285 × 3,500 = 4,500 pounds, nearly, which is the same as the pressure on the other shoe.

Since lever *E* is a second-class lever, with fulcrum supported by truck pull rod *F*, the force acting on that rod is 4,500 less 3,500 pounds, or 1,000 pounds, as indicated in the figure. As the levers on the two sides of the truck are similar, the force acting on the other truck pull rod is also 1,000 pounds, making the total stress on the brake rod *Y* 2,000 pounds. This force of 2,000 pounds is applied to the far end of lever *B*, whose fulcrum is supported by tension rod *C*, whose weight is the force exerted by the piston push rod, whose power arm is 9 inches, and whose weight arm is 7 inches. As the power arm is $1\frac{2}{7}$ times as long as the weight arm, the applied force of 2,000 pounds is able to exert a force of $1\frac{2}{7} \times 2{,}000$ pounds = 2,571 pounds on the push rod.

By working backwards from the brake shoes, it is shown that, in order to produce a pressure of 4,500 pounds on each of the four shoes on the right-hand truck, the cylinder push rod must exert a force of 2,571 pounds. As the braking force of either truck is the resisting force of the other, through tension-rod *C* and back cylinder lever *A*, the same braking force per shoe is transmitted to the left-hand truck, whose levers and rods are the same as those of the truck considered.

75. Size of Cylinder Required.—The size of brake cylinder to be used to give the necessary 2,571 pounds (or, in round numbers, 2,600 pounds) push-rod force depends on the pressure at which the brake cylinder and reservoir are assumed to equalize in emergency applications. The governor can be adjusted to keep the reservoir at the pressure necessary to secure equalization at any desired degree, within safe limits. Assume, as indicated in the diagram, that the pressure at equalization is 70 pounds per square inch. As each square inch of the piston is to exert a pressure of 70 pounds, the area of the piston must be as many square inches as the number of times 70 is contained in 2,600. $2{,}600 \div 70 = 37\frac{1}{7}$ square inches, which may be taken as 38 square inches. The next step is to determine what diameter of piston is required to give a piston area of 38 square inches. This can be approximated nearly enough for all practical purposes, as follows:

To find the diameter of a piston, when its area is known, use the following:

Rule.—*Divide the piston area, in square inches, by 3 (to be more nearly exact, by 3.1416). The result is a certain number. Then find, by trial, what smaller number multiplied by itself produces that number. The smaller number multiplied by two is the required diameter, in inches.*

Example.—The area of a piston is 38 square inches; what is its diameter?

Solution.— $38 \div 3 = 12.67$

$3 \times 3 = 9$ (too small)
$4 \times 4 = 16$ (too large)
$3.2 \times 3.2 = 10.24$ (too small)
$3.4 \times 3.4 = 11.56$ (too small)
$3.5 \times 3.5 = 12.25$ (too small)
$3.6 \times 3.6 = 12.96$ (too large)

The required number is between 3.5 and 3.6: take their average, 3.55. The required diameter, then, is $3.55 \times 2 = 7.1$ in. This is close to the standard 7-in. cylinder, which is the one that would be selected in this case.

CARE AND INSPECTION

76. Lost Motion.—So far as the foundation rigging is concerned, the points of care and precaution to be observed in maintaining an air-brake equipment and a hand-brake equipment are practically the same. Few brakemen correctly appreciate the effect excessive wear or clearance between shoes and wheel has on the amount of chain wrapped on the brake staff. The more clearance between the shoes and wheel and the more wear in parts, the more turns will the motorman be compelled to take on the brake handle to set the brakes. In the case of the air brake, the farther will the piston and push rod have to travel before pressure begins to be applied to the shoes.

In addition to the lost motion due to wear of shoes, wheels, pins, and holes, another factor adds to the distance that the brake piston must travel before the brake shoes become effective in retarding the car. On a single-truck car, application of the braking power causes the two axles to draw together, until the clearance of the axle in the journal-box and any possible looseness of the journal-boxes themselves are taken up. On a double-truck car more than these effects obtain; these two trucks approach each other bodily. All these effects cause an increase in the travel of the piston. On an air-braked car, the travel of the power is known as **piston travel.**

77. Excessive Travel.—Excessive travel of an air-brake piston or hand-brake handle is to be avoided. In neither case does the braking pressure apply usefully until all levers are past the position of best action. The pressure then applies at a disadvantage and cannot produce the shoe pressure called for. The first indication of excessive travel on a hand-brake rigging is that several turns of the handle are required to set the brake, which then will not reduce the speed of the car rapidly enough. In such cases, it is often the practice to *hook up* (shorten) the chain. This lessens the time required to set the brake, but does not improve the shoe pressure. It amounts to the same thing as running with the chain wound once or twice about the staff. The excessive wear and give that were the original causes of the excessive travel still exist, and all levers still pass their position of best action before exerting appreciable braking force on the shoes.

78. On an air-brake equipment, excessive piston travel produces one, and possibly two, additional conditions tending to impair the effectiveness of the brake apparatus. The longer the piston travel, the greater is the amount of space left behind the brake-cylinder piston, when the brake is applied, which space must be filled with air under pressure before the braking is effective. The greater the cylinder space to be equalized, the less will be the pressure at equalization and, hence, the push-rod force applied to the already inefficient rigging. The farther the push rod moves out of the cylinder, the greater is its tendency to bear against its enclosing sleeve. It is possible for excessive travel to increase their side thrust to a degree that splits the end of the sleeve.

79. Single-Truck Riggings.—The main points of care to be observed on single trucks are as follows: See that all brake-staff bearings are kept lubricated. They should be oiled frequently; but, to avoid soiling passengers' clothes, little oil should be used at one time. The brake-staff ratchet wheel should not be allowed to run with teeth missing, nor should the dog be allowed to have a blunt point; both should be renewed as soon as defective. In case a ratchet brake handle is used, the action of the ratchet within the head of the handle should be perfect. If the handle ever fails to catch while being applied and the clicking noise emitted on release seems to be weak, it means that the dogs inside the handle hub have become blunt, or that the springs pressing them into the ratchet have become weak; such a condition should be reported at once, as it is liable to cause a serious accident.

Should the brake handle appear to be much harder to turn at one point of its revolution than at all others, it probably means that the brake staff is bent. To avoid this, the brake staff should be well supported on its lower end where the stress is greatest. The brake chain should be so fastened to the staff that it will wind on the staff and not on itself; otherwise, the leverage will decrease as the brakes are applied. In case there are any tripod brackets to support the lower end of the brake staff, care should be taken to see that the legs of the brackets are so disposed as not to interfere with the winding up and paying out of the chain. To facilitate the dropping into place beside one another of the successive turns of chain, it is a good idea to use the close-twist link chain and give it some motor grease now and then. Wear of wheels and shoes is taken up by screwing up the turnbuckles in the equalizer rods.

80. Double-Truck Riggings.—The points to be taken care of in double-truck riggings are about the same as those in single-truck riggings as regards the renewal of fulcrum pins and parts in the hand-brake rigging. On double trucks, however, the truck rigging must be considerably modified, in consequence of space limitations and the method of adjusting piston travel to suit all conditions of brake-shoe wear. On double trucks, also, the shoe beams are supported, as a rule, by hangers instead of slides. The hangers are inclined away from the wheels, so that, except when the brake is applied, the force of gravitation keeps the shoes clear of the wheels. The hangers must be kept free in movement and not allowed to wear to the breaking point, so as to let the brake beam drop. Wear on shoes and wheels is taken up by means of the dead levers or bottom rods, or by both. In Fig. 39 is shown the method of changing the position of the upper end of the dead lever. A rack fastened to the truck contains a series of holes; a pin fitted into one of these holes supports the upper end of the dead lever. The position of the pole containing the pin determines the angle between the dead lever and a vertical line. By moving the lever a hole or more to the left, the clearance between the shoes and wheels is increased. By moving the lever a hole or more to the right, the clearance may be decreased. Therefore, as the brake shoes wear down to the dotted lines shown in Fig. 39, and the clearance increases, thereby increasing the piston travel, the top ends of all dead levers must be moved toward their respective wheels.

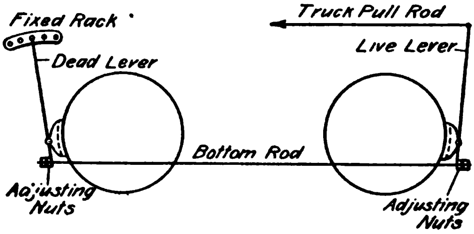


Fig. 39

The same effect can be obtained by taking up on the adjusting nuts on the ends of the bottom rods. Screwing up on these nuts in effect shortens the bottom rod, thereby bringing the shoes on opposite ends of the truck closer together and nearer to their respective wheels, thus decreasing the clearance. If either the bottom rod or the dead lever is used to the exclusion of the other, both the dead and live levers, before a set of new shoes has worn to minimum thinness, have assumed an undesirable degree of angularity.

Excessive angularity can be avoided by dividing the adjustment between the dead lever and bottom rod. To do this, move the dead lever over one hole, and then screw the nut on the bottom rod a sufficient distance forwards to insure that the live and dead levers hang almost vertically when the brake shoes are about half worn out. The Christensen Company recommend that in adjusting their equipment the piston travel should be not less than 4 inches nor more than 5½ inches just after an adjustment. As soon as wear brings the piston travel to 8 inches on a full application, a new adjustment should be made. The adjustment should be such that when the brakes are applied, the two brake-cylinder levers make approximately the same angle with the center line across the car body.

81. Inspection of Parts.—All brake-chain fastenings should be inspected every day. Each small amount of wear weakens a chain, and it is only a question of time when it will get weak enough to break. Bad brakes are often caused by some rod or lever rubbing on a part of the car or against some other device. "Brake rod rubbing wheel," "brake rod rubbing resistance," "brake rod rubbing gear-case," etc. are familiar expressions in depot life. When a brake rod is interfered with, the friction not only puts extra work on the motorman or air-brake apparatus, but it may also put so much work on the release springs that they become useless. The constant rubbing will weaken the rod, so that in course of time it will break. Rods and levers may clear everything when the car is light, and yet interfere with each other or with some part of the motor rigging when the car is loaded. A rod may clear a wheel of one type and interfere with one of another type. Excessive end play in axle collars will let the motor over against the brake rods. Excessive load on a car with weak springs may let the rods down on top of a gear-case or motor. In placing or inspecting a set of rigging, all these points must be kept in mind, making due allowance for the effects of increased weight on the car body, of weakening of truck springs, and of wear on the moving parts of the brake rigging. All turnbuckles, brake slides, fulcrums, and, on double-truck cars, strap hangers should be kept lubricated. Release springs should be renewed when they get too weak to pull the shoes to off-position.

CONDITIONS AFFECTING BRAKING

STATE OF RAIL

82. An important factor to be considered on trolley roads is the condition of the rail. The T rail on steam roads is mostly laid in the open country and affords very little lodging for accumulations of snow and slush on its wearing surface. A T rail used in trolley-road construction has the same advantages. Trolley roads using a girder rail, whose flat top and open groove are inviting places for the lodgment of foreign substances, are apt to have more trouble as a result of occasional conditions of the rail.

USE OF SAND

83. When the rail is slippery, it is easy to apply too much brake pressure, thereby causing the wheels to slide and wearing flat spots on them. To offset the disadvantage of a slippery rail, it is the custom to use sand, which is not always used with the best judgment, either in the manner of provision by the management or in the manner of application by the men. The use of sand improves the friction between wheels and rail, but most managements make the mistake of sanding only one rail instead of both. Sanding two rails instead of one doubles the *rolling friction*, or the tendency of the rails to pull the wheels around. Assuming that proper facilities are provided for sanding the rail, there is a wrong and a right method of applying the sand. The wrong method is the most widely used, and consists in applying the brake first and the sand next, with the result that the wheels become locked before reaching the sand, and, sliding into it, get flat spots worn on them. The right method consists in applying the sand and then the brake. The prevalence of the wrong method is largely due to the poor judgment used in locating the sanding device.

84. Sand Boxes.—Sanding devices are generally called **sand boxes.** Fig. 40 shows one type of sand box, in which *a* is a section through the car floor or platform; *b*, the sand box, or hopper, containing the sand supply *c*; *d*, the operating push button; *e*, a lever; *f*, the valve rod; *g*, a slide valve; *h*, an upright extension that moves with the slide valve and stirs the sand; *i*, the release spring; and *j*, the spout out of which the sand flows to the rail. The sand box or hopper is preferably located under the corner seat of a closed car and under the end seat of an open car. In either case, it must be protected from the weather and must be easily accessible for refilling.

The operation of the device is very simple. Foot-pressure on button *d* draws lever *e* and pull-rod *f* and valve *g* to the left, thereby making an opening between the hopper and the pipe leading to the spout. Instead of a push button, an upright lever for operation by hand is sometimes used. The foot push button, however, is the better arrangement, because it does not withdraw the motorman's hand from either his brake handle or controller.

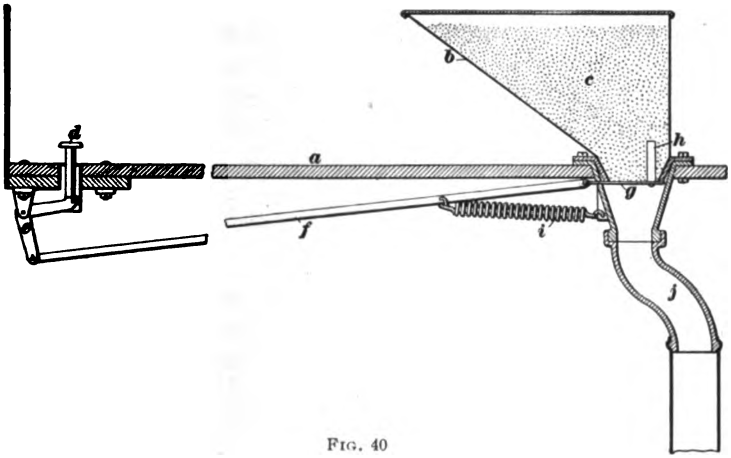


FIG. 40

If a motorman should put his foot on the button and forget to take it off, all the sand would escape from the hopper. To avoid such an accident, an intermediate valve chamber having a slide valve above and below it is provided in some boxes. The two valves have their open positions at opposite ends of the stroke. When there is no pressure on the foot-button, the upper slide is open and the bottom one closed; this allows sand from the hopper to flow into the intermediate valve chamber, but no farther. Pressure on the button closes the upper slide valve, cutting off communication with the hopper, and opens the lower slide valve, allowing the sand in the intermediate chamber to run out at the spout. The proper method of operating any manual type of sanding device is by opening and closing the valve by short successive applications of pressure.

85. Sand Cars.—Some roads dispense with individual sand boxes on passenger cars and run regular sand cars when conditions demand it. But independent sand boxes on every car are more economical, for sand is then used only when it is needed. On cars that are run from the same end all the time, sand rigging is needed on but one end; but on cars that are run from both ends, sand rigging must be provided on both ends.

SHOE PRESSURE

86. The pressure required to brake a car depends on the weight and speed and on the number of wheels that have shoes applied to them. If a car has eight wheels and the brakes are applied to four, the pressure per shoe must be the same as would be necessary were all wheels supplied with shoes, because the braked wheels carry only one-half the weight of the car; the maximum pressure to be applied to a wheel depends on how much weight the wheel supports. To avoid sliding, the pressure applied to a wheel should be a little less than the weight it supports.

The amount of pressure necessary to cause a wheel to slide depends on the relation between the rail-and-wheel friction and the shoe-and-wheel friction. At high speeds, the shoe-and-wheel friction is less than at low speeds, but the rotative energy of the wheel or its tendency to keep turning is greater. This suggests one of the strongest points in favor of power brakes, namely, that the maximum braking power is almost instantaneously applied at maximum speed, when the tendency of the wheels to skid is least. When the wheels have heavy motor armatures geared to them, the effect of the rotating energy of those armatures is considerable.

It has always been asserted that the friction between a shoe and wheel is independent of the amount of surface exposed between them. The claim is based on the supposition that for a given total pressure applied, the effect of varying the surface of a brake shoe is simply to vary the pressure per square inch; this claim is true when the wheel is perfectly round and the shoe truly concentric with it. There is, however, a growing tendency to use long brake shoes because they not only tend to keep the wheel round, but also reduce the pressure per square inch and therefore last longer.

How much of the pressure applied to a wheel is useful in stopping a car depends on the nature of the material of the shoe and wheel. Some car wheels are soft and others hard; the same is true of brake shoes. A soft shoe will give more friction at a given pressure than a hard shoe, but it will wear out sooner.

AUTOMATIC AIR BRAKES

INTRODUCTION

1. In the **automatic air-brake system,** the air used in operating the brake-cylinder piston is not taken directly from the main reservoir, as in the straight air-brake system; the air first passes through a triple valve and an auxiliary storage reservoir. The action of the triple valve is automatic and depends on the air pressures in the different parts of the system. In the following pages, the principles of operation of the several devices composing an automatic air-brake equipment, and the relations existing among them, are explained. The actual devices in use on electric trains are then considered.

Many of the devices used on steam trains can be used on electric trains; but in the case of others, the substitution of electricity for steam renders some changes necessary. In both kinds of service, every car that is to be braked must have a brake cylinder, an auxiliary reservoir, a triple valve, a system of pipe connections, and levers for applying pressure to the shoes. On a steam train, as all braking power is generated and applied from the engine, the compressed air is provided by a steam-driven air pump located on the engine; the air is compressed into a main tank located on the engine, and the pressure in this tank is controlled by an air-actuated governor, also located on the engine. On modern electric trains, each motor car supplies and applies its own air through the agency of an electrically driven compressor located on the car. The air is compressed into a main tank attached to the car, and the pressure in that tank

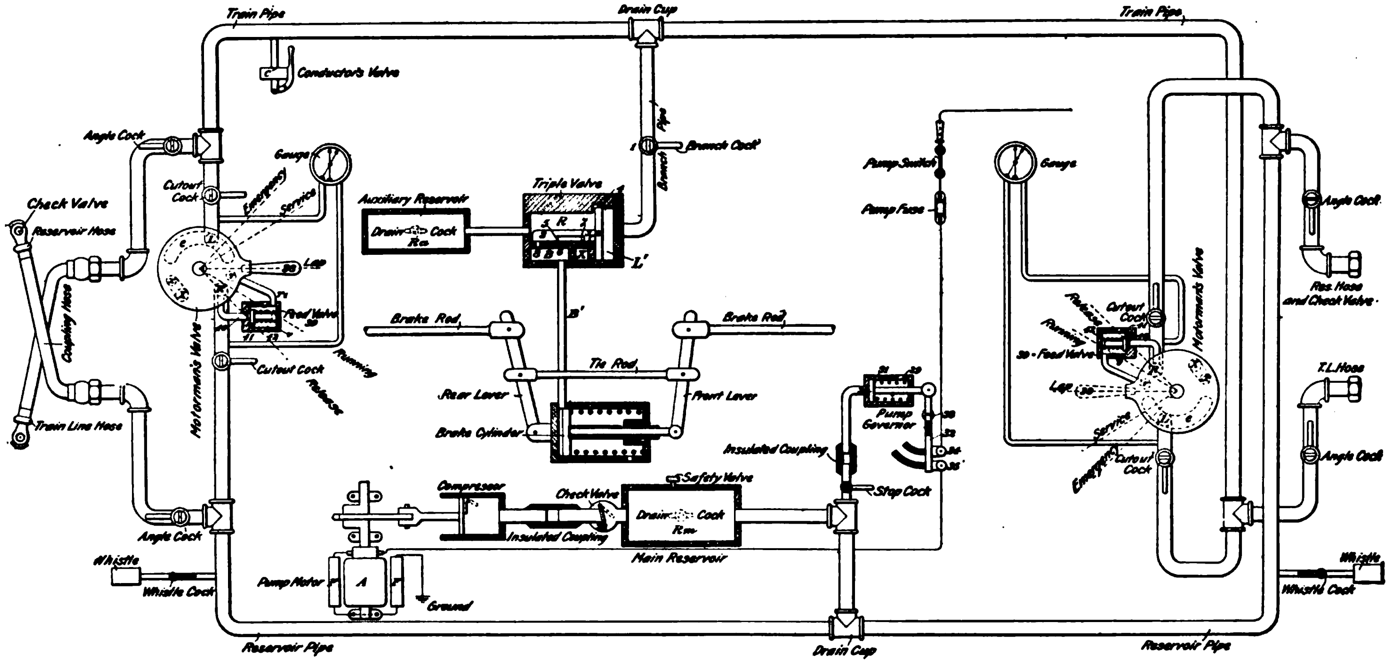

Train Pipe
Drain Cup
Train Pipe
Conductor's Valve
Pipe
Branch
Branch Cock
Angle Cock
Cutout Cock
Emergency
Service
Gauge
Check Valve
Reservoir Hose
Coupling Hose
Train Line Hose
Lap
Feed Valve
Running
Release
Cutout Cock
Motorman's Valve
Auxiliary Reservoir
Drain Cock
Ra
Triple Valve
R
L'
B'
Brake Rod
Brake Rod
Tie Rod
Rear Lever
Front Lever
Brake Cylinder
Compressor
Check Valve
Insulated Coupling
Safety Valve
Drain Cock
Rm
Main Reservoir
Pump Motor
A
Ground
Whistle
Whistle Cock
Angle Cock
Reservoir Pipe
Drain Cup
Reservoir Pipe
Pump Switch
Pump Fuse
Pump Governor
Insulated Coupling
Stop Cock
Gauge
Release
Running
Cutout Cock
30 • Feed Valve
Lap
Service
Emergency
Cutout Cock
Motorman's Valve
Angle Cock
Res. Hose and Check Valve
T.L. Hose
Angle Cock
Whistle
Whistle Cock

FIG. 1

is controlled by a governor actuated by air and by an electric current. The governor also is mounted on the car. A steam train has but one pipe line running its full length; an electric train generally has two. Comparatively short trains are used in electric service, and on such trains either straight air brakes (already considered) or automatic air brakes may be used.

GENERAL DESCRIPTION

RELATION OF DEVICES

2. Names of Devices.—Fig. 1 shows the devices used on an electric car equipped with an automatic air brake; they are as follows: one motor-driven air compressor; two air gauges; one air-pressure governor (commonly called pump governor); two motorman's, or engineer's, valves; one main reservoir; one auxiliary reservoir; one triple valve; one brake cylinder; two whistles; reservoir pipes, train pipes, and couplers; four angle cocks; four cut-out cocks; one branch cock; various check-valves, safety valves, connecting pipes and wires, electric switches and fuses, insulated coupling hose, drain cocks and levers, all of which are named in the diagram.

3. Location of Devices.—The devices are located with the following points in mind: To use the least amount of pipe and the least number of bends; to use a bend in preference to an elbow fitting; to distribute the weight equally between the sides of the car; to place all devices, as far as possible, where they will be best protected from bad weather and mechanical injury; to make all devices readily accessible to inspection; and to so locate them that they will clear all other devices on or under the car, whether the car is light or loaded, on a curve or on a straight track, or whether the brakes are applied or released.

THE TRIPLE VALVE

4. The air used to brake each car is stored in the auxiliary reservoir located on that car, and can reach the brake cylinder only through the agency of the **triple valve** on that car. In Fig. 1, triple-valve chamber L' connects to the train pipe through the branch or cross-over pipe, which includes branch cock *1*. When the handle of this cock is turned as shown, train-pipe air can enter triple-valve chamber L'. When the handle is parallel to the branch pipe, the cock is closed and no air can pass through it.

Triple-valve chamber R connects to the auxiliary reservoir and is, therefore, at auxiliary-reservoir pressure. Triple-valve chamber B carries brake-cylinder pressure, and chamber X is permanently open to the atmosphere. Triple piston *2*, which is rigidly connected to slide valve *3*, has, therefore, train-pipe pressure on one side and auxiliary-reservoir pressure on the other. When the train-pipe pressure exceeds that of the auxiliary reservoir, piston *2* and slide valve *3* must take the position shown, where train-pipe air can flow through feed groove *4* and charge the auxiliary reservoir to train-pipe pressure, under which condition they are said to be **equalized.**

In this position, the piston and slide valve are as far to the left as they can go; the triple valve is said to be in *release position*, because in this position the brake-cylinder air can escape to the atmosphere, thereby releasing the brake. Slide-valve cavity *5* is over ports *6* and *7* simultaneously, thereby connecting the pressure end of the brake cylinder to atmosphere by way of path B'–B–*6*–*5*–*7*–X.

When the air is let out of the train pipe, thereby reducing its pressure, a *reduction* is said to have been made; if the reduction takes place gradually, it is called a *service reduction*. A reduction can be due to any of several causes: to gradual leakage in the train pipe or any of its connections; to a service or emergency application made by the motorman through the agency of the engineer's valve; to bursting of a train-line hose; to the parting of the train, the hose being thereby pulled loose; or to the operation by one of the train crew or a passenger of a conductor's valve to be found in the closet (or elsewhere) on every car. To whatsoever cause the reduction may be due, if train-pipe pressure is reduced sufficiently below that of the auxiliary reservoir, the excess of auxiliary-reservoir pressure will overcome the friction of the triple piston and slide valve and move them to the right, closing feed groove *4* and opening service port *8*, so that auxiliary-reservoir air can pass into the brake cylinder by way of path R_a–R–8–B–B', force out the brake piston, and set the brakes.

If the reduction has been due to service operation of the engineer's valve, piston *2* will move to the right slowly; and after a certain amount of air has passed into the brake cylinder, will move to the left again, closing the service port and leaving the brake partially set. Piston *2* returns to the left a little, because the expansion of auxiliary-reservoir air into the brake cylinder reduces the auxiliary-reservoir pressure a little below that of the train pipe. In this midway position, the triple valve is said to be on *lap*.

If, however, the reduction has been due to extended use of the service position of the engineer's valve, or to a burst hose, or to any condition that reduces train-pipe pressure to a value below the lowest normal auxiliary-reservoir pressure, the triple piston and slide valve will remain to the right, allowing the auxiliary reservoir and brake cylinder to equalize and setting the brake in full. This fact is the basis of the strongest argument in favor of automatic air brakes. If for any reason an abnormal opening is created between the train pipe and atmosphere, an emergency reduction obtains and all brakes go into quick action. If a train parts, both sections come to an emergency stop and there is little danger of a serious collision, because both sections stop at nearly the same rate.

To release the triple valve after an application, train-pipe pressure must be raised above that of the auxiliary reservoir. If an accident has caused the application, normal conditions must be restored before this can be done. Having removed the cause of the application, the motorman places his valve on a position that allows main-reservoir air to flow into the train pipe, thereby charging all train pipes and all auxiliary reservoirs attached to them. As the train pipes of the several cars that make up a train are connected together, they, with their coupling hose, constitute what is called the *train line.* When an empty train line is filled with air from the main reservoir, the operation is referred to as *charging the train line.* When restoring train-line pressure after an application, the operation is referred to as *recharging the train line.* When the train-line pressure is allowed to exceed a certain value, the train line is said to be *overcharged.* As soon as train-line pressure moves the triple pistons to release position, train-line air begins to recharge the auxiliary reservoirs by way of the triple piston feed grooves *4*.

The conventional triple valve indicated in Fig. 1 suffices to show the main feature of operation of the service parts of triple valves in general; namely, the movement of the triple piston to the right or to the left, according to the side on which there is a predominance of pressure. Such a crude form of triple valve will stop a car; but in the desire to avoid complications, there have been omitted from the sketch several refinements that greatly increase the sensitiveness and effectiveness of the modern triple valves.

THE BRAKE CYLINDER

5. One end of the **brake cylinder** is called the *live end* of the cylinder, since it is connected by a pipe to triple-valve chamber *B*. The space on the other side of the brake piston is called the *dead end* of the brake cylinder: it opens directly to the atmosphere. The push rod is attached to the front lever, and the rod can move independently of the sleeve connected to the piston. When there is no air pressure in the chamber at the left end of the brake cylinder, a spring keeps the piston and sleeve to the left in release position, the push rod being forced to follow by the brake-rigging release springs acting through the brake levers. When a train-line reduction causes the triple valve to admit air to the brake cylinder, the piston moves to the right, carrying the sleeve and push rod with it and compressing the spring.

As soon as sufficient air pressure is obtained in the brake cylinder, all moving parts take up service position. The service and emergency positions of the brake cylinder are the same, except in so far as the greater force due to an emergency application might slightly increase the piston travel. When the triple valve releases, the brake cylinder exhausts to the atmosphere through the triple valve, the brake-cylinder spring forces the piston back to release position, and the push rod is forced back by the springs of the brake rigging. A leakage groove near the top or side of the brake piston carries to the atmosphere any air that may leak into the brake chamber when the triple valve is in service position in consequence of a very light application of the brakes, such as is brought about by train-pipe leaks; this has the effect of preventing the brake from creeping on.

THE COMPRESSOR

6. The **compressor** includes the air pump and the motor that runs it. The pump motor is of the series-type and is of high internal resistance to avoid the use of a starting coil. The motor may be directly connected to the crank-shaft, as indicated, or it may be geared to the crank-shaft. In Fig. 1, *A* is the armature and *F*, *F* are the field coils of the motor. A crank-shaft is coupled to the armature shaft, so that the crank-shaft must make a revolution every time the armature shaft makes one. A flap valve is provided on the compressor piston. When the motor circuit is closed, the armature turns, turning the crank-shaft with it and causing the compressor piston to move back and forth in the compressor cylinder. The left end of the cylinder is open to the atmosphere; the right end is connected, by a pipe, to the main reservoir R_m through check-valve *28*. Movement of the piston to the left creates a vacuum on its right; the vacuum allows main-reservoir pressure to close check-valve *28*, atmospheric pressure opens the flap valve on the piston, and air rushes in to fill the vacuum. When the piston gets to the left end of its stroke, the cylinder space to its right is full of air at atmospheric pressure.

As the piston starts to the right, it compresses the air ahead of it. A small amount of compression closes the flap valve if gravity has not already closed it. Further movement of the piston to the right compresses the confined air to a greater extent. As soon as the cylinder pressure exceeds that in the main reservoir, the check-valve *28* opens and the compressed air flows into the main reservoir. When the piston again starts to the left, the main-reservoir pressure promptly closes the check-valve, so that main-reservoir air cannot follow the piston; atmospheric pressure once more opens the flap valve and the cylinder is filled again with air from outside. On the return stroke, the piston must travel farther and compress the cylinder air more before check-valve *28* opens against the main-reservoir pressure, which was increased by the preceding stroke. Each cylinder of air compressed into the main reservoir increases the main-reservoir pressure, and also increases the amount of work that the pump motor must do per stroke.

THE GOVERNOR

7. The **governor** is the device that stops the motor when main-reservoir pressure exceeds a certain fixed value, and starts the motor when main-reservoir pressure falls below a certain fixed value. In Fig. 1, *29* is a cylinder in which piston *30* can be forced to the right against spring *31*; and to the left against whatever pressure may be to the left of it. Insulated switch blade *32* is mounted on an arm free to move around fulcrum *33*. When there is no pressure in the main reservoir, spring *31* forces piston *30* to the left. Switch arm *32* connects contacts *34* and *35*, so that if the pump switch is closed and the fuse intact, the pump motor starts. As main-reservoir pressure increases, it forces piston *30* to the right, compressing spring *31* and causing arm *32* to move to the left. On main-reservoir pressure reaching the maximum value allowed—90 pounds per square inch, for example—arm *32* leaves contacts *34* and *35* with a snap, and the pump motor stops..

If, for any reason, main-reservoir pressure falls below 90 pounds per square inch, spring *31* overcomes the reduced pressure and begins to force piston *30* to the left and arm *32* to the right. Before arm *32* can touch contacts *34* and *35* again, it must traverse the gap caused by its having been snapped away from contacts *34* and *35*. While this distance is being covered, main-reservoir pressure continues to fall. The throw of arm *32* is such that just as the pressure reaches its lower limit—80 pounds per square inch, for example—the arm again touches contacts *34* and *35*, thereby starting the compressor, which restores standard pressure in the main reservoir. For a given spring *31*, the pressure at which the governor will *cut out* depends on the length of contacts *34* and *35*. The margin of pressure variation, and hence the value at which the governor will *cut in*, depends on the throw of arm *32*. The governor just described suffices to show what a governor is required to do; such a crude device, however, has several faults that are not found in actual types now used.

MOTORMAN'S, OR ENGINEER'S, VALVE

8. The conventional valve of Fig. 1 shows the general operating principle of all **engineer's valves**. This device consists of a metal body whose top is surfaced to act as a seat for the rotary valve, which turns on it when handle *38* is turned. In the seat are five holes, R, r, L, X, x; R, L, and X extend through to the bottom of the body, where they connect to the reservoir pipe, the train pipe, and the exhaust pipe. The under side of the rotary has a circular cavity e. The movement of handle *38* causes cavity e to move over holes L, r, R, X, and x, and establish certain combinations instrumental in applying the brake or releasing it, or in keeping it applied or released. The valve-seat holes are called ports. Port *x* is an extension of port *X*. Port *r* has no direct connection to port *R*, except when cavity *e* covers both. Ports *R* and *r* are indirectly connected through feed-valve *39*, to be considered later. Port *X*, called the ***exhaust port***, always carries atmospheric pressure. When the cut-out cock handles are across their containing pipes, as indicated near the left-hand motorman's, or engineer's, valve of Fig. 1, port *R* contains main-reservoir pressure and port *L* contains train-line pressure. When the cut-out cock handles are parallel with their containing pipes, the engineer's valve above them is cut out.

The motorman's, or engineer's, valve is sometimes called the ***brake valve***. The conventional brake valve of Fig. 1 has five positions, indicated by dotted lines, each of which is named. In Fig. 1, both brake valves are shown with a handle, but only one handle is necessary for a whole train. The handle shown in the figure points almost straight back toward the motorman; in this position, rotary cavity *e* does not connect any of the valve-seat ports. There can be no flow of air through the brake valve, so that the valve simply maintains the condition existing at the time that it assumed that position. In this position, the brake valve is said to be *lapped* or to be on *lap*. The act of moving the valve to lap position is called *lapping the valve*. When a perfect brake valve is lapped, it is as effectually cut out as if each port had a plug in it. On account of this feature, all brake-valve handles are designed to be installed or removed *only on lap position*, thereby securing a condition of neutrality in any valve that a motorman may fail to cut out by the cut-out cocks before going to another valve. It is best, however, to cut out a brake valve under such conditions, for if the rotary happens to be leaky, complications may arise. Lap position is used, in operation, mainly to hold some given braking condition.

To make a stop of any kind, a train-line reduction must be made. To make a service stop, the reduction must be made gradually. To make a gradual reduction and bring about a service stop, the brake-valve handle is moved one notch to the right—to service position. Here cavity *e* connects train-line port *L* and service exhaust port *x* simultaneously, allowing train-line air, hence air from triple-valve chamber *L'*, to exhaust gradually to the atmosphere. The pistons of all the triple valves then operate to admit to the brake cylinders an amount of air depending on the length of time the brake valve has been allowed to rest in service position. The brake valve can be held in service position long enough to allow the auxiliary reservoirs and brake cylinders to equalize, but such action will not be conducive to smooth operation. The correct method of making a service stop will be considered later.

9. The emergency position is used to produce an emergency stop in time of pending danger. To make this stop, the brake-valve handle is thrown to emergency position at once and held there until the train stops or all danger is over. In this position, cavity *e* covers train-line port *L*, service exhaust port *x*, and emergency exhaust port *X* simultaneously.

The rush of train-line air to the atmosphere causes all triple pistons to move quickly to the right and stay there. In a modern type of triple valve, the force with which an emergency reduction moves the triple piston over enables it to operate parts that are not disturbed by service action. The parts referred to are the emergency parts of the triple valve that are not shown in Fig. 1. One result of the operation of the triple-valve emergency parts is to uncover a large port that allows train-line air to discharge either to the atmosphere or to the brake cylinder (according to the make of the triple valve) at the triple valve itself. This local train-line reduction at one triple valve throws the next one into emergency action; and the local reduction there throws the next, and so on throughout the length of the train. The final effect of these local triple-valve reductions is to move all triple-valves to emergency action practically at the same instant. This condition could not obtain as a result of the brake-valve reduction alone without inviting complications. Following the local triple-valve reductions closely, a larger and more direct opening is created between the auxiliary reservoirs and brake cylinders, allowing their pressures to equalize at once and set all brakes in full immediately.

On some makes of triple valves, the effect of an emergency reduction is to apply all brakes simultaneously and immediately, and with more force than a full-service application can produce. The triple-valve emergency valve, instead of producing a local reduction of train-line air to the atmosphere, discharges the air into the brake cylinder. The train-line and brake cylinders equalize first; a fraction of a second later, auxiliary-reservoir air rushes into the brake cylinder through a large opening.

As the brake cylinder already contains air at train-line pressure, it can equalize with the auxiliary reservoir at a greater final pressure than would obtain in the first case. A greater pressure, therefore, operates to apply the brakes harder.

Emergency action depends, mainly, on the suddenness of the reduction, that is, on the amount of reduction per unit of time. This, in turn, depends on the pressure acting and on the size of the hole through which the reduction takes place. It is important that the brake valve be thrown to emergency position as soon as occasion requires an emergency stop; if it is allowed to rest on service position, the reduction of auxiliary-reservoir pressure, due to discharge of auxiliary-reservoir air through the triple-valve service port into the brake cylinder, may reduce the auxiliary-reservoir pressure to a value that is unable to throw the triple piston into emergency action when the brake valve is finally moved to the emergency position.

The first notch to the left of lap position is called *running position;* it is used for running. Here cavity *e* connects train-line port *L* and charging port *r*, so called because through it main-reservoir air recharges the train line after an application. Feed-valve chamber *40*, connected to port *R*, carries main-reservoir pressure, which tends to move valve *41* against the resistance of spring *42*. A pressure of 20 pounds per square inch will unseat valve *41*. When this valve is unseated, main-reservoir air feeds through it into the train line; when it is seated, as shown, the train line can get no more air through it.

Assume the train line and main reservoir to be empty. On closing the pump switch, the pump will start. The brake valve is in running position. As soon as the pressure gauge shows 20 pounds, valve *41* will unseat and main-reservoir air will pass into the train line, move the triple pistons to release position, and pass through the feed grooves to charge the auxiliary reservoirs. Train-line pressure will increase until it reaches its fixed standard value—70 pounds per square inch, for example. On reaching its standard value, the train-line back pressure added to that of spring *42* is able to seat valve *41* against the effort of the main-reservoir pressure to keep it open. This assumes that the governor stops the pump at 90 pounds per square inch. It does not matter at what main-reservoir pressure the governor is set to act, the pressure will always be greater than train-line pressure by an amount equal to the pressure required to unseat valve *41* against the resistance of spring *42*. This difference in pressure is always maintained on automatic air-brake systems and is called *excess pressure*, the feed-valve being sometimes called the excess-pressure valve. If the pressure gauge is correct, the difference in the indications of its hands will show the amount of excess pressure.

10. The feed-valve is operative only on running position. If, however, on any other position of the brake valve, leakage or use of air should reduce the train-line pressure below its standard value, as soon as the brake valve is returned to running position, main-reservoir pressure will open the feed-valve against the combined opposition of spring *42* and the reduced train-line pressure, and the train line will be recharged to standard pressure. As long as the brake valve is on running position, all triple pistons are released and all brake cylinders connected to atmosphere, so that any tendency that train-line or triple-valve leaks may have to cause brakes to creep on is offset by the ability of the main reservoir to counteract the effects of leaks by forcing air through the feed-valve.

To promptly release brakes after an application, the brake-valve handle is moved to the extreme left to *release position.* Here cavity *e* is over ports *R*, *r*, and *L*, and main-reservoir air rushes into the train line through the large and direct passageway thus created. Train-line pressure being thus rapidly raised above that of the auxiliary reservoirs, the triple pistons promptly move to release position, allowing the air in the brake cylinders to discharge to the atmosphere. If the brake valve is left on release position too long, main-reservoir and train-line pressure will equalize, thereby destroying excess pressure and overcharging the train line. Several disadvantages attend the loss of excess pressure in this manner. To avoid such a condition, the brake valves now used in electric service are usually provided with a strong spring, which is forced into action by the movement of the brake valve to release position and which returns the brake valve to running position when the motorman relaxes his holding effort. When excess pressure is lost as a result of overcharging the train line, a great deal of air at high pressure is wasted if the next application of the brakes must be made immediately.

The feed grooves in the triple valves are small, and if the train pipe is charged 15 or 20 pounds higher than the auxiliary reservoirs, the latter may not have time to equalize with the train pipe before the second application becomes necessary. Suppose that the train-pipe pressure is 6 or 7 pounds higher than the auxiliary pressure when the second application is about to be made; to set the brakes with the first reduction, a reduction of 12 or 13 pounds must be made—6 or 7 pounds to make the train-pipe pressure equal to the auxiliary-reservoir pressure, and 5 or 6 pounds to apply the brakes.

Assuming that the abnormally high train-line pressure has had time to equalize with the auxiliaries, and that they have equalized at 80 pounds per square inch, two undesirable conditions obtain; namely, the overcharged auxiliaries may, unless care is taken in operating the engineer's valve, create excessive brake-cylinder pressures on the next application, thereby rendering the wheels liable to slide, should local conditions favor that tendency. The brakes cannot be released after application as promptly as they could under normal conditions, as the difference between the main-reservoir pressure and the high train-line and auxiliary-reservoir pressure is less than normal. It is the difference of pressure that allows air from the main reservoir to move the triple valve to the release position.

PIPE LINES

11. Fig. 1 shows the two **pipe lines** to have coupling hose on both ends, by means of which they may be coupled to the pipe lines of abutting cars. When diagonally opposite hose on abutting cars are coupled, all main reservoirs in a train become connected together and are part of the reservoir line. All triple valves become parts of the common train line. Both pipe lines connect to all brake valves. The main-reservoir coupling-hose heads, as a rule, contain check-valves to prevent main-reservoir air from leaking away should the train part; this affords a ready means of identifying for coupling the corresponding hose ends. The main-reservoir angle cocks and hose heads are usually painted *red;* those of the train line *black*. A red coupler should never be coupled to a black coupler, or one with a check-valve to one without a check-valve, where such are used. While these reservoir coupler check-valves are not indispensable to the service and are not always used, they are a good feature.

Assuming a car to stand north and south and an observer to stand behind it, facing north, the train-line hose will be on the east side at one end of the car but on the west side at the other end of the car. The same is true of the main-reservoir line hose. The hose are thus crossed at the two ends of the car, so as to render the manner of coupling independent of the relative end-on position of abutting cars. When coupling, *couple diagonally opposite hose.*

12. A train in good order must have both angle cocks on both ends of the train closed, but all intermediate angle cocks must be open. All branch or cross-over pipe cocks must be open. All brake-valve cut-out cocks, except those under the brake valve that is in use, must be closed. All governor cocks must be open. All whistle cocks, except the one on the operating end of the operating car, must be closed.

13. All main reservoirs being connected by the reservoir line, the pressure in all is the same. All triple valves being connected by the train line, any condition obtaining in the train line through the action of the brake valve affects all triple valves practically at the same time. As the train and reservoir lines are in common to all brake valves, the train can be operated from any brake valve on it. When the triple valves operate to admit pressure to the brake cylinders, the resulting movement of the pistons and push rods is transmitted to the connecting brake levers and rods in such a way as to exert a pull on the main brake rods, thereby pulling on the circle bars and individual truck riggings.

SUMMARY

14. Consideration of Fig. 1 has shown the following, among other things: An electric motor is used to operate an air pump, which stores air in a tank called the main reservoir. The starting and stopping of the motor is controlled by a governor, which, in turn, is actuated by main-reservoir pressure. The action of the governor is such as to start the motor when main-reservoir pressure falls below a certain fixed value, and stop the motor when the maximum pressure is reached. Main-reservoir pressure can vary between these limits without affecting the motor. The difference in pressure, expressed in pounds per square inch, included between the starting and stopping limits is called the margin of variation, and is usually about 10 pounds. On every car, the main-reservoir pipes to the governor, brake valves, and coupling hose on that car. When cars are made up into a train, the main-reservoir pipes and couplers constitute the reservoir line. The reservoir line, main reservoirs, compressors, and governors have to do simply with providing, at a certain pressure, a certain amount of air, to be used as circumstances may require. Main-reservoir air has nothing directly to do with applying the brakes. On every car is a triple valve that pipes to the train pipe, auxiliary reservoir, and brake cylinder on that car. The triple valve is, therefore, in communication with the brake valves and train-pipe couplers on that car. When cars are made up into a train, the several train pipes and their couplers constitute the train line. The auxiliary reservoir on a car holds the air that brakes that car. The auxiliary reservoir gets its air from the train line through the triple valve; the train line gets its air from the main reservoir through the brake valve. Any brake valve can place the whole reservoir line in communication with the whole train line.

To apply the brakes, train-line pressure is reduced below that in the auxiliary reservoirs by letting some train-line air escape to the atmosphere through the brake valve. The greater auxiliary-reservoir pressure then forces the triple pistons over to a position where auxiliary-reservoir air can pass into the brake cylinders. To release the brakes, main-reservoir air is admitted to the train line to raise its pressure above that in the auxiliary reservoirs. The greater train-line pressure then forces the triple pistons over to a position where the air in the brake cylinders can escape to the atmosphere. After the triple pistons have moved over to release position, train-line air passes through the triple piston feed grooves and recharges the auxiliary reservoirs to standard train-line pressure.

15. The angle cocks are used principally to cut out a defective car, to close the pipe lines on end cars, and to use temporarily when making a coupling to avoid complications to be described later. The branch pipe cut-out cocks are used to cut out defective brakes by rendering their triple valves inoperative. Closing the branch cock cuts out the triple valve without interfering with the continuity of the train line. The brake-valve cut-out cocks are used to render neutral all brake valves except the one from which the train is to be operated. Closing the cocks under all idle brake valves eliminates any bad effects tending to arise as a result of brake-valve leaks. The governor cock is used to connect or disconnect the main reservoir and the pump governor.

16. The most important point brought out in the preceding is the degree of safety inherent in automatic air-brake systems. If a train so equipped parts, the brakes on both sections automatically and immediately go into emergency action. Both sections are brought to a sudden stop, and there is little danger of the rear section running into the forward one.

COMPARISON OF STRAIGHT AND AUTOMATIC AIR-BRAKE SYSTEMS

17. While an automatic air brake has many advantages over a straight air brake in the handling of long trains, its advantages decrease as the length of the train decreases; and on single cars, such as are found on ordinary trolley lines running through cities, a straight air-brake equipment is simpler and cheaper. On long trains, a straight air brake is not used because the air meets with so much friction in passing from the main reservoir to the last cars on the train, that time is lost in setting the rear-end brakes, with the result that the forward brakes set first and the rear cars run into the front ones. On long trains, the possibility of the train parting is increased; but by the operation of automatic air brakes, the danger of a serious collision between the two parts of the train is eliminated. With a straight air brake, an application of the brake can be graduated with the same degree of certainty and precision as with the hand-brake. The motorman turns a handle that lets the air directly into the brake cylinder; if he finds that he has not let in quite enough to make the stop at a designated point, he can let in a little more; if he finds that the car is going to stop too soon, he can let out a little of the air in the brake cylinder. Such a feature is a very desirable one in city service, where stops are frequent and precise. Since a straight air brake is simpler than an automatic air brake, it costs less to maintain and gives less trouble to the caretaker. Also, the first cost of a straight air-brake equipment is much less than that of an automatic equipment, so that if it can satisfactorily perform the duties required, it cannot fail to appeal to the railway manager.

ACTUAL AIR-BRAKE DEVICES

18. Complete equipments of automatic and straight air brakes are manufactured by several companies. Some railway managements prefer one equipment, some another, and still others prefer an equipment composed of the best devices of several manufacturing companies. The motor compressors, brake cylinders, and reservoirs described in *Straight Air Brakes* can be used with automatic air brakes, and need not be again described. In an electric service using single cars, or trains propelled by a single motor car, the governor described under that heading is all that is required. Where a train is composed of several motor cars, a special type of governor, known as a *multiple-unit governor*, is sometimes used. Accordingly, this governor, a typical triple valve, and a typical engineer's valve will be described.

THE WESTINGHOUSE TRIPLE VALVE

DESCRIPTION

19. In Fig. 2 (*a*) is shown a section through a Westinghouse triple valve; Fig. 2 (*b*) represents the valve as transparent, so as to show the ports better; (*c*) shows the ports in the valve seat. The parts are: *1*, *2*, triple-valve body;

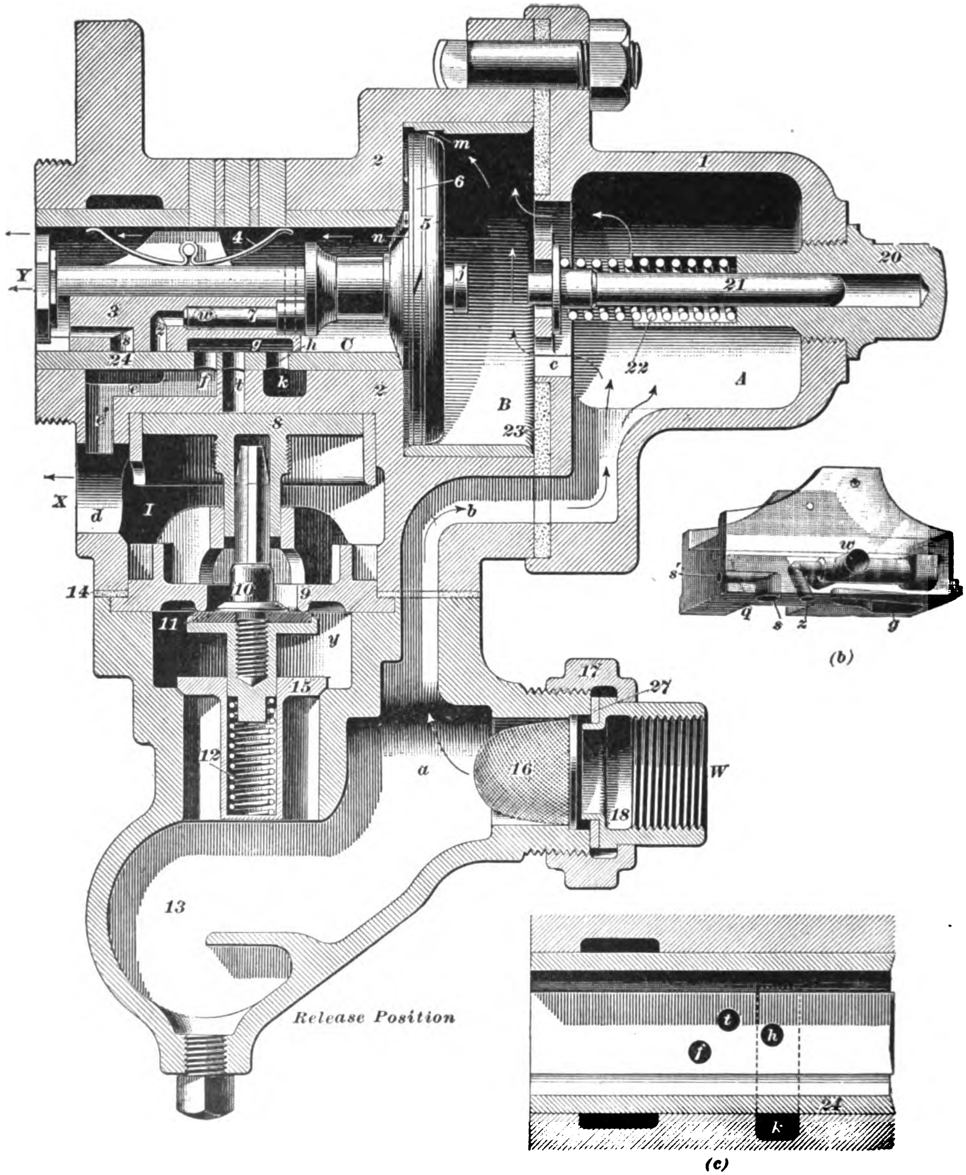
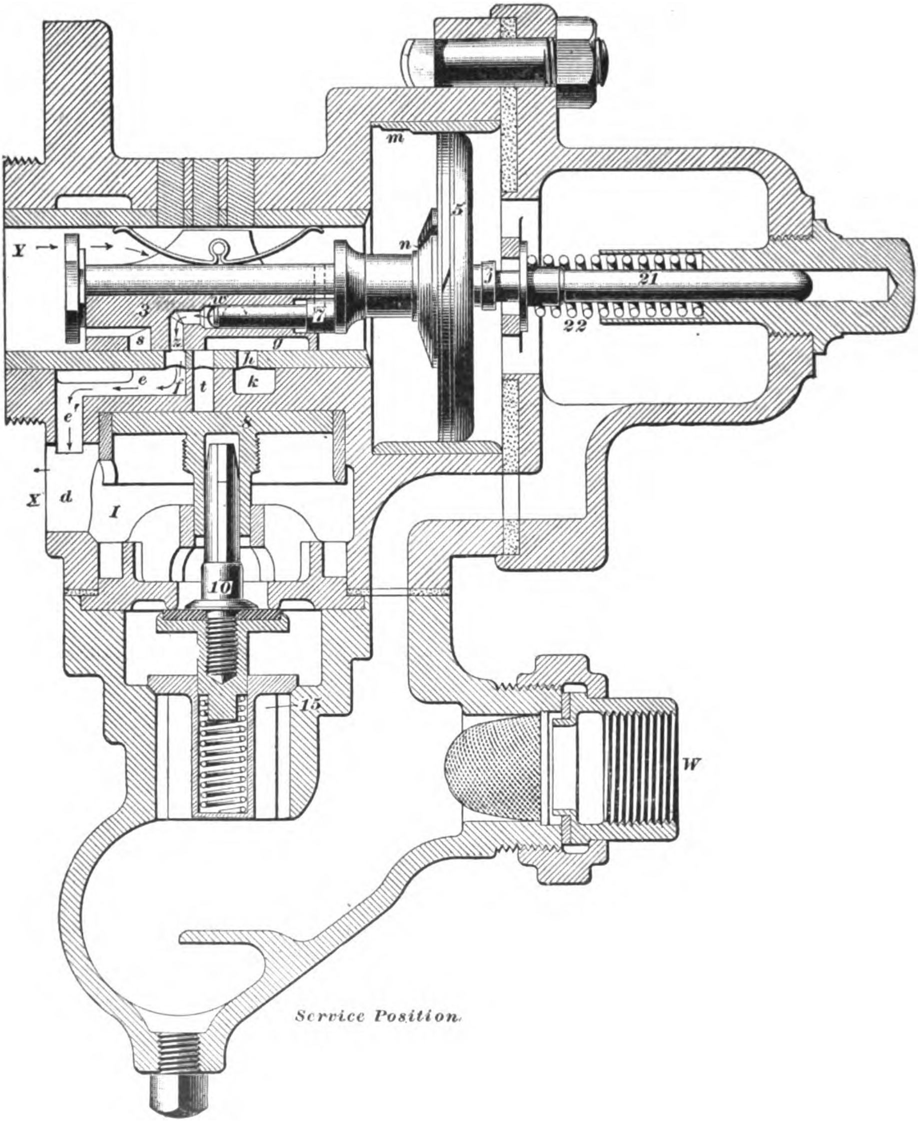

m
6
5
n
4
j
1
2
20
21
22
Y
3
w
7
s
24
e
e'
f
t
g
h
C
k
c
A
B
23
8
X
d
I
b
10
9
14
11
y
15
17
27
12
a
16
18
W
13
Release Position
s'
q
s
z
(b)
t
h
f
24
k
(c)

Fig. 2

3, slide valve; *4* slide-valve spring; *5*, triple-valve piston; *6*, piston packing ring; *7*, graduating valve; *8*, emergency-valve piston; *9*, emergency-valve seat; *10*, emergency valve; *11*, rubber seat; *12*, check-valve spring; *13*, drain cup; *14*, check-valve case gasket; *15*, check-valve; *16*, train-pipe strainer; *17*, *18*, *27*, union joint; *20*, graduating-stem nut; *21*, graduating stem; *22*, graduating spring; *23*, leather gasket; *W*, train-line branch pipe; *X*, brake-cylinder connection; *Y*, auxiliary-reservoir connection; *m*, *n*, feed grooves; *t*, port to let auxiliary-reservoir pressure down on emergency piston *8*. Piston *5*, slide valve *3*, graduating valve *7*, and stem *21* constitute the triple service parts. Emergency valve *10*, piston *8*, and check-valve *15* constitute the triple emergency parts.

OPERATION

20. In Fig. 2, triple piston *5* is in the *release* position. Train-line air enters at *W*, flows to chamber *A*, through port *c* to chamber *B*, then through feed grooves *m* and *n* to the auxiliary reservoir at *Y*. If, when air enters the triple valve, there is no pressure above check-valve *15*, this valve is raised against the resistance of spring *12*, thereby admitting train-line air to chamber *y* and seating more firmly rubber-seated valve *10*. When the pressures above and below check-valve *15* equalize, spring *12* seats the valve, which remains seated until there is an emergency action. The duty of emergency valve *10* is to prevent train-line air from lifting check-valve *15* and passing on through chamber *l* to the brake cylinder connected at *X*. Without valve *10*, admission of air to the train line would apply the brakes at once, and triple exhaust port *k* being open, there would be a steady rush of air to the atmosphere. Check-valve *15* prevents a return of brake-cylinder air to the train line in case of accident to the train line during an application. In the release position of the triple valve, brake-cylinder air can exhaust to atmosphere through passage *e'*, *e*, port *f*, cavity *g*, port *h*, and exhaust cavity *k*. The brake-cylinder piston and the brake shoes then move to their release positions.

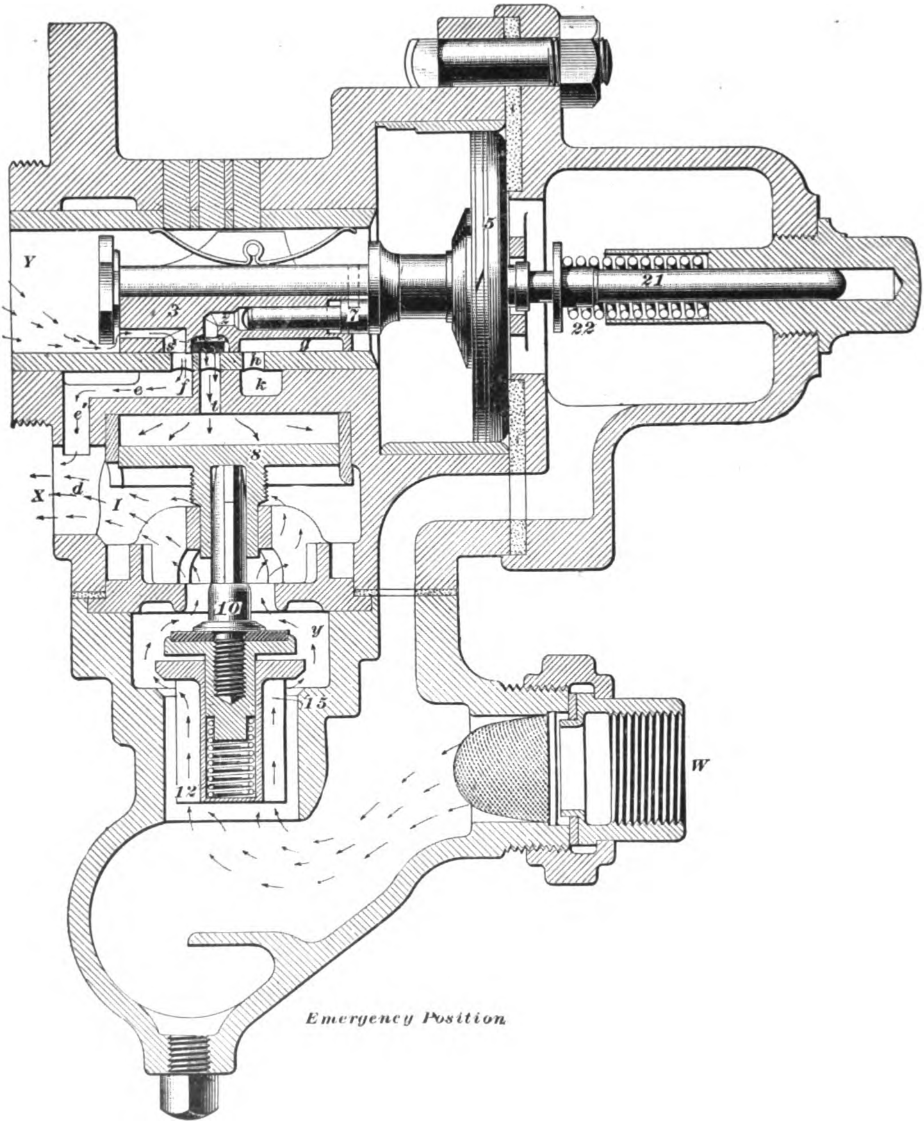


Service Position.

Fig. 3

21. When the motorman makes a 5- or 6-pound train-line reduction, piston *5* moves to the right until knob *j* touches stem *21*, preventing further movement of piston *5*, unless a much greater force is applied. Feed groove *m* is closed by the piston. The triple is now in service position, as indicated in Fig. 3. Graduating valve *7* is off its seat and port *z* is opposite to or registers with port *f*, so that auxiliary-reservoir air in valve chamber *C*, Fig. 2, can reach the brake cylinder, as indicated by the arrowheads in Fig. 3. Port *t*, leading to emergency piston *8*, is connected to the atmosphere through cavity *g*, port *h*, and exhaust cavity *k*. As slide valve *3* has a small free motion or play between the triple piston-stem shoulders, and as graduating valve *7* connects rigidly to the piston stem, the graduating valve opens before the slide valve reaches service position. The expansion of auxiliary-reservoir air in the brake cylinder reduces the auxiliary-reservoir pressure sufficiently below that in train-line chamber *B*, Fig. 2, to overcome the slight friction of piston *5*, Fig. 3, and move it toward the left without disturbing the heavier slide valve. Piston *5* thus moves far enough to the left to seat the graduating valve and stop the flow of air to the brake cylinder. The triple is now in lap position. To set the brakes harder, subsequent reductions may be made, which move piston *5* to the right, thus unseating the graduating valve *7* and allowing air to enter the brake cylinder. The graduating valve is again seated automatically by piston *5* when the auxiliary pressure becomes a little less than that in the train pipe. The slide valve *3* remains in service position until the brakes are released.

22. An emergency train-line reduction causes auxiliary-reservoir pressure to slam piston *5* to the right the full length of chamber *B*, Fig. 2, to the emergency position indicated in Fig. 4. An opening in the lower portion of the slide valve admits auxiliary-reservoir air to port *t*, leading down to the top of emergency piston *8*, forcing the piston downwards and unseating emergency valve *10*, thereby



Emergency Position

FIG. 4

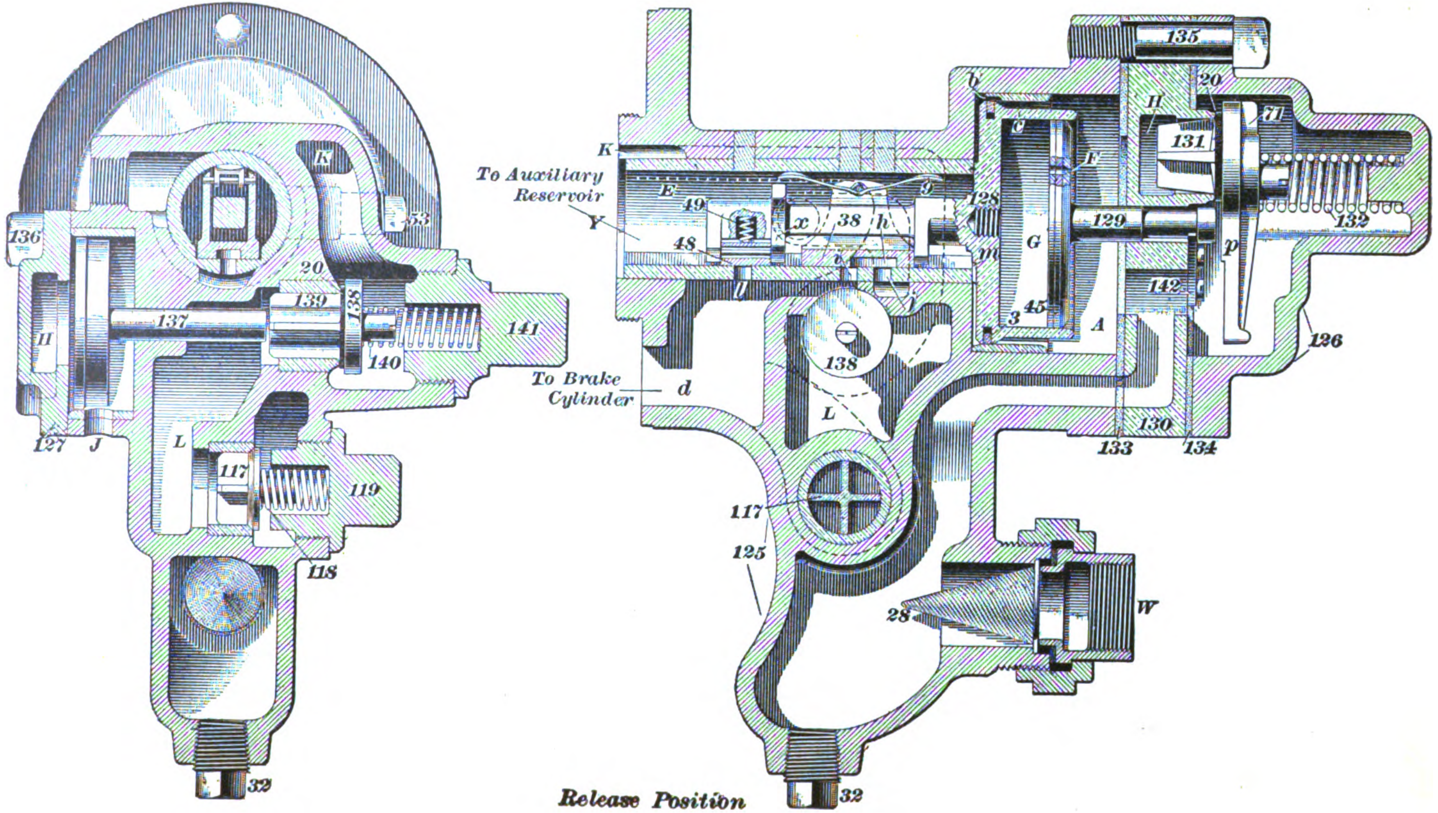
liberating the air in chamber *y* so that train-line air from chamber *a*, Fig. 2, can raise check-valve *15*, Fig. 4, and pass through chambers *y* and *l* to the brake cylinder at *X*. Valve *10* remains open until brake-cylinder and train-line pressures are nearly equalized, when spring *12* closes it. In the meanwhile, slide-valve port *s* has registered with port *t*, allowing auxiliary-reservoir and brake-cylinder pressures to equalize with a rush.

The size of port *s* is such that the train-line and brake-cylinder pressures have time to equalize before auxiliary pressure can affect them, with the result that the brake-cylinder air is at about 20 pounds pressure when the auxiliary reservoir air reaches it, thereby permitting the auxiliary-reservoir and brake-cylinder to equalize at a higher final pressure than would obtain were the brake cylinder at zero pressure. Therefore, the Westinghouse triple valve operates to apply the brakes quicker and harder in emergency than in service applications. The strong feature of the Westinghouse triple valve is its quickness and economy in emergency action. Almost simultaneous operations of all the brakes are obtained by the action of all the triple valves in allowing air from the train pipe to flow into the brake cylinder. This results in local reductions of train-pipe pressures at each triple valve, which aids in the quickness of action of all the valves, greater than would be the case were the reduction made only at one point on a long train; also, the air pressure in the brake cylinder due to the train-pipe air increases the final braking pressure.

THE NEW YORK TRIPLE VALVE

DESCRIPTION

23. The triple valve made by the New York Air Brake Company is shown in its release position in Fig. 5. Here *128* is the triple piston; *38*, the exhaust valve; *48*, the graduating valve; *3*, the triple piston packing ring; *9*, the exhaust-valve spring; *49*, the graduating-valve spring;



Release Position

FIG. 5

c, the triple-piston extension; *129*, the vent-valve piston; *45*, packing ring; *130*, middle section containing vent-valve seat; *133*, *134*, leather gaskets; *126*, triple head; *71*, vent valve; *132*, vent-valve spring; *20*, vent-valve rubber seating; *142*, piston stop; *127*, emergency cap; *136*, bolt of emergency cap; *137*, emergency piston; *138*, emergency valve with *20*, its rubber seating; *140*, emergency-valve spring; *141*, emergency-cap nut; *117*, non-return check-valve; *32*, drain plug; *W*, train-pipe connection to triple; *28*, strainer; *F*, a small port connecting chambers *A* and *G*; *K*, a cavity through which auxiliary-reservoir air can reach emergency valve *138*; *L*, a cavity between valves *138* and *117*; *125*, drainage part of the triple-valve body; *M*, Fig. 6, vent port to atmosphere; *J*, another atmospheric vent port; *b*, *m*, Fig. 5, leakage grooves through which the auxiliary reservoir charges.

OPERATION

24. A train-line service reduction causes piston *128*, Fig. 5, to move to the right, closing feed groove *b* first; then collar *x* of the piston-stem extension comes into contact with and moves exhaust valve *38* and graduating valve *48* to the right until exhaust ports *j* and *i*, Fig. 6, are closed and service port *l* is open. Auxiliary-reservoir air passes to the brake cylinder at *X*, through port *l*, and applies the brakes to a degree depending on the length of time port *l* remains uncovered. As auxiliary-reservoir air expands into the brake cylinder, auxiliary-reservoir pressure falls enough to allow train-line pressure in chamber *G* to force piston *128* and graduating valve *48* far enough to the left to cover service port *l* and stop the flow of auxiliary-reservoir air to the brake cylinder. The triple is then in lap position and holds the brakes partially applied. In subsequent reductions, made in order to apply the brakes harder, only the piston and graduating valve need be moved; the exhaust valve remains in service position until the brakes are released.

To release the brake, the main-reservoir pressure is allowed to feed into the train pipe, thus increasing the pressure in

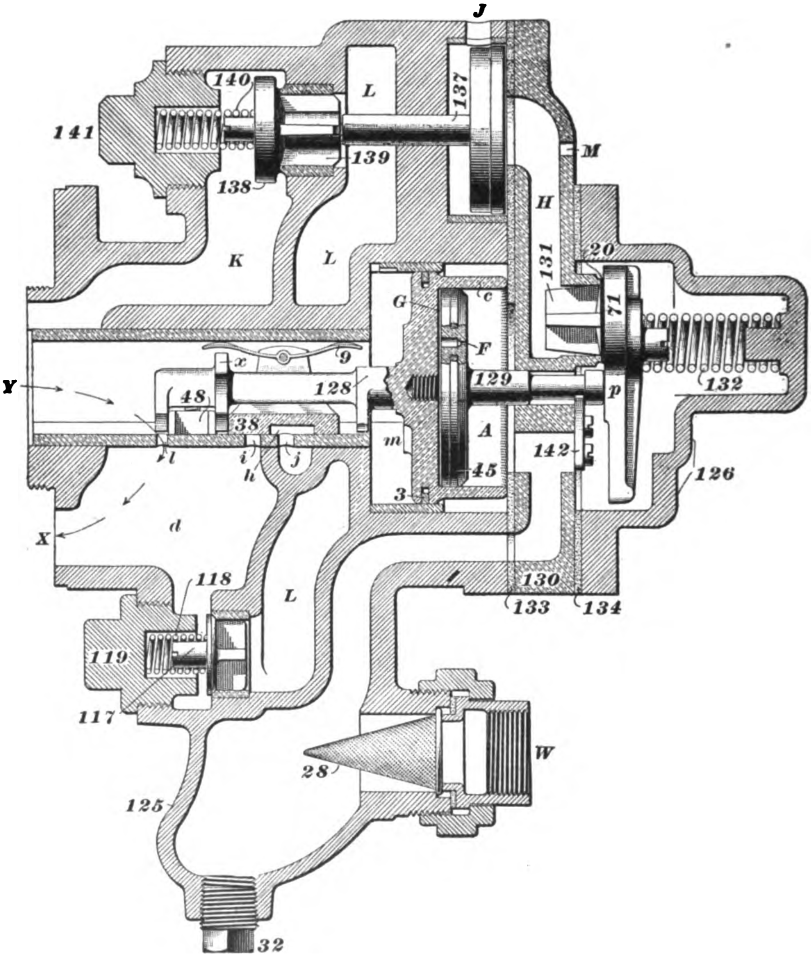

J
140
L
137
141
M
139
138
H
K
L
131
20
G
c
71
F
x
9
Y
48
128
129
p
132
38
A
m
142
l
i
j
h
45
126
3
d
X
118
130
133
134
L
119
117
W
28
125
32

FIG. 6

chamber *A* (and in chamber *G* by feeding through the port hole *F*) above that in the auxiliary reservoir and forcing the triple-valve piston, exhaust valve, and graduating valve back to their normal positions. In the release position, Fig. 5, feed grooves *b* and *m* are uncovered, allowing air from the train pipe to pass to the auxiliary reservoir and recharge it. Exhaust ports *j* and *i* are uncovered, and air in the brake cylinder escapes to the atmosphere, thus releasing the brakes.

25. An emergency reduction in train-line pressure causes piston *128*, Fig. 5, to move to the right faster than the air in chamber *G* can escape through port *F*, with the result that the air in *G* acts as a cushion to force piston *129* to the right; stem *129* bearing against vent-valve lever *p*, Fig. 7, unseats vent valve *71*, Figs. 6 and 7, against the resistance of spring *132* and admits train-line air to chamber *H*, Fig. 7. The pressure in *H* forces piston *137*, Figs. 6 and 7, to the left, unseating emergency valve *138* and allowing auxiliary-reservoir air, always present in chamber *K*, to pass into chamber *L*, and thence, by lifting check-valve *117*, into the brake cylinder at *X*, as indicated by the arrows in Fig. 7. (*L* above the chamber containing valve *38* and *L* below it, Figs. 6 and 7, are parts of the same chamber.) At the same time, auxiliary-reservoir air is passing through service port *l* to the brake cylinder. The combined openings allow the auxiliary reservoir and brake cylinder to equalize with a rush, applying the brake immediately and with full force.

Air admitted to the chamber *H* by the unseating of vent valve *71*, after forcing the emergency piston over, exhausts to atmosphere through ports *J* and *M*; the heavy local train-line reduction thereby obtained causes the next triple to go into quick action, that triple causes the next triple to go into action, and so on through the whole train. As soon as the pressures in chambers *A* and *G* equalize through port *F*, spring *132* seats vent valve *71* and forces piston *129* back; as there is now no pressure in chamber *H*, spring *140* reseats emergency valve *138*. The pressure on both sides of check-valve *117* being the same, spring *118* reseats the valve and

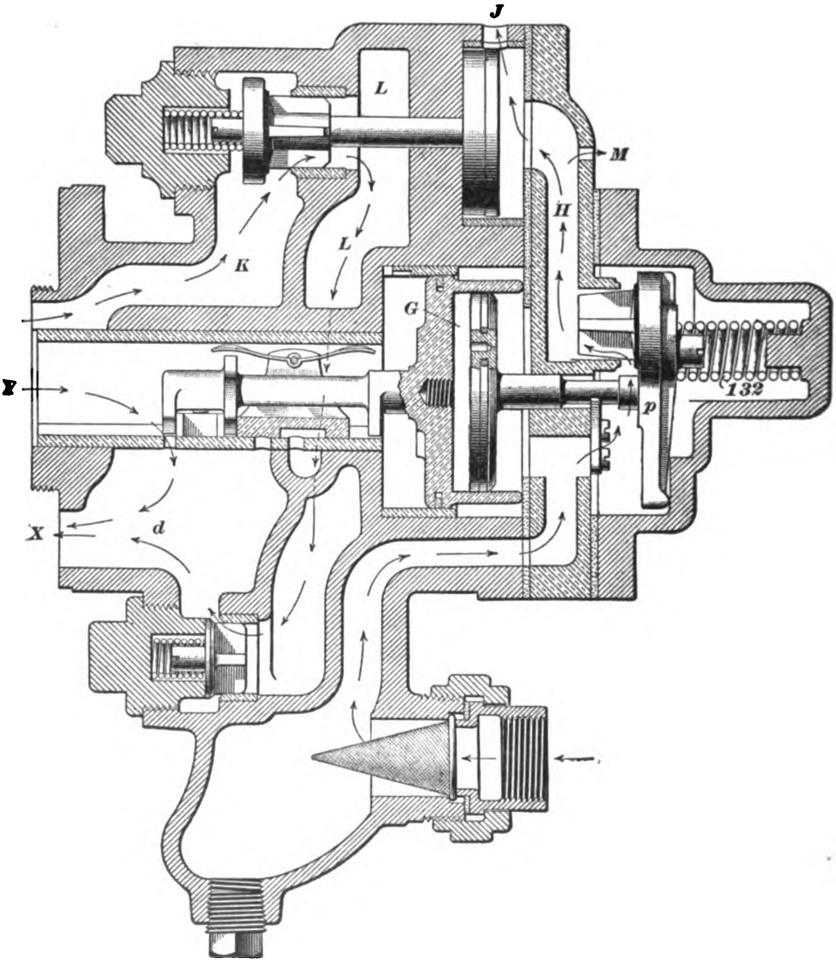


Fig. 7

prevents brake-cylinder air from getting back into chamber *L*. The emergency application sets the brakes more quickly, but not with greater force, than the service application. The release of all brakes on the train is effected in the same manner as after a service application.

THE WESTINGHOUSE ENGINEER'S VALVE

DESCRIPTION

26. Fig. 8 shows the exterior of a **Westinghouse engineer's valve** as applied to short trains. Fig. 9 shows the more important parts of the valve. The valve base, or body, is shown at *a*, Fig. 9; *b* is the cap; *c*, the notch plate; *e*, Fig. 8, the handle; *f*, Fig. 9, the reservoir port of the feed-valve *g*; *h*, Fig. 8, cap nuts, of which there are four; *i*, Fig. 9, train-pipe port of the feed-valve; *j*, Fig. 8, a spring pawl to emphasize the notches; *k*, Fig. 9, a release spring; the lap, service, emergency, running, and release positions of the handle and valve are marked *0*, *+1*, *+2*, *−1*, and *−2*, respectively; studs *l* pass through holes in cap *b* and by means of cap nuts *h*, Fig. 8, hold the base and cap together; *m*, Fig. 9, is a guide pin on the valve body, and *m'* is the hole for the pin in the cap; *n* is the rotary or valve proper, on the top end of whose stem *o* the handle fits; *p* is a guide pin; *q*, *q* are graduated service

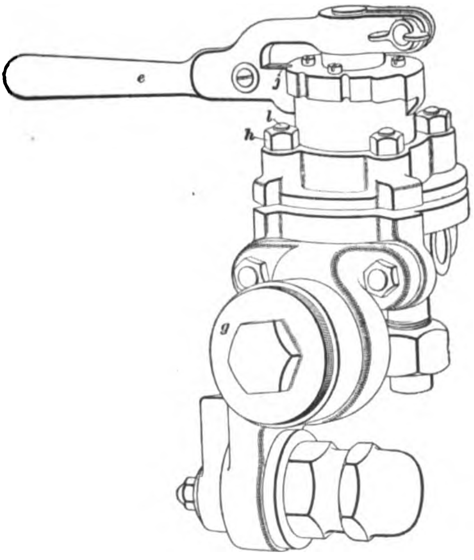


FIG. 8

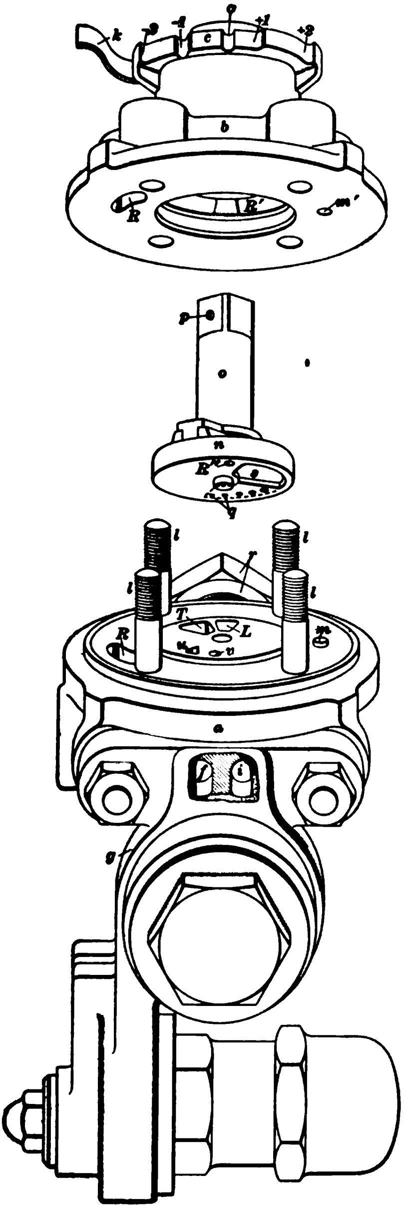


Fig. 9

ports; *r* is a stud and nut by means of which the valve body is secured to the car. Ports *q*, *q* connect with the cored extension of cavity *s*; cap port *R* connects permanently to cap chamber *R'*. Valve port *R* connects to the main-reservoir pipe and to the red-hand gauge fitting. Port *T* opens to the atmosphere; port *L* connects to the train pipe, to port *u*, to the black-hand gauge fitting, and to port *i*, leading to the feed-valve. Port *v* connects to port *f* of the feed-valve. Facing an installed valve on an automatic air-brake car, the reservoir pipe is on the left, the train pipe on the right, and the exhaust pipe behind them.

OPERATION

27. If the parts of Fig. 9 be moved together just as they lie, base pin *m*, and cap hole *m'* will register. Bolts *l* are so set that they can only enter their proper holes, and are spoken of as being set *staggered*. Valve port *R* registers with cap port *R*. Main-reservoir pressure is always in cap chamber *R'*; but as rotary port *R''*, which passes through the rotary, rests on a smooth part of the valve seat, main-reservoir pressure can get no farther. As the handle can be installed in only one position of the rotary—the lap position—if the valve is assembled at all it must be correctly placed, with the operating handle pointing toward the operator. In this position, all ports are blanked and there can be no movement of air through the valve.

28. To make a service stop, the handle is moved to the first notch to the right—service position. In this position, graduated service ports *q*, *q* connect exhaust port *T*, cavity *s*, and train-line port *L*. Train-line air exhausts to atmosphere gradually, and the brakes apply to a degree depending on the length of time the valve is held in this position. To make an emergency stop, the handle is pushed as far to the right as it will go, that is, to emergency position. Here rotary cavity *s* connects train-line port *L* and exhaust port *T* at the same time; the heavy and sudden train-line reduction obtaining through the large passage to atmosphere, moves the triples to emergency action. To promptly release the brakes, the handle is forced to the left as far as it will go against the resistance of spring *k*. This is the release position. Here the through rotary port *R''* covers triangular valve-seat port *u*, which is directly connected to the engineer's valve train pipe: main-reservoir air flows directly into the train pipe. The valve must be left in this position only an instant—to avoid having the reservoir and train lines equalize and destroy excess pressure – and must then be returned to running position to restore excess pressure. When not applying, releasing, or holding the brakes, and always when coasting or running between stations, the valve rests on running position, which is the first notch to the left of lap—where rotary port *R''* covers valve-seat feed-port *v* leading to port *f* of the slide-valve feed-valve. Only on running position can the feed-valve operate to establish excess pressure.

SLIDE-VALVE FEED-VALVE

29. Description.—Fig. 10 shows a back view of the **slide-valve feed-valve,** with part of the valve so broken away as to show the passages *a*, *f*, and *i* and their relations to ports *b* and *l*. When the feed-valve is in position on the brake valve, the passage *f* connects with the passage leading to port *v* in the brake valve, Fig. 9, so that it is charged with air at main-reservoir pressure when the brake valve is in running position. Since port *l*, Fig. 10, in the supply-valve bushing connects passage *f* with chamber *F* (the space surrounding the supply valve *55*), it follows that chamber *F* is charged with main-reservoir pressure whenever passage *f* is so charged.

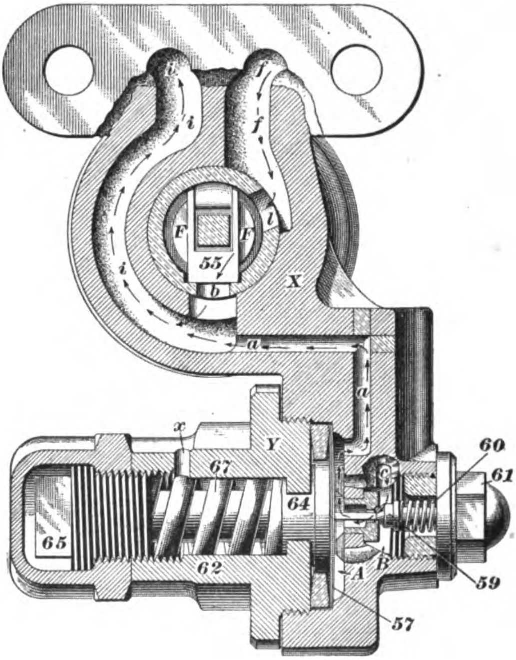


FIG. 10

Passage *i* in the feed-valve connects with the passage leading to port *L* in the brake valve, Fig. 9; hence, it is always in direct communication with the train pipe and charged with train-pipe air. Furthermore, passage *i* is connected with chamber *F*, Fig. 10, through the supply port *b* in the supply-valve bushing. Passage *a* connects passage *i* with chamber *A* (the space between the diaphragm *57* and the regulating valve *59*), hence, chamber *A* is always charged with train-pipe air, since it is in direct communication with it.

The arrows indicate the flow of air through the feed-valve when it is open and supplying air to the train pipe. It will be observed that a portion of the feed-valve has been broken away in such a manner as to show the regulating valve *59*; also, it shows how the end of the passage *c* opens into chamber *B*—the space surrounding the regulating valve.

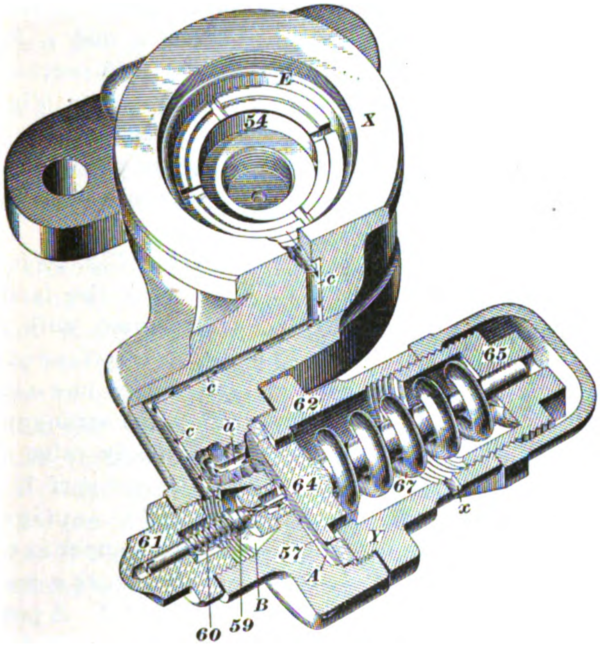


Fig. 11

30. Fig. 11 is a perspective view of the feed-valve with the cap nut *53*, Fig. 12, removed and part of the valve broken away to show the course of the passage *c*, Fig. 11, and its relation to the regulating valve *59* and to passage *a*. Passage *c* connects chamber *B* with chamber *E*—the space between the supply-valve piston *54* and the cap nut *53*—thus maintaining equal pressures in the two chambers. The regulating valve *59* controls communication between chambers *A* and *B*, so that when it is open chamber *E* is in direct communication with the train pipe through the passage *c*, chamber *B*, valve *59*, chamber *A*, and passages *a* and *i*, Figs. 10 and 11. A portion of the feed-valve in Fig. 11 is broken away so as to show how the end of passage *a* opens into chamber *A*.

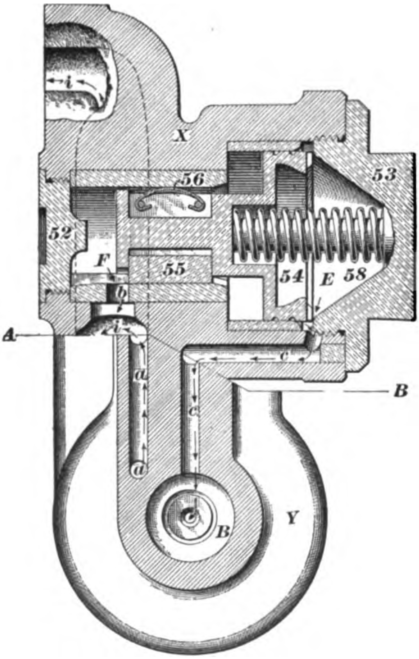


Fig. 12

31. Fig. 12 is a side view of the feed-valve attachment, with the upper part *X* sectioned through the center to show the arrangement of the supply valve *55*, and the lower part *Y* below line *AB* sectioned in such a manner as to show the passages *a* and *c* and chamber *B*. A portion of the upper part *X* of the valve is broken away to show the end of the passage *i*.

The supply valve *55* controls port *b* leading from chamber *F* into the passage *i*. This slide valve is operated by means of the supply-valve piston *54* and the supply-valve piston spring *58*. Although piston *54* makes a snug fit in its bushing, it is not provided with a packing ring for the reason that a certain amount of leakage from chamber *F* into chamber *E* is necessary in order that the feed-valve may work properly. The spring *58* is made sufficiently strong to force piston *54* and supply valve *55* back against the flush nut *52* (which acts as a stop for the piston) whenever the difference in pressures in chambers *F* and *E* allows the spring to move the piston against main-reservoir pressure. Port *b*, therefore, is closed when the pressure in chamber *E* equals that in chamber *F*. Whenever the pressure in chamber *E* is less than that in chamber *F*, the greater pressure on the chamber *F* face of piston *54* forces the piston forwards, moving valve *55* with it, and thus opening port *b*. Therefore, port *b* is always open when the pressure in chamber *E* is less than that in chamber *F*. The supply-valve spring *56* is intended to hold supply valve *55* on its seat when that valve is relieved of pressure, in order to prevent dirt from getting between the valve and its seat. In Fig. 12, chamber *B* is shown with the regulating valve *59*, Fig. 11, removed.

32. Operation.—On account of the parts *X* and *Y* being at right angles to each other, it is difficult to illustrate the operation of the valve by means of true sectional views. For that reason, two conventional views, Figs. 13 and 14, have been prepared for use in explaining the operation of the slide-valve feed-valve.

At such times as the feed-valve is not under pressure, port *b* is closed while the regulating valve *59* is open. The spring *58* forces the supply valve *55* back until it covers port *b* (as in Fig. 14), while the regulating spring *67* forces the diaphragm to unseat the regulating valve *59* (as in Fig. 13).

Fig. 13 shows the position of the parts of the feed-valve when the train pipe is charged to less than 70 pounds and air is feeding through the feed-valve into it. Under those conditions, main-reservoir air enters passage *f* and chamber *F*, forcing piston *54* forwards until it uncovers port *b*. The air then flows from chamber *F* through port *b* into passage *i* and thence into the train pipe, increasing the pressure there.

While train-pipe pressure is less than 70 pounds, the regulating valve *59* is held off its seat by the regulating spring *67* and there is direct communication between chamber *E* and the train pipe through passage *c*, valve *59*, and passages *a* and *i*. The leakage that takes place past the piston *54* therefore passes directly to the train pipe, as indicated by the arrows, so that chambers *E* and *A* are maintained at train-pipe pressure. When 70 pounds is obtained in the train pipe, the pressure on the diaphragm *57*, Fig. 14, is sufficient to compress the regulating spring *67* enough to allow the regulating valve *59* to close. This cuts off communication between chamber *E* and the train pipe, and the leakage then occurring past piston *54* quickly charges chamber *E* to the same pressure as chamber *F*, which allows the spring *58* to move the supply valve *55* to the *closed* position, as shown in Fig. 14. In this position, no air can feed into the train pipe, since port *b* is closed.

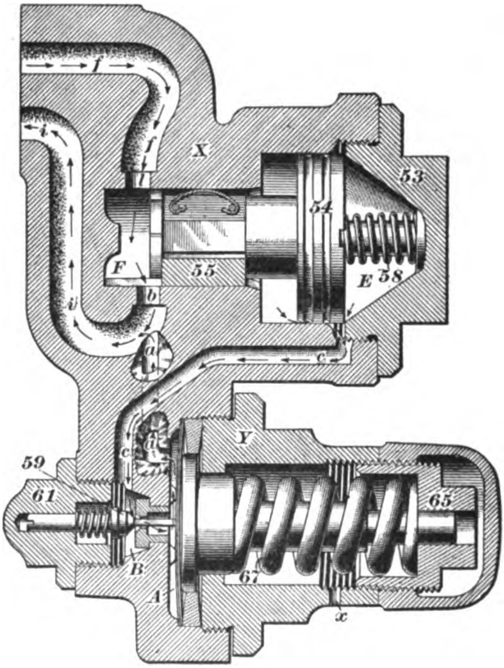


FIG. 13

The parts of the feed-valve remain in the positions shown as long as the train-pipe pressure remains at 70 pounds. Any reduction of train-pipe pressure, however, allows the spring *67* to expand and unseat the regulating valve *59*; pressure in chamber *E* is then immediately reduced to train-pipe pressure, so that the greater pressure of the air in chamber *F* forces the piston *54* to the *open* position, as shown in Fig. 13.

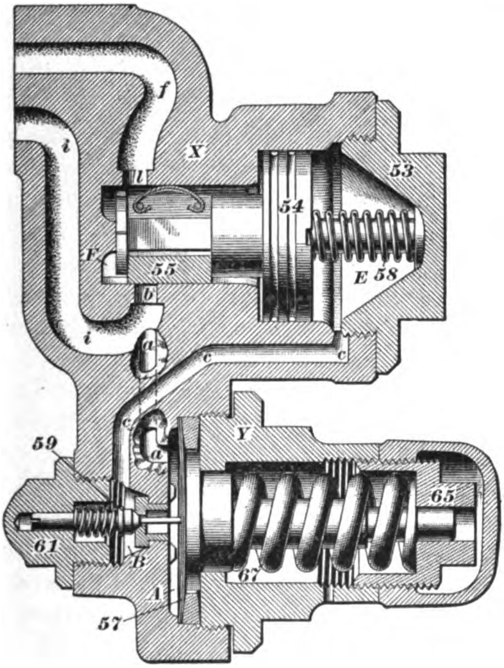


FIG. 14

33. Regulation.—If the slide-valve feed-valve does not regulate train-pipe pressure to the proper amount, it can be made to do so by adjusting the regulating nut *65*, Fig. 14.

If it maintains a pressure below the standard, turn the regulating nut *65* slowly until the tension of the spring *67* is sufficiently increased to give proper regulation.

If it maintains too high a pressure, place the brake valve in service position and reduce the train-pipe pressure several pounds below standard; then turn the regulating nut *65* so as to relieve the spring *67* of a little of its tension, place the brake valve in running position, and note the pressure that is then maintained. If still too high, proceed as before, and continue to so regulate until the feed-valve is properly adjusted.

34. Care.—In order that the feed-valve may perform its functions properly, it is necessary that it be cleaned and oiled occasionally. If the feed-valve is to be cleaned when the air-brake system is charged with air, it must be relieved of all pressure before it can be taken apart. To do this, close the cut-out cock in the train pipe underneath the brake valve, so as to save the air in the train pipe, and place the brake valve in service or emergency position to empty the feed-valve and the short piece of train pipe above the cut-out cock; the feed-valve may then be taken apart and cleaned. Clean both the piston *54* and its cylinder, and the slide valve *55* and its bushing, very carefully, leaving no lint on the parts, for it will cause trouble; clean, also, the regulating valve and its seat and the hole in the cap nut *61* into which the valve *59* extends.

In oiling the supply valve *55*, only a small amount of valve oil, vaseline, mutton tallow, or some similar lubricant should be used, the oil being applied with the finger. Only a very small amount of some light lubricating oil should be used on the supply-valve piston *54* and its cylinder, and that should be well rubbed on with the fingers. If too much or too heavy oil is used on these parts, it will get into the grooves of the piston and act as an oil packing and will interfere very materially with the action of the feed-valve. The regulating valve *59* should not be oiled, but should be replaced dry.

THE CHRISTENSEN TRAIN GOVERNOR

DESCRIPTION

35. Figs. 15, 16, 17, and 18 are illustrative of the **Christensen style C governor,** adaptable to any class of governor service, but intended particularly for the multiple-unit system of control, where it is necessary to start and stop several compressors simultaneously. Fig. 15 is a general view and Fig. 16 a top view of the governor. Arm *a*, Fig. 16, is free to turn on pin *b* as a center. Fork *c* and arm *a* are insulated from each other. Contact tips *d*, *d* are on arm *a*, and tips *e*, *e* are on fingers *f*, *f*, which are mounted on contact blocks *g*, *g*. All current passing to the governor flows through the blow-out coil *h*; *i*, *i* are the plungers of two of the operating coils *j*, *j* which are near the blow-out coil *h*. The plungers pass down through these coils and are forced upwards, when the current flows through the coils, by means of small armatures at the lower portion of the coils.

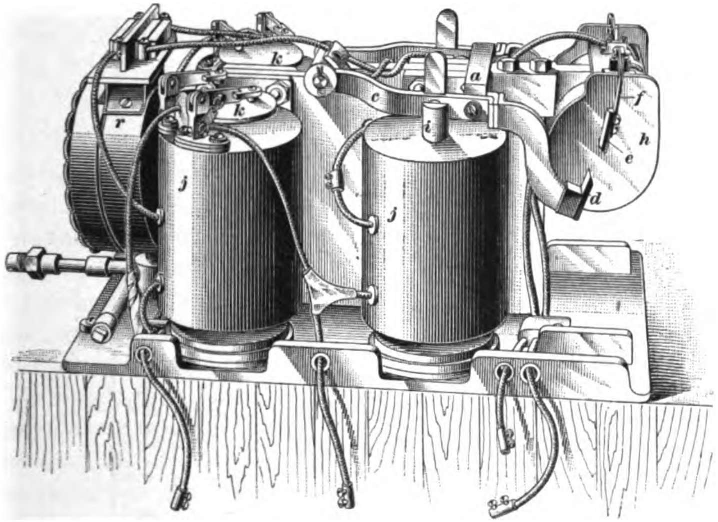


Fig. 15

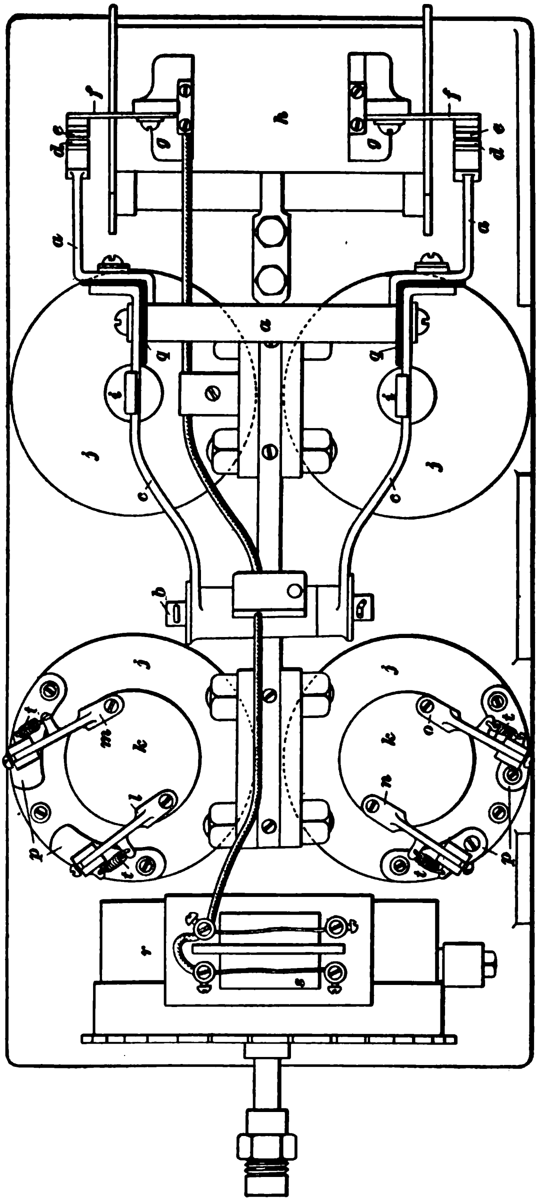


FIG. 16

The upper ends of these two plungers engage the sides of the fork *c*. The two coils *j*, *j*, near the other end of the governor are also provided with plungers and armatures at their lower ends. At the upper ends of the coils, two movable contact disks *k*, *k* are mounted, which in their upper positions make contact with fingers *l*, *m*, *n*, *o*. These disks are operated by their plungers and armatures. Pieces *p*, *p* are of hard insulation; *q*, *q* are the pieces of insulation between arm *a* and yoke *c*; *r* is the regulator; *s*, a fuse box; *t*, *t*, *t*, *t* are small spiral springs that provide tension for fingers *l*, *m*, *n*, *o*. A portion of the regulator *r* is shown in Fig. 17. This device is practically the same as the Christensen regulator explained in *Straight Air Brakes*.

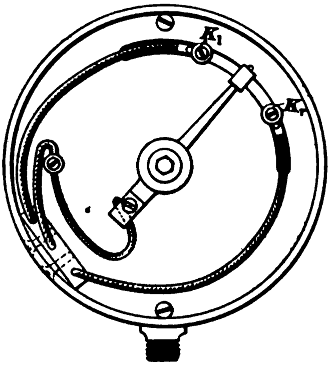


FIG. 17

36. Fig. 18 is a diagrammatic sketch of the connections; *T* is the wire from the governor main fuse and switch; *M* leads to the motor; *G*, to the ground wire; and *E*, to the balance wire through switch *H*; *q* represents the insulation interposed between arm *a* and its supporting yoke *c*. It will be noted that the two fuses are connected together on one end, but lead to different circuits on the other. Coils *1* and *2* are in series with each other and coils *3* and *4* are in series with each other

---

OPERATION

37. When main-reservoir pressure is below 80 pounds, knob *t* in the regulator is to the left against post K_1, arm *a* is down, so that tips *K*, *K* and K_1, K_1, do not touch, and if all trolley switches are open, all governors are dead. As soon as the main governor switch is closed, current takes the path $T-K_2-f_2-4-3-7-t-K_1-2'-4'$ to the ground at *G*, exciting coils *3* and *4* and causing them to lift their disks *k'*, *k'*, thereby connecting fingers *1'* and *2'* and also fingers *3'* and *4'* through

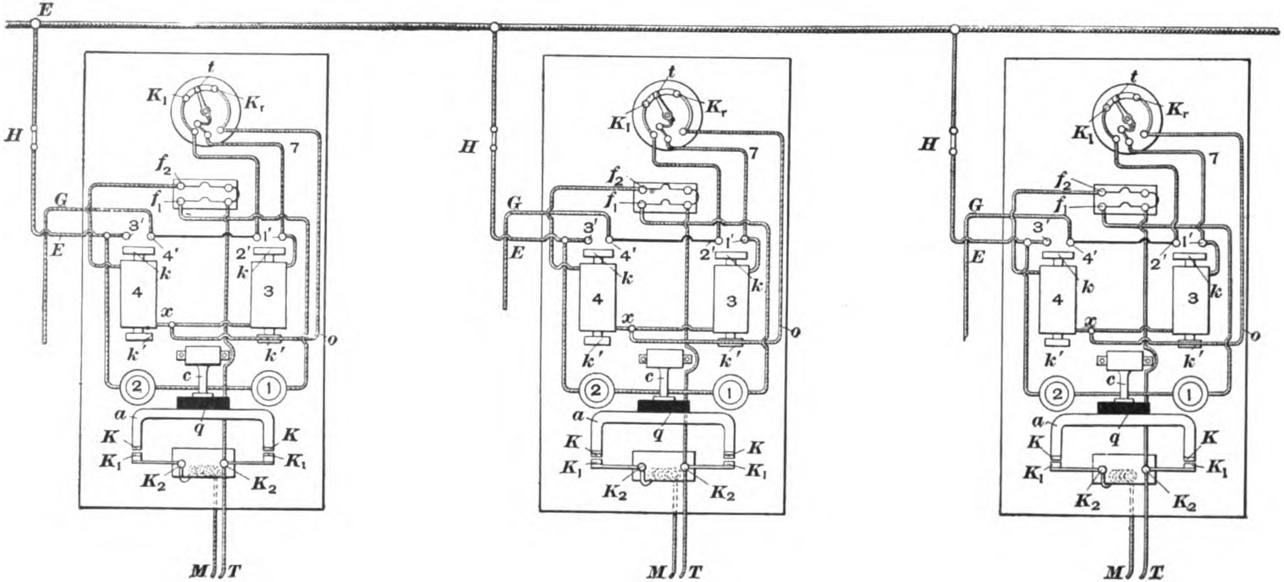


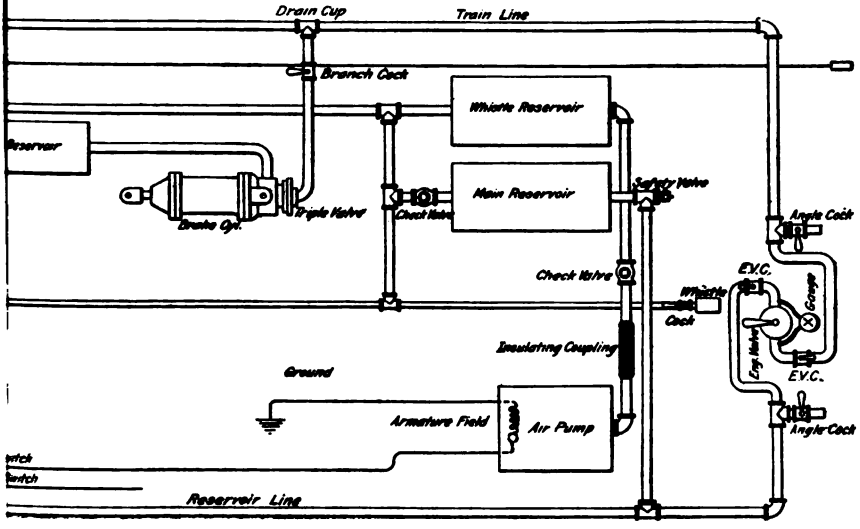
Fig. 18

disks *k*, *k*. The path now becomes $T–K_2–f_2–4–3–1'$–disk $k–2'–4'$ to the ground; the regulator is cut out by the right-hand disk *k*, so that when knob *t* leaves post K_l, the circuit through the balance coils *4* and *3* is not opened. Current through a second circuit by way of path $T–K_2–f_1–1–2–3'–4'–G$ excites the lift magnets *1*, *2*, which pull up their disks and plungers, thus raising arm *a* until tips *K*, *K* touch tips K_1, K_1. Current can now take path $T–K_2–K_1–K–a–K–K_1–K_2–M$ through the pump motor and start it. When disks *k*, *k* rise, one short-circuits the regulator and the other not only provides a ground for lift magnets *1* and *2*, so that they can start the compressor motor on that car, but also grounds the balance wire *E*, so that the lift magnets on every other car whose trolley and balance switches are closed can operate to start their respective motors. Thus it is seen the most sensitive governor will operate to start all compressors on the train simultaneously.

Should disorder in any governor cause disks *k*, *k* to drop, the pump motor on that car will not stop, because as long as disks *k*, *k* are up on any governor in the train, all lift magnets get a ground through the balance wire. As long as one governor is in order, the balance feature is operative. As long as main-reservoir pressure is below 80 pounds, knob *t* rests against post K_l; as soon as the pressure reaches 80 pounds, knob *t* moves toward post K_r; in leaving post K_l, knob *t* draws no arc, because it is part of the circuit that is short-circuited by the right-hand disk *k*. When main-reservoir pressure reaches 90 pounds, knob *t* touches post K_r, thereby closing a circuit that short-circuits balance coil *3* and causes it to drop its disk and open the circuit between fingers *1'* and *2'*. Circuit $T–K_2–f_2–4–x–o–K_r–7–1'$ being thus deprived of its ground connection, the left-hand disk *k* drops also; the balance devices on that particular car are dead for the time being; but the pump does not stop, because the lift magnets still get a ground through the balance wires and the balance devices on governors that have not yet cut out; nor will that pump or any other pump on the train stop until the governor that cuts out at the highest pressure does cut out and drop its k disks, thereby robbing all lift magnets of their grounds and allowing all arms a to drop by their own weight and open the motor circuits. Therefore, all compressors stop at the same time.

ADJUSTMENT

38. Posts K_l and K_r, Fig. 17, are provided with a screw that, when tight, clamps them in the position they may have in the slot; but when loosened permits them to be slid toward or from each other. The regulator is adjusted in much the same manner as that explained in connection with the same device in *Straight Air Brakes*. Start the compressor at 80 pounds gauge pressure and stop it at 90 pounds pressure, the pressures at which the compressor is usually started and stopped, then proceed as follows: Start the compressor by closing the pump switch and lifting arm a, Fig. 18, by hand. Let posts K_l and K_r be in the extreme ends of the slot. As the pressure begins to rise, knob t will move to the right; watching the pressure gauge, note the position of the knob t when the red-hand gauge shows 80 pounds; then move post K_l to that position. Further, note the position of the knob t when the gauge hand shows 90 pounds and move post K_r to that position. Finally, stop the pump. The governor is now adjusted to cut in at approximately 80 pounds and out at approximately 90 pounds. By alternately raising and lowering the main-reservoir pressure, noting the gauge reading as the pump cuts in and out, and moving posts K_l and K_r a little to the left or right, as occasion may demand, a final adjustment can be obtained, such that the pump starts at exactly 80 pounds and stops at exactly 90 pounds.


Drain Cup
Train Line
Branch Cock
Whistle Reservoir
eservoir
Main Reservoir
Safety Valve
Brake Cyl.
Triple Valve
Check Valve
Angle Cock
E.V.C.
Gauge
Whistle
Cock
Check Valve
Insulating Coupling
Eng. Valve
E.V.C.
Ground
Armature Field
Air Pump
Angle Cock
witch
witch
Reservoir Line

§ 20

GENERAL INSTRUCTIONS

PRELIMINARY INSPECTION

39. When a crew is assigned a train, the train is supposed to be in good order, but sometimes it is not. Any or several of many trifling conditions may render its action irregular. Some of these conditions can be profitably considered in conjunction with Fig. 19, which shows two completely equipped electric cars made up into a two-car train. On a single car, both angle cocks on both ends must be closed; on a train of two or more coaches, both angle cocks must be closed on both ends of the train, but all intermediate angle cocks must be open. If an end reservoir-line angle cock be left open, no bad effect is felt immediately, because the check-valve in the coupler head prevents the escape of air; but should a dangling hose catch an obstruction and pull off, all main-reservoir air will escape.

All coupling hose not in use should be coupled to the dummy coupler provided for that purpose. If an end train-line angle cock is left open, it will be impossible to charge the train line, because the air escapes through the tail-hose as fast as the reservoir line delivers it through the engineer's valve. If the tail-cock be opened while the train line is charged and the brakes released, the brakes will immediately go into emergency action, and cannot be released until the open tail-cock is closed and the train line recharged through the engineer's valve. If any intermediate reservoir-line angle cock be closed, the effective main-reservoir capacity is decreased, for in recharging the train line after an application to release the brakes, only that part of the reservoir line that is between the closed cock and the operating engineer's valve can deliver air to the train line, and the more the main-reservoir capacity is decreased the more sluggish will be the release of the brakes. For example, with the intermediate reservoir angle cock of the head or operating car closed, only the reservoir capacity of the head car is available for releasing the brake. Should an intermediate train-line angle cock be closed, the brakes on all cars behind the closed cock will be cut out and the braking power of the train thereby proportionately decreased, because a train-line reduction made to apply the brakes cannot affect the pressure to the rear of the closed cock and cannot, therefore, operate the triple valves on that section of the train.

40. If a branch-cock handle be turned parallel to its containing pipe, the brake on that car is cut out, because train-line reductions cannot affect the pressure in the train-line side of the triple valve, which becomes inoperative, except in so far as it may be affected by leaks. The operation of cars ahead or behind the car with the closed branch cock is not affected, because the continuity of the train line is not broken by the closed branch cock.

41. The cut-out cocks under the operating valves, when the handles are parallel to the containing pipes, cut out the valve above them. All cut-out cocks, except those under the valve that is being used to operate the train, should be closed. A perfect valve in lap position is as effective in rendering the valve neutral as if both cut-out cocks were closed; but should the valve be leaky, or should it have been turned to any other than lap position and left there, complications will result. The whistle cut-out cock should be closed except when its whistle is on the operating end. A leaky whistle valve will reduce the pressure of the device from which the whistle draws air.

42. The governor cut-out cock should be open on all governors not defective; otherwise, the governors will be inoperative. All drain cocks and plugs must be closed on a train in service. The main- and auxiliary-reservoir drain cocks are commonly called *bleed cocks.* A leaky auxiliary-reservoir bleed cock will release the brake on that car.

A leaky main-reservoir cock will reduce or destroy excess pressure and keep the compressors working the greater part of the time, when they should be idle.

PUMPING UP PRESSURE

CONDITION OF VALVES

43. Before a train is ready for pumping up pressure, all engineer's valves must be on lap; all engineer's valve cut-out cocks must be closed; all end angle cocks closed, and all intermediate angle cocks opened; all whistle cocks closed, except the one that is connected to the whistle in service; all branch cocks open; all governor cocks open; all drain cocks and plugs closed. Assuming these precautions to have been observed and the train to be properly coupled—reservoir hose to reservoir hose and train-line hose to train-line hose—the next step is to charge the main and auxiliary reservoirs and train line and obtain excess pressure, if these things have not already been attended to by the yardman. If the pressure gauges are in good order, the red hand on any gauge will show main-reservoir pressure throughout the train and the black hand will show train-line pressure as soon as the engineer's valve cut-out cocks below it are opened. If all air devices are at atmospheric pressure, both gauge hands will indicate zero.

STARTING THE COMPRESSOR

44. In the hood or cab of every motor car, or in some other convenient place with which every motorman should be acquainted, is a small electric switch called the pump switch. On closing this switch, all governors that are not cut out will operate to start their respective compressors. As every compressor gets its current through the pump switch on its own car, all pump switches in the train should be closed. If any pump switch in the train is left open, the governor and compressor on that particular car will be rendered inoperative, but the operation of those ahead and behind will not be affected. Each governor has a balance switch, and may have a trolley switch of its own located near the governor, and these two switches must be closed.

CHARGING THE TRAIN LINE

45. As soon as the pump switches are closed, the governors operate to start the compressors, which compress air into the main reservoirs and reservoir line. If the main-reservoir connections are in good order and all compressors working, no more time will be required to charge a whole train than is required for a single car. By placing the motorman's valve on release position, the reservoir line, train line, and auxiliary reservoirs can be charged simultaneously. When the pressure becomes 70 pounds per square inch, the motorman's valve should be placed on running position and the reservoir line will be charged to standard pressure—for instance, 90 pounds per square inch.

Care must be taken to turn the valve to running position before the train-line pressure exceeds 70 pounds, because every pound above 70 in the train line means 1 pound less of normal excess pressure. If the pressure in the train line is over 70 pounds and train-line leaks should cause the brakes to be partly set, the action of the excess-pressure valve, or feed-valve, will prevent air from passing into the train pipe from the reservoir pipe, and thus releasing the brakes, until the train-line pressure has been reduced to less than 70 pounds.

The action of the gauge hand as the main-reservoir pressure accumulates depends on the kind of feed-valve used. In charging the train line from zero to standard pressure through feed-valves of the New York Air Brake Company's type, the red hand will show 20 pounds before the black hand shows anything, because a 20-pound main-reservoir pressure is required to unseat the feed-valve. When the feed-valve unseats, air begins to enter the train line and the black hand moves up; the black hand always remains

20 pounds behind the red hand; this means that valves of this type always maintain an excess pressure of 20 pounds irrespective of the main-reservoir pressure, provided that it equals or exceeds 20 pounds. As soon as the main-reservoir pressure reaches 90 pounds, the compressors cut out, train-line pressure then being 70 pounds.

CONDITIONS AFFECTING CHARGING

46. Assuming that a car or train requires an unusual length of time in which to charge, any one or more of several conditions may exist. The line voltage may be so low that the compressors run at a much reduced speed. Some of the compressors may be cut out, so that instead of each having to charge only its own car, it must assume its share of the load properly belonging to the idle compressors. The balance wire itself, or some local balance-wire connections, may be open, allowing one or more governors to cut out their compressors before standard pressure obtains. Some main-reservoir or auxiliary-reservoir drain cock may be partly open. There may be general or isolated pipe-line leaks. Should it be impossible to raise main-reservoir pressure at all with the valve on running or release positions, throw the valve to lap position; if this stops the leak, the trouble is in the train line. It may be due to a burst hose or pipe, or an open train-line end angle cock, or some other motorman's valve on the train turned to service position or turned so far round that its rotary connects the train-line port directly to the atmosphere. If lapping the valve does not cut out the leak, the trouble is in the main-reservoir line. It may be due to a burst pipe or hose, or a burst insulation hose, or some other motorman's valve turned with a wrench to a position where main-reservoir and atmospheric ports are connected.

Should the train charge in an abnormally short time, the indications are that part of the train line is cut out by an intermediate angle cock being closed. If the train line is charged by bringing the main-reservoir line up to 90 pounds, and the valve is thrown successively to release and running positions, the compressor will start and stop several times before both lines are charged to standard, because the main-reservoir capacity is such that when it equalizes with the train line, its pressure falls below 80 pounds—the lower limit of variation. If no trouble is experienced in securing standard pressure, but after it is secured there is found to be no excess pressure, it means either that the feed-valve leaks or is stuck open, or that somewhere in the train a main-reservoir hose end is coupled to a train-line hose end. Either of these conditions allows the main-reservoir and train lines to equalize, thereby destroying excess pressure and overcharging the train line. To couple a main-reservoir hose end to a train-line hose is an inexcusable mistake, for not only are main-reservoir fittings painted red, but the check-valves in the main-reservoir couplers are a ready means of identification.

PRELIMINARY TEST

47. When the standard pressure has been obtained, open the whistle cock and try the whistle. Next, make a 20-pound service reduction, so that the inspector can see if any of the brakes show a tendency to stick, or if the piston travel on any car needs adjusting. The brakes are then released and the inspector looks for any that may not have released fully. Should the brake on any car fail to apply, see if the triple valve is cut in and turn up the auxiliary-reservoir bleed cock to see if the auxiliary reservoir is charged. If the trouble, whatever it may be, is such that the brake is useless and the train must go, the faulty brake must be cut out by closing the branch cock and bleeding the auxiliary reservoir. This is done by opening the bleed cock. If, with full excess pressure operative, some brake fails to release after an application, charge the train line to full excess pressure and bleed the auxiliary reservoir; should this fail to release the brake, look for an applied hand-brake or for some interference in the foundation rigging. Should some brakes to the rear of the operating car apply promptly, but fail to release, look for a closed intermediate reservoir-line angle cock or disconnected reservoir-line hose.

If the brakes on the rear cars fail to apply, look for a closed intermediate train-line angle cock. Before starting a train from a yard or terminal, blow the whistle to warn repair men who may be in exposed places. Before leaving a yard or terminal, the motorman should apply and release the brakes with the train in motion, in order to get the "feel" of the train; that is, ascertain the condition of the air brakes. An experienced motorman can tell from the duration of the exhaust necessary to produce a certain train-line reduction how many cars in the train are braking. He can also get a general idea of the promptness with which the brakes release from the length of time elapsing between throwing the valve handle to release position and the noise made by the triple valves exhausting the brake-cylinder air to atmosphere.

HANDLING A TRAIN

STARTING AND STOPPING

48. Starting.—The motorman must not start until he gets the proper signal from the conductor, and the conductor must not give the signal until he is reasonably certain that there is no red flag on the front end of the train, that there is no passenger or employe in a dangerous position, that the gates are closed and the rear guard chains hooked, and that the rail is clear. Before starting, the motorman should sound his whistle; he should look at the gauge to make sure of the presence of excess pressure; he must be certain to release the brakes before applying the power, but it is not well to throw the brake valve to release position, after excess pressure is established, without first making a reduction, for fear of destroying excess pressure and overcharging the train.

In multiple-unit service, it is easier to destroy excess pressure than in steam service, because in steam service the margin of variation of main-reservoir pressure is small, and the steam governor keeps main-reservoir pressure constantly at as nearly 90 pounds as is practicable. Where electric governors are used, however, the compressors raise main-reservoir pressure to 90 pounds and then stop, and leakage can lower that pressure to 80 pounds before the governors operate to start the compressors again. The margin of variation is 10 pounds as opposed to a very small variation in steam service. Therefore, where leakage exists to reduce main-reservoir pressure, the motorman need overcharge the train line but little to destroy excess pressure when main-reservoir pressure is down near the lower limit of variation—80 pounds. Once under headway, the brake valve is placed on running position and kept there until occasion arises for applying the brakes to slow down or stop the train.

49. Stopping.—Only when the brake valve is in running position can the main-reservoir line feed air into the train line and supply train-line leaks without destroying the excess pressure, because only in running position is the excess-pressure valve, attached to the motorman's valve, operative. It is therefore desirable to leave the brake valve on its running position whenever it is possible to do so. To slow down when approaching a curve, crossing, or target, the brake valve is thrown to service position and held there until the black hand of the gauge shows a train-line reduction of from 5 to 7 pounds, when it must be at once returned to lap position. The time required to reduce train-line pressure an average of 6 pounds depends on the length of the train, since the size of the service ports through which the air escapes to atmosphere remains constant. A little practice gives the motorman an idea of what is needed. A reduction of less than 5 pounds might not be sufficient to move all brake pistons beyond their leakage grooves, in which case the air delivered by the auxiliaries through the triple valves to the brake cylinders will exhaust to the atmosphere and be wasted, instead of contributing toward setting the brakes. A reduction of more than 7 pounds is not recommended, because it is liable to result in a shock to the train, especially if it contains any coaches whose piston travel is too short.

For slow downs, for holding the train together on curves, and for making the first application preparatory to making a station stop, the 5- to 7-pound reduction is sufficient, if made in time. It is also sufficient to hold a train in check when descending a grade, provided that the speed is not allowed to get too high before any effort is made to check it. It takes more braking power and therefore more air to reduce a speed of 40 miles per hour to 30 miles per hour than is required to hold the speed at 30 miles per hour, the same length and degree of grade being assumed in both cases.

On approaching a long grade, the train must be brought under perfect control with a 5- to 7-pound reduction; this will hold down the speed or allow it to increase gradually. On approaching a curve or "let up," a stretch of rail where the grade is not so steep, the speed of the train should be considerably reduced by a further application of the brake, and the brake valve should be thrown to release position to recharge the train line and auxiliaries to 70 pounds; then it should be moved to lap position preparatory to making another reduction.

The electric governor is not piped to train-line pressure but is actuated by main-reservoir pressure; therefore, it will keep the compressors running until main-reservoir pressure reaches 90 pounds. The compressors will thus maintain excess pressure, unless the train line is greatly overcharged. Successive reductions without recharging, together with possible leaks, reduce auxiliary-reservoir pressure to a point where checking the speed of the train will be impossible, should it become high. As safety is the first consideration, it is urgent that the motorman avail himself of every opportunity to recharge and keep the pressure as near standard as possible, thus holding the train under constant control.

To bring a train to a service stop, there are two methods in common use. One method, very much abused in present multiple-unit service, where time is considered of more importance than the points of good braking, is called the *one-application method.* On approaching a station, the usual 5- or 6-pound reduction is made, and this is followed by a series of 2- or 3-pound reductions, made as the motorman's judgment may direct, until the train stops. An experienced man will stop a train smoothly and exactly by following this method, irrespective of the grade or the condition of the rail: a less-experienced man is not so apt to. The tendency of the latter is to apply the brake at a rate that will stop the train long before the stop sign is reached; the result is that the brake must be released, the train allowed to coast, and the brake again applied to stop at the proper point. Such action on the part of green men embraces the general features of the two-application method, the natural merits of which are being recognized.

To make a *two-application stop*, the usual 5- to 7-pound reduction is made, and this is followed by a series of lighter reductions, until the application is such that if the air were held by lapping the valve, it would stop the train several car lengths short of the desired point. Before reaching this point, however, the brakes are released and the train allowed to roll into the station at reduced speed, when a mild graduated application will stop it at the exact point desired. A given reduction followed by a full release constitutes one application, irrespective of the number of times the brake valve is moved to service and back to lap to make the given reduction. The two-application method, being flexible and exact, is well adapted to close stops where platform-rail gateways and car gates must register. After making the first application, the brake valve is returned to lap and not to running position, because the second application follows the first so closely that the train line and auxiliaries have but little time to equalize through the small feed groove of the triple piston; the result of holding the brake valve on release too long or of throwing it to running position would be to put the train-line pressure considerably above that of the auxiliaries by the time the second application fell due. This condition would mean a loss of time and air, because in making the second application the pressure of the overcharged train line must be reduced below that of the auxiliaries in order to operate the triples. After the first application in a two-application stop, then, the brake valve is held on release until train-line pressure is sufficient to release the triples (the release being indicated by the sound of the triple exhaust), when the valve is immediately returned to lap.

50. More than two applications in making a stop are to be avoided, as each application reduces the auxiliary-reservoir pressure, hence the braking power, and each release exhausts an air-filled brake cylinder to the atmosphere. When using the one-application stop, the brake should be released just before the train comes to a stand, to avoid the disagreeable lurch due to the reaction of the trucks and springs, which are under a strong tension, owing to the depression of the front end of every coach and to the fact that the brake riggings take up a position to suit this depression. When using the two-application method, the tendency to lurch is slight, because the trucks right themselves after the first release; consequently, the second slight application can be continued until the train stops.

51. Emergency Stop.—When impending danger requires the quickest possible stop, sand is applied to the rails, and the brake valve is thrown to emergency position and left there until the train stops. Even if the brake valve is already on service position, the valve must be thrown for emergency action, for although the service reduction may in some cases render emergency action of the triples impossible, they will at least go into full service action and reset any brakes that may have leaked off. On a long train, the idea in holding the valve at emergency until the train stops is to avoid the head-brakes being kicked off by the rush of air from the rear end of the train. This rush of air and consequent increase of head-end train-line pressure may be caused by lapping the valve too soon after an emergency application. The air in the train line, rushing to exhaust from the forward brake valve, may, if the valve is suddenly lapped and its exhaust passage closed, react on the triples and release the brakes. There is great increase of pressure at the forward end and a decrease of pressure at the rear end of the train, produced by the motion of the long column of air.

52. Excess Pressure.—From the operator's standpoint, it is as essential that the brakes should release promptly and certainly as it is that they should apply. Normally, excess pressure is obtained only on running position, and is provided to insure prompt movement of the triple pistons to release position as well as prompt recharging of the train line, triples, and auxiliary reservoirs. After an application, train-line pressure is below auxiliary pressure and the triple pistons are on lap position. To force the pistons of a lot of triple valves in good order to release position, standard train-line pressure is sufficient; but where a triple shows a tendency to stick, it is often necessary to admit a main-reservoir pressure of 90 pounds into the train line. In a tank of given size, there is more air, by weight, at 90 pounds pressure, than at 70 pounds pressure, so that carrying 20 pounds excess pressure, virtually amounts to increasing main-reservoir capacity nearly 29 per cent. ($\frac{20}{70}$) without increasing the size of the main reservoir. This question naturally suggests itself: Why not carry 90 pounds pressure in the train line? Because, in ordinary service, 70 pounds in the auxiliaries provides all the force necessary to apply the brakes. Since it costs more to compress air to 90 pounds than to 70 pounds per square inch, a given train-line reduction from 90 pounds will cost more than from 70 pounds, so that every pound above the pressure needed to apply the brakes represents just so much waste. By carrying excess pressure, air is efficiently stored at high pressure and efficiently used at a lower pressure. Whenever the reservoir and train lines are allowed to equalize, it means that in the next application of the brakes, there occurs a discharge of air at unnecessarily high pressure and a consequent loss of comparatively expensive energy. It also means that if the next application comes before the train line has had time to equalize with the auxiliaries through the small triple piston feed groove, a further and similar loss of energy must be incurred in order to bring train-line pressure below that in the auxiliaries. Finally, it means that if the 90-pound train-line has time to equalize with the auxiliaries through the triple-valve feed groove before the next application comes, that application will apply to the brake piston a pressure for which the brake rigging was not designed; the result in this case being a liability to make flat spots on the car wheels. Excess pressure, judiciously handled, is a great help on long grades, where the opportunities for recharging the train line are few and far between, because, at a pressure of 90 pounds, a main reservoir will rush air into the train line faster than one at 70 pounds pressure could do.

53. Train Break; Burst Hose; Conductor's Valve. Should train-line pressure, as indicated by the black hand of the gauge, show a violent and abnormal reduction and the brakes apply at emergency from causes unknown to the motorman, it is his duty to lap the brake valve at once and leave it lapped until he gets the signal to release brakes. The emergency stop may have been caused by the train line emptying in consequence of the parting of the train, uncoupling the hose connections, or to a burst train-line hose or pipe, or to some one having operated a conductor's valve to its full open position, thereby throwing all triple valves into emergency action. In any case, if the brake valve is allowed to rest on running position, main-reservoir air will pass through the feed-valve into the train line and then through the opening in the train line to the atmosphere, necessitating an entire recharging of the train and reservoir lines before the brakes can be released.

54. The conductor's valve, located inside of every coach near one end, is a valve used in emergencies to let train-line air exhaust to atmosphere and throw all triple valves into action. The valve can be operated to stop the train gradually, or so as to bring about an emergency stop. Opening a conductor's valve has the same effect as opening a train-line end angle cock. Some conductor's valve handles must be pushed up to operate the valve, while others must be pulled down. There should be but one type of valve in the same service, and all train crews should be perfectly familiar with its mode of operation. If occasion arises for using the conductor's valve, open the valve and keep it open until the train stops. It must be kept open until the train stops, because, if the motorman has failed to lap his brake valve and it rests on running position, the main-reservoir line will recharge the train line and release all the triples, perhaps before all danger is over. Under conditions where the brakes are applied without the action of the motorman, he should place his valve on lap position.

PRECAUTIONS

55. Train Parting.—In case a train breaks, the couplings pull loose and both sections of the train come to an emergency stop. On a train composed entirely of motor cars, the braking force per unit of weight being the same on both sections, except in so far as one section may have more live load than the other, the two sections will brake at the same rate and stop without serious danger of a disastrous collision. Should the head-section contain any "dead-brake" cars, its speed will be reduced more slowly than the rear section, and it will, therefore, run away from it; but should only the rear section contain dead-brake cars, it will be brought to a stand by the head-section, which will stop first.

In case the break occurs while current is not on the motors, it is not advisable for the motorman to try to pull away from the rear section to avoid collision, by turning the controller to on-position, as such an effort will probably result in blowing all the fuses on the front section. If the two sections must come together, it is highly desirable that they should be kept as near together as possible until they do. Any effort to run away might temporarily increase the distance between the two sections only to increase the violence of the collision later. The chances of a train parting are exceedingly slight, because the trains are short and the drawbar pull is therefore comparatively low; as each coach or unit is a seat of motive as well as braking power, all coaches tend to move at almost the same rate, and there is no bunching or stretching to shock the couplings. Should a train break while the current is being used, the sudden load put on the motors by the emergency action of the brakes increases the current to a point where the fuses or circuit-breakers operate to open the power circuit.

As soon as both sections of a broken train stop, precautions must be taken to flag the following train. The train-line angle cocks on both sides of the break must be closed; if necessary, a hand-brake must be set on each section. As no main-reservoir air has been lost, provided that reservoir line check-valves are used, each section is ready to charge its own train line by placing a brake valve on running position. As soon as both sections are charged, the rear section is run up or the head-section backed down, the hose coupled, and the angle cocks opened. The motorman then applies and releases the brakes from the head end to insure that everything is in order, and, on getting the conductor's signal, pulls ahead. In case it has been necessary to set a hand-brake to hold the train while the air brake is released, care must be taken to release the hand-brake and not to start the train with the hand-brake on either section set.

56. Burst Reservoir-Line Connection.—If a main-reservoir line hose or an improperly disposed insulation hose bursts, all main-reservoir air escapes to the atmosphere. As all governors are operated by main-reservoir pressure, the compressors immediately start and will continue to run, wasting energy in their endeavors to charge the broken reservoir line. To avoid this, as soon as the fall of the red hand to zero warns the engineer that the reservoir line is open, all pump switches should be opened. Should the brake valve be on release position at the time of the break, train-line air will exhaust to atmosphere and apply the brakes. If the brakes are once applied, it will be impossible to release them, except by bleeding the auxiliaries, as long as the main-reservoir leak exists, because the result of placing the brake valve on release position is to connect the train line to the leaky reservoir line, allowing train-line air to escape to atmosphere and set the brakes harder. The running position has no effect at all, because train-line air cannot get back through the closed feed-valve.

57. The first thing to do when it is known that the reservoir line is open is to stop, unless local conditions suggest making a near-by station or siding. If the location of the burst hose is evident, close the reservoir angle cocks immediately ahead of and behind the burst hose, start the compressors on the operating section, get excess pressure, release the brakes, and apply them again to make sure that they are in order, and then pull out.

If the location of the burst hose is not evident, place the trainmen where they can hear the noise of the escaping air and move the brake valve to release position, where train-line air can get into the reservoir line and out through the leak. If this fails, start all compressors and close a reservoir angle cock somewhere in the center of the train; this will separate the reservoir line into two sections. Next cut in the pressure gauge on the last platform. If the pressure gauge on the tail-end indicates accumulation of pressure, the leak must be somewhere between the closed angle cock and the head end; now close the next angle cock toward the head end and open the one first closed. Keep on doing this, until the leak is cut in, when the pressure gauges toward the rear end will lose main-reservoir pressure and thus show that the cock last opened cut in the leak. Should a compressor discharge-pipe insulation hose burst, the check-valve between it and the main reservoir will prevent the escape of main-reservoir air, but the compressor on that car, having no work to do, will run at a noticeably higher rate of speed than the other compressors. If no check-valves are used in the main-reservoir piping, the bursting of an insulation hose will have the same effect as the bursting of a coupling hose.

58. Burst Train-Line Connection.—The bursting of a train-line hose sets the brakes immediately at emergency.

If the burst is bad, it can be seen; if it must be tested for, move the brake valve at intervals to release and then to lap, and let the crew listen for the sound of escaping air. If this fails, begin at the head end of the last coach and close successively all train-line angle cocks, noticing each time if the closing of the cock will allow any accumulation of pressure in the train line when the head brake valve is put on release position. If the closing of any cock restores normal train-line conditions, the burst must be somewhere between that cock and the one closed immediately before it. If these two cocks are respectively on the head end of one coach and the rear end of the abutting coach, the burst is in the intervening coupling; but if the two cocks are on the same coach, the burst is somewhere in the train piping of that coach. If the burst is in the main train pipe, the only thing to do is to close the angle cocks on both ends of the coach and bleed its auxiliary. If practicable, the dead coach can be switched to the rear end of the train, but as a rule there is neither time nor facilities for doing this.

If the burst is between the triple valve and branch cock, close the branch cock and bleed the auxiliary. If the burst is in the coupler hose, replace it with the coupling hose taken from the rear end of the tail-car, if there is no extra hose aboard. As a rule, in multiple-unit service, trains run under short headway and there is little time to do more than get the brakes released and cut out all of that part of the train that is behind the faulty coach. This is done by closing the rear train-line angle cock on the coach ahead of the burst; this is, perhaps, the best thing to do; but if the burst is so located that less than two car brakes are cut in when the train is operated from the front end, it is best to close the head train-line angle cock on the coach immediately behind the burst, operating the train from the head end of that coach and bleeding all auxiliaries ahead. A flagman must be placed on the front end of the train, to take the conductor's signals and transmit them to the motorman, and as soon as a point is reached where the faulty car can be cut out or switched to the rear end, this should be done.

59. A burst empties the train line just as the parting of the train does. Assuming the burst to have been located and repaired, the whole train line is recharged at once, the brakes released and tried, and, if satisfactory, the signal given to go ahead. Where a train parts, however, the brakes on one section must be released before the section can be brought together for coupling. If train-line pressure on both sections be brought up to standard, the coupling can be made without special precaution; but if a charged train line is to be coupled to an empty train line, whether of a single or of several coaches, care must be taken to avoid emergency action of the triples connected to the live section. If the two sections are coupled and the train-line angle cocks between them are opened wide at once, the rush of air throws the brakes on the live section to emergency action and releases those on the dead cars, if these are applied. To avoid this action, place the brake valve on running position; next open the end angle cock on the live section; finally, by tapping, open the end angle cock on the dead section just enough to allow the air to feed into the dead section at about the same rate it is being fed into the live section through the feed-valve of the engineer's valve.

60. Cutting Off or Coupling On a Car.—A car can be cut out of a multiple-unit train more readily than out of a locomotive train, which is alive only at one end. Before breaking a coupling, see that the angle cocks on both sides of it are closed, because breaking a live train line sets all brakes in emergency. If the car is to be switched to the end of the train, the hose between it and the car ahead should be coupled and the train line angle cock on the car ahead opened, but that on the disabled car should be closed; this insures that if the train should part here, the head-section would stop. Where a dead car is coupled to the end, it is well for the rear guard to stay on it as much as possible, so as to be ready to set the hand-brake if the train should part. If the cut-out car is not disabled but is to be dropped from the train, the air brake must be released and the hand-brake set before leaving it. The air brake can be released by the motorman before the car is uncoupled, or it can be released afterwards by means of the auxiliary bleed cock, which is held open until the sound of the triple exhaust is heard. In picking up cars, the usual care must be taken, when coupling, to avoid applying the train brakes at emergency. The hand-brakes should be released and all brakes applied by the motorman to insure proper connections and to find out whether or not the brakes on the added car are in good order.

ELECTRIC BRAKES AND SIGNALS

ELECTRIC BRAKES

INTRODUCTION

1. In any automatic-electric braking system, the generative ability of the car motors is largely depended on to produce the braking power effective in retarding the motion of the car. In some cases, the braking power is entirely dependent on the generative ability of the motors; while in other cases, the line current is used at certain stages of the braking operation. In the perfected form of electric brake, the car motors are not simply left to oppose each other in a local circuit established by throwing the reverse switch, but are given a path in common through a variable resistance, the control of which is in the hands of the motorman. In such a case, should one motor become disabled, the other can still be used for braking purposes. The retarding force can be regulated to suit existing conditions, and but little skill is required to make a stop as smoothly as that obtainable with a hand-brake. Where the line current is used in conjunction with the motor current, stops at very low speeds become independent of the "picking up" ability of the motors. Finally, it is practicable to introduce means whereby the braking power may be made to adjust itself to varying speeds of the car. This means that maximum braking power can be applied when the speed is highest, and gradually decreased as the speed decreases, which is an ideal condition in brakes of any kind.

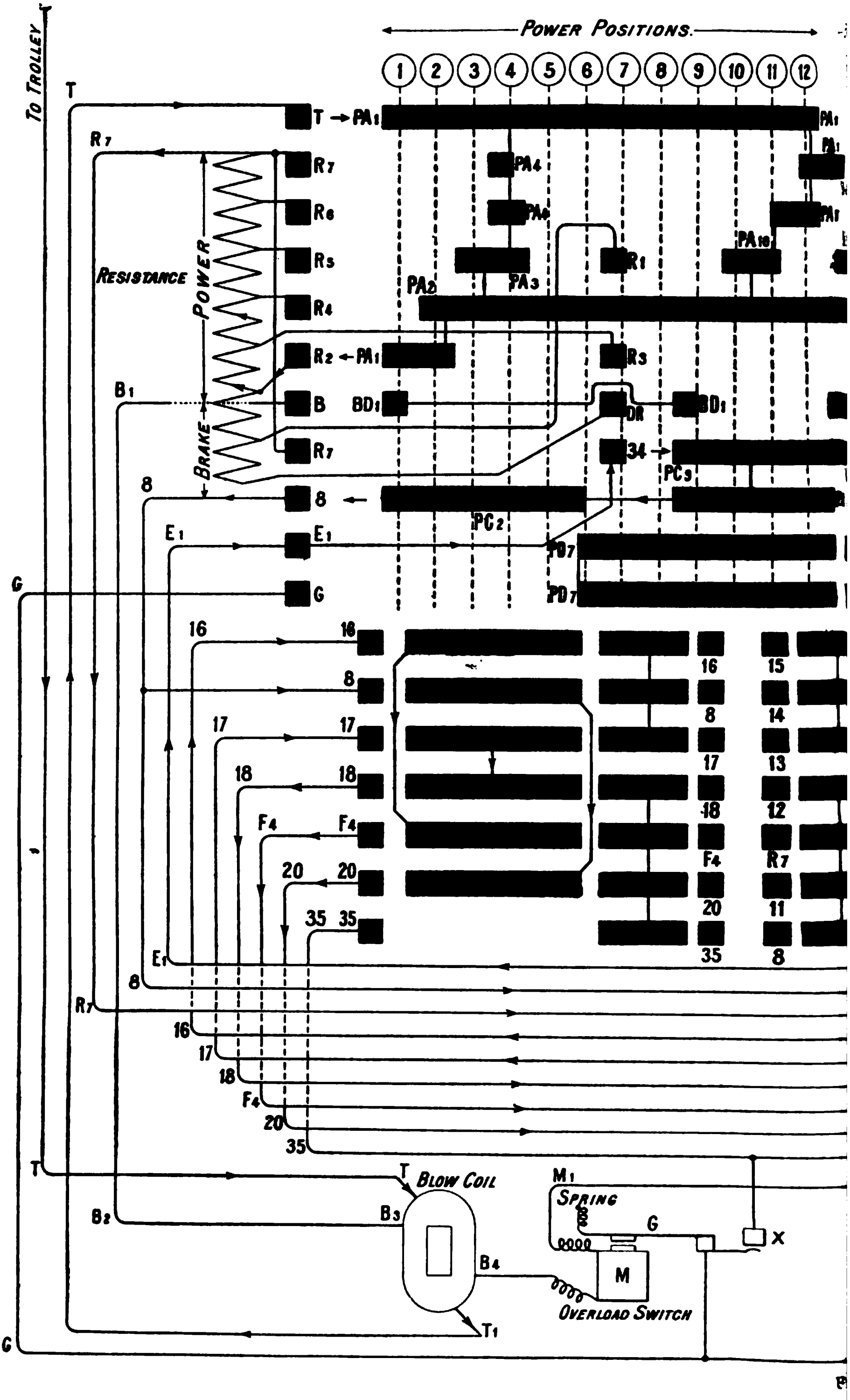
THE GENERAL ELECTRIC BRAKE

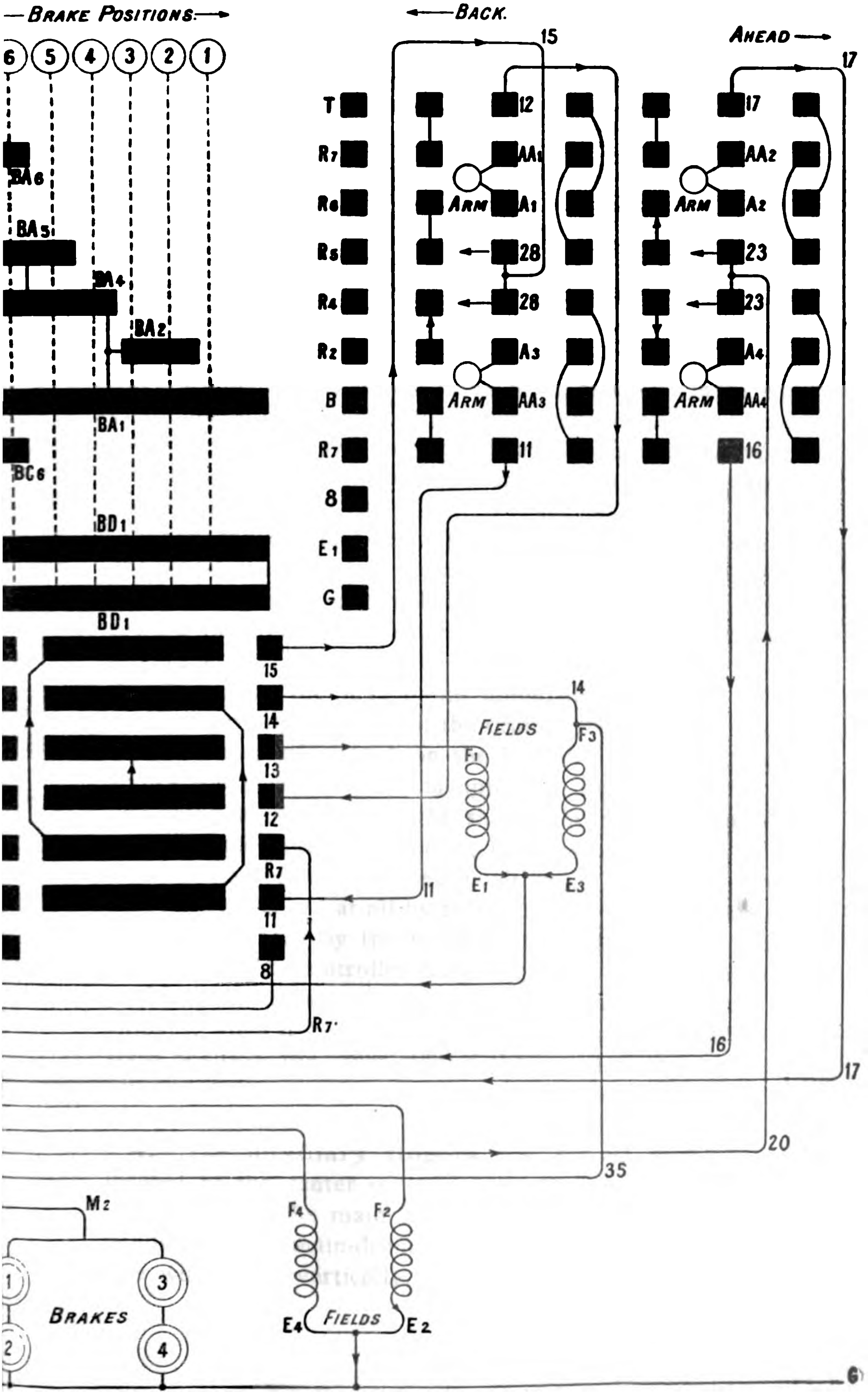
DESCRIPTION

2. On the main controller of the electric brake made by the General Electric Company is a neutral position decisively emphasized by the drum index; the power contact tips are on one side of this position, and those for the brake are on the other. To start the car or to throw off the current, the controller handle is operated as usual. To apply the electric brake, the handle is kept moving on past the off-position to a distance depending on the degree of brake pressure desired. The current used for braking the car is produced by the generative action of the motor. To interrupt the braking current, the handle is returned to the off-position. The brake is not released simply by this motion, because its parts have sufficient residual magnetism to hold the car for a while after it has stopped and the motors have ceased to generate.

To do away with the residual magnetism at the proper time, and to insure that the brake will be fully released on all power notches, provision is made whereby, on the first power notch, trolley current passes through the brake coils in such a direction as to completely demagnetize their cores, which are, in effect, the braking shoes.

3. The Controller.—The main drum is shown in the upper left-hand corner of Fig. 1, which shows the connections for the brake used in a four-motor equipment. There are eleven rows of main-drum contact tips. All tips that are marked with the same letter are metallically connected, and the position on which the tip comes into action is indicated by the small figures near the letter. For example, PA_1 indicates that the tip is a power tip, that it is a part of the A drum casting, and that it comes into action on the first power position. PA_{10} is a power tip on the A casting and comes into action on the tenth power position. BA_4 is a brake tip of the A casting, and it comes into action on the


To Trolley
Power Positions
1
2
3
4
5
6
7
8
9
10
11
12
T
T → PA1
PA1
R7
R6
R5
R4
R2 ← PA1
B
R7
8
E1
G
PA4
PA4
PA3
PA2
R1
PA10
R3
BD1
DR
BD1
34 →
PC3
PC2
8 ←
PD7
PD7
Resistance
Power
Brake
B1
16
17
18
F4
20
35
15
14
13
12
11
Blow Coil
B2
B3
B4
T1
M1
Spring
G
X
M
Overload Switch


—BRAKE POSITIONS—
6 5 4 3 2 1
BA6
BA5
BA4
BA2
BA1
BC6
BD1
BD1
—BACK.
AHEAD—
15
17
T
R7
R6
R5
R4
R2
B
R7
8
E1
G
12
AA1
ARM
A1
28
28
A3
ARM
AA3
11
17
AA2
ARM
A2
23
23
A4
ARM
AA4
16
15
14
13
12
R7
11
8
14
FIELDS
F3
F1
E1
E3
11
R7
16
17
20
35
M2
F4
F2
1
3
BRAKES
2
4
E4
FIELDS
E2
G
1
421

fourth brake position. All the tips marked *A* are connected; if the *A* is preceded by a *P*, the tip is used in applying the power to start the car; if it is preceded by a *B*, it is used on a brake position to stop the car. Thus it will be seen that some of the castings have tips, such as PA_1 and BA_2, etc., in common to applications of both the power and the brake, but are not in use at the same time. On the left of the main drum are shown the eleven main-drum fingers T, R_7, R_6, R_5, R_4, R_2, B, R_7, *8*, E_1, and G. On the right of the main drum, these fingers are reproduced, not because there are actually two rows of fingers, but simply to make it easier to trace current paths; therefore, no wires are run to these fingers.

When the car is being started, the main-drum contacts should be considered as moving toward the left-hand row of fingers; when the car is being stopped, the drum moves toward the right-hand row. Thus, on the first power notch, fingers T, R_2, B, and *8* make contact on the left-hand side of the drum; on the first brake notch, fingers B, E_1, and G touch the right-hand side of the drum. The row of enclosed numbers beginning at *1* on the left and running up to *12* shows the positions used in applying the power; the row beginning at *1* on the right shows the positions used in applying the brake. There is, therefore, a portion of the main drum, between power position *12* and brake position *6*, not touched at all by these fingers. This untraversed space is dictated by the width of the lug on the controller top; when the controller handle gets to the full multiple position, which is the twelfth position, one side of the lug stops it; when it gets to the last brake position, which is the sixth position, the other side of the lug stops it; the handle cannot, of course, traverse the space occupied by the stop lug.

4. The **auxiliary fingers** are R_1, R_3, $D\ R$, and *34*, located in the center of the space, Fig. 1, devoted to the power part of the main drum. These fingers, being independent of the main-drum fingers proper and not being in line with them vertically, but being in line with some of them horizontally, can make contact with one part of a drum tip while one of the drum fingers proper is resting on another part of the same tip. For example, on the first power notch, main finger B makes contact with tip BD_1 at the same time that auxiliary finger DR makes contact with the right-hand tip BD_1. The object and action of these auxiliary fingers will be considered later.

5. The **reverse drum** proper, used to reverse the direction of motion of the car, appears in the top right-hand corner of Fig. 1. There are two rows of reverse fingers, each row handling two motors. Under the main drum are two auxiliary drums, called *generator reverse drums* because their object is to insure that the motor connections may always be such that the motors can generate when generative action is required. The left-hand drum is coupled directly to the main-drum shaft and rotates in the same direction. The right-hand reverse drum, however, is geared to the main drum and rotates in the opposite direction from that of its mate. Both of the generator reverse drums are operated by the main drum. Each of these drums has a neutral or off-position and a row of fingers of its own.

Under normal conditions, when the car moves forwards and the brake is off, fingers *16*, *8*, *17*, *18*, F_4, and *20*, near the left-hand drum, and fingers *15*, *14*, *13*, *12*, R_1, and *11*, near the right-hand drum, engage the long-strip portions of their respective drums and continue to do so throughout the main-drum power positions. It should be borne in mind that when the left-hand drum is moving toward the left, the right-hand drum is moving toward the right. On moving the power handle to off-position and continuing its movement to the first brake notch, the generator reverse-drum fingers leave the long strips and engage the short ones, remaining in this relation throughout the six main-drum brake notches. The two rows of reproduced fingers between the two drums can then be considered as being in action.

What a motorman usually accomplishes manually, on a car not equipped with electric-brake attachments, by throwing the reverse switch preparatory to making an emergency stop by motor generation, is accomplished automatically by the action of the two generator reverse switches.

6. Brake Details.—Before going into the question as to the way the controller affects the several combinations, the details of the brake apparatus itself will be considered.

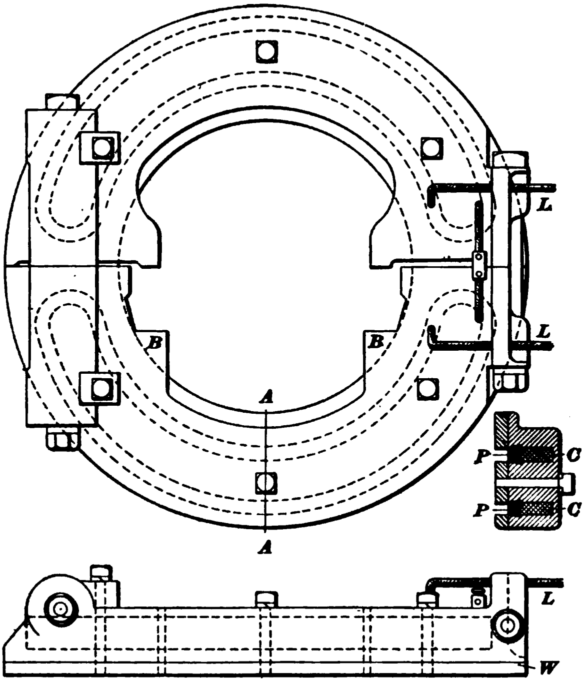


FIG. 2

Fig. 2 shows the brake used on a motor car. It consists of a cast-iron ring, split horizontally and held together, as shown, by bolts. There are magnetizing coils *C*, *C* in each half of the ring; these are indicated by the dotted lines. Each coil consists of 32 turns of No. 8 wire. The sectional view shows how the coils are embedded in the iron and held in place by pouring in lead *P*, *P*, the insulation of the coil being protected from the hot lead by a thin layer of asbestos not shown in the figure. The wearing plate *W* is in two pieces, one on each half of the brake ring and held on by capscrews. The two magnetizing coils are in series, connection with the car wire being made by means of leads *L*.

7. Fig. 3 shows the manner of support. The motor-bearing cap *C* has two projecting horns *A*, one behind and the other in front of the car axle. Lugs *B*, Fig. 2, of the brake ring engage these horns, and thus the brake is held close to the disk *S*, Fig. 3, that turns with the axle. Setscrew *M* is used to take up the wear in the disk and ring. The ring has $\frac{1}{32}$ inch end play, but cannot rotate; when magnetized, however, it is drawn over, clutches disk *S*, and tends to prevent its rotation and that of the axle on which it is mounted. Both the disk and the ring have wearing plates *W*, Fig. 4. In this figure are shown the ring and disk used on trailer cars that have no motors, these cars being drawn by the motor car ahead. The brake is designed to rest on the axle, a babbitted bearing serving as the means of support. Bar *E* connects the two brakes of the same truck and prevents them from turning. Split collar *G*, adjustable by device *H*, serves to take up wear. *O* is a grease cup for the bearing on the axle. Clamp *F* holds bar *E*, and springs *D* prevent rattling. Ring *R* is stationary, but disk *T* turns with the axle.

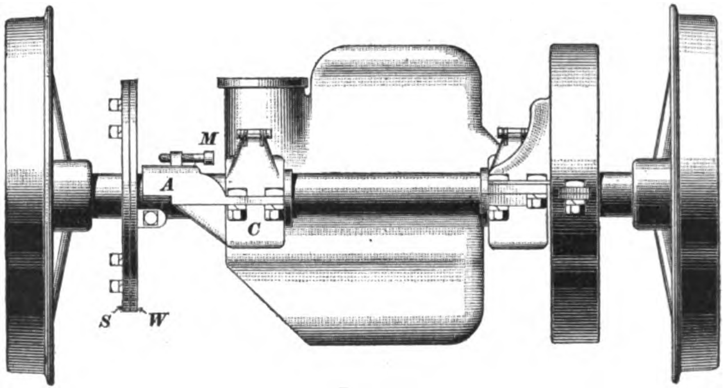


FIG. 3

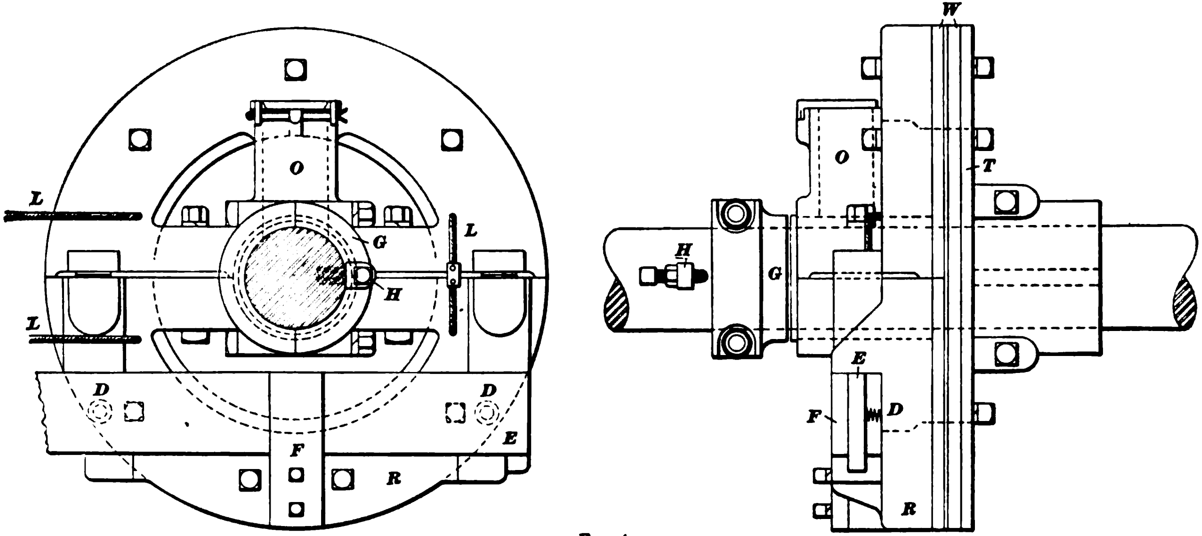
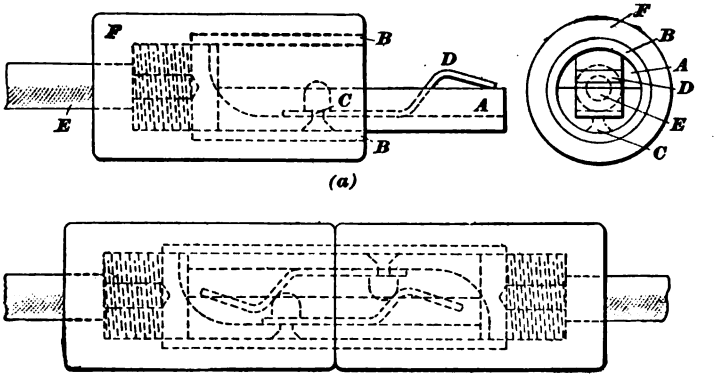


FIG. 4

8. Fig. 5 shows the plugs used for connecting the brake circuits of coupled cars—motor car and trailer, for example. The single plug in (*a*), consists of a brass piece *A*, to which a brass spring *D* is riveted by a brass piece *C*. Brass ferrule *B* is slipped over *A*, and wooden socket *F* serves as a handle.



(*a*)

(*b*)

Fig. 5

E is the wire leading to the plug. Fig. 5 (*b*) shows two plugs snapped together.

WIRING DIAGRAM

9. Fig. 1 is a car-wiring diagram of the B6 controller designed to operate a four-motor equipment with electric brakes. For simplicity, the connecting board is omitted, and all wires run directly to the operating devices. In the bottom left-hand corner of the sketch is the double-coil blow-out magnet. One coil belongs to the power circuit and the other to the brake circuit. To the right of the blow coil is the **overload switch**; this consists of an electromagnet *M* in the brake circuit and of a contact *G* operated by the magnet. When the contact is closed, braking current is decreased. To the right of the overload switch are shown four brake coils, permanently connected, two coils in series in each set and the two sets in parallel. F_1E_1, F_2E_2, F_3E_3, and F_4E_4 are the motor fields. The armatures are indicated as directly connected to their respective reserve-switch fingers. The brake circuit begins at main-drum finger B and takes the path $B-B_1-B_2-B_3-B_4-M-M_1-M_2-\left\{\begin{matrix}1-2\\ 3-4\end{matrix}\right\}-G$; that is, through the blow coil, overload-switch coil, and brake coils to the ground. The bottom section of resistance, that between fingers DR and R_1, is the demagnetizing resistance, so called because it limits the line current sent through the brake coils on the first power notch, to demagnetize them to full release.

10. Power Positions.—On the first power position, fingers T, R_2, B, DR, *34*, and *8* make contact on the main drum; all fingers on the lower drums, except Nos. *35* and *8*, make contact when the reverse switch is forward. The current path, when the reverse switch is at forward position, that is, the contacts to the left of the reverse fingers touching the fingers, is: trolley–T–T–blow coil–T_1–T–finger $T-PA_1-PA_1-R_2$–resistance coil–$R_7-R_7-R_7-R_7-R_7$–right-hand generator drum–$15-28-\left\{\begin{matrix}A_1-A\,A_1-12-12-13-F_1-E_1\text{———}\\ A_3-A\,A_3-11-11-11-14-14-F_3-E_3\end{matrix}\right\}-E_1-E_1-E_1-34-PC_9-PC_9-PC_2-8-8-8-20-20-20-20-23-\left\{\begin{matrix}A_2-A\,A_2-17-17-17-17-17-17-18-18-18-F_2-E_2\\ A_4-A\,A_4-16-16-16-16-16-F_4-F_4-F_4-F_4-E_4\text{——}\end{matrix}\right\}-G$. The current path on the first notch is indicated by the arrowheads. It starts at the trolley; when it gets to reverse finger *28*, it splits, the current dividing between the No. 1 and No. 3 motors; the two currents reunite and flow as one to finger *23*, where they split again through the No. 2 and No. 4 motors, reuniting at G, the ground wire. On the second position, the current path is the same, except that finger R_4 cuts out two sections of resistance. On the third position, R_5 cuts out another section, and on the fourth position, the remaining sections are cut out by finger R_7 and T making direct connection through tips PA_4 and PA_1. On all the positions just considered, the motors are in series-parallel.

11. The change from series-parallel to full parallel will seem more simple if two features are borne in mind: (1) The four motors should be conceived as divided into two groups of two motors each, each group being composed of two motors in parallel. No. 1 and No. 3 are in one group; No. 2 and No. 4 are in the other. Consider each group as one big motor, twice the size of the ordinary motors. On the series-positions, the two groups are in series; on the parallel positions, the two groups are in parallel. (2) On all the series-notches, consider the path through the first group (motors 1 and 3) to begin at the trolley and end at the E_1, or *34*, finger, where the currents through the two motors reunite; consider the path through the second group to begin at main-drum finger *8* and end at the ground. On the first four power notches, the controller keeps the end connection *34* of the first group connected to the forward connection *8* of the second group, so that the first group gets its ground through the second group and the second group gets its trolley connection through the first group. Going from series to parallel consists in giving the first group a ground of its own and the second group a direct trolley connection. This is done as follows: On the fifth and sixth positions, fingers R_5, R_6, R_7 have ceased to make contact and R_4 does make contact, so that resistance is cut back into the circuit to lessen the current during the change from series-connection to parallel connection. Near the sixth position, fingers E_1 and G engage drum tips PD_7, thereby giving the first group a ground connection. An instant later, finger *8* leaves tip PC_5, thereby opening the circuit of the second group, which can get no current until finger *8* touches tip PC_6; as lower finger R_7 touches PC_6 at the same time, the second group is provided with a trolley connection. The two groups are now in parallel and have in the circuit ahead of them all the resistance that was cut in on the fifth position. None of this is cut out until the tenth position is reached, when finger R_5 engages tip PA_{10}; on the eleventh position, R_6 cuts out another section of resistance, and on the twelfth position, R_7 cuts out the remainder, leaving the two groups in parallel across the line.

12. Brake Positions.—To operate the brake, the handle is moved backwards from the off-position. To follow the combinations, it is easier to conceive of the main-drum tips moving toward the row of fingers reproduced on the right of the brake positions. It is also simpler to imagine the short tips of the two generator reverse drums to move toward the two rows of fingers shown between the two drums, as these two auxiliary drums turn in opposite directions. When the controller drum is moved backwards from off-position, the auxiliary-drum fingers engage tips to the left of them. Main-drum fingers E_1 and G connect through tips BD_1; fingers B and R_1 connect through tips PA_3, BA_4, BA_2, and BA_1. Finger B is the same distance from tip BA_1 that finger R_1 is from tip PA_3, so that when all the tips move to the right, those two fingers engage their respective tips at the same time. When the generator reverse-drum fingers pass from the long drum tips to the short ones, the armature connections of all the motors are reversed, thereby connecting the motors to act as generators. Considering armatures 1 and 3, while the long strips on the right-hand drum are in action, R_7 connects through *15* and reverse fingers *28* to A_1 and A_3, while AA_1 and AA_3 connect by way of *12* and *11* to fingers *13* and *14*. When the short strips are in action, A_1 and A_3 connect to *13* and *14* and AA_1, AA_3 to R_7. In the brake positions, the T trolley finger makes no connection and the brake circuit is independent of the trolley circuit.

13. Starting at finger *15* at the top of right-hand lower drum, the path to the right is $15-\left\{\begin{array}{l}28-A_1-AA_1-12-12—\\28-A_3-AA_3-11-11-11\end{array}\right\}-R_7$ $-R_7-R_7-R_7-$resistance to auxiliary finger $R_1-PA_3-BA_4-BA_1-B-B_1-B_2-B_3-B_4-M-M_1-M_2-$*Brakes*–to the ground wire G.

The path to the left from finger *15* is $15-\left\{\begin{array}{l}14-14-F_3-E_3\\13-F_1-E_1—\end{array}\right\}-E_1-$ $E_1-E_1-BD_1-BD_1-G-$to the ground wire G. The No. 2 and No. 4 motors have one end of their fields grounded at E_2 and E_4. Tracing the circuit back, the path is $G-\left\{\begin{array}{l}E_2-F_2-18-18-18\\E_4-F_4-F_4-F_4-F_4\end{array}\right\}$ $-20-20-20-20-\left\{\begin{array}{l}23-A_2-AA_2-17-17-17-17-17-17\\23-A_4-AA_4-16-16-16-16-16—\end{array}\right\}-8-8-8-R_7-$ $R_7-R_7-R_7-R_1-PA_3-BA_4-BA_1-B-B_1-B_2-B_3-B_4-M-M_1-M_2-$

Brakes–G. All four motors have both ends grounded and are, therefore, in parallel. No change is made after the first brake notch, except that resistance is cut out successively by fingers R_3, R_4, R_5, and R_7, thus regulating the current through the brake coils.

14. Fig. 6 is a simple sketch showing the connections of the motors, plugs, blow coil, overload switch, and brakes. The action of the overload switch is as follows: The magnet coil carries the braking current of all the motors; if this current exceeds a certain predecided value, magnet M pulls on its armature, thereby causing contacts c and x to touch, bringing together wires xyz and $cdef$; wire xyz connects to one end of all the motor fields, and wire $cdef$ to the other end of all the fields, so that when they touch, the motor fields are short-circuited, depriving the motors of their ability to generate. As soon as this happens, magnet M releases, opening the short circuit and allowing the fields to build up again. This action prevents an excessive flow of current through the windings of the motors. The coupling plugs are shown at S and S_1, which are at opposite ends of

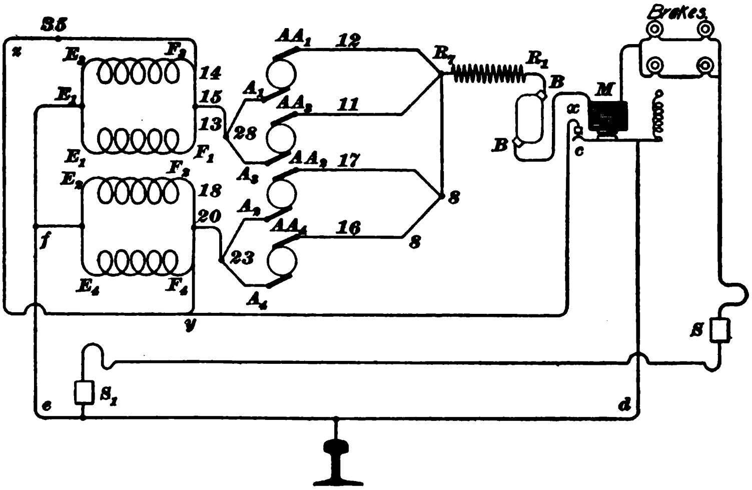


FIG. 6

the car. The reference letters in Figs. 1 and 6 mean the same.

15. Releasing Brakes.—Full release of the brakes is accomplished by passing a demagnetizing trolley current through the brake coils. This operation is performed through the agency of finger DR and tip BD_1, Fig. 1. The demagnetizing resistance is about 60 ohms. The demagnetizing current need be but very small, as the demagnetizing effect is helped considerably by the vibration incidental to the starting of the car. On the first power position, finger B engages one BD_1 tip and finger DR the other, so that on this position current from the trolley wire takes the path trolley-T-T-T_1-T-T-PA_1-PA_1 to finger R_2; here the current splits, part taking the path through the power part of the resistance to R_7, thence to the motors, and part taking the path through the brake part of the resistance to finger DR, thence through path DR-BD_1-BD_1-B-B_1-B_2, etc. to the brakes. The resistance in the demagnetizing current path between fingers R_2 and R_1 is slight compared to the resistance between fingers R_1 and DR. This trolley current passes around the brake coils in the opposite direction to that taken by the braking current (due to the generative action of the motors), and so destroys the residual magnetism sufficiently to release the brakes.

16. An Exceptional Condition.—In ordinary applications of the brake, it is, of course, only necessary to throw off the power and continue in that direction to the brake notches, the generator reverse drums tending to the reversal of connections ordinarily accomplished with the reverse switch proper on cars not equipped with electric brakes. In case, however, a car is ascending a hill and the blowing of a fuse causes it to start to roll backwards, the direction of rotation of the armatures has been reversed, so that their connections need not be; but the act of putting the power handle on a brake notch has reversed the connections. With the direction of rotation and armature connections both reversed, the motors cannot generate. Under such a condition, throw the reverse switch proper before putting the controller handle on a brake notch.

STANDARD TRACTION BRAKE

17. The **standard traction brake** made by the Westinghouse Company is a form of electric brake that is energized by current due to the generative action of the motors. The braking combinations are governed either by braking attachments incorporated within the ordinary operating controller, or through the agency of a simple auxiliary controller provided for that purpose. The braking force is applied both through the ordinary brake-shoe rigging and through heavy magnetic shoes that drag on the rail when in operation. The unique feature of operation, however, is that the regular brake-shoe effects are due not to the exertion of manual force on the hand-brake handle, but to an automatically applied force due to the friction of the track shoes on the rail. Applications are regulated by means of resistance inserted in the motor circuit when the motors are being used as generators. Change-over devices of simple construction and operation provide that the regulating resistance may be either a special resistance under the car or may be the car electric heaters. In summer, the regular brake resistance coils may be used; in winter, the car heaters may be substituted, thereby materially contributing to the heating of the car by current that otherwise would be wasted.

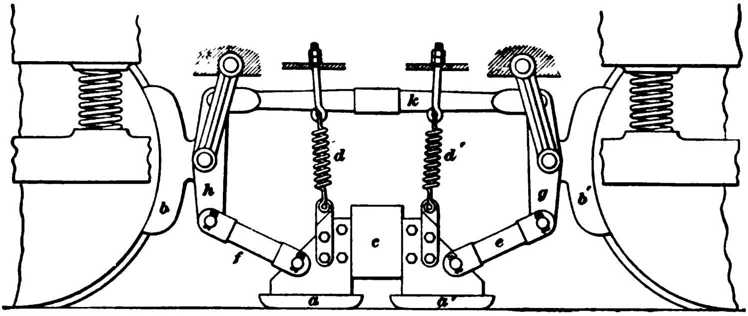


FIG. 7

DESCRIPTION

18. In Fig. 7 is shown the brake device on one side of a single trunk. In this figure, *a* and *a'* are the track shoes; *b* and *b'* are the regular car-wheel brake shoes; *c* is the brake coil; *d* and *d'* are adjustable springs supporting the track shoes and normally keeping them a short distance from the rail; *e*, *f*, *g*, *h*, and *k* are levers and connecting-rods used in applying the wheel brake shoes. Brake shoes *b* and *b'* are supported by hangers. The brake levers *h* and *g* are connected to their respective shoe heads *b*. and *b'*. The upper ends of the brake levers are connected by an adjustable connecting-rod *k*. The lower ends of the brake levers are connected to the track shoes by push rods *e* and *f*.

19. Heater and Resistance.—Fig. 8 shows one form of special heater adapted to regulation of the braking current. These heaters may be so installed that not only does the braking current pass through them, but also the current used. in starting the car and in operating it on notches that ordinarily it is considered very uneconomical to operate from. The heaters are so connected, sectioned, and distributed that, whatever may be the existing circuit combination, the total heating effect will be uniformly distributed among all the heaters. Fig. 9 is a diagram of the starting-coil and heater connections.

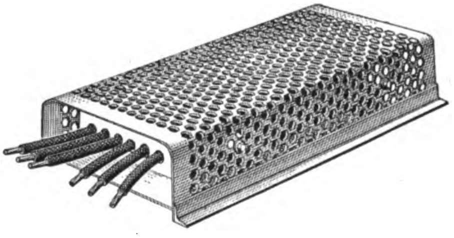


FIG. 8

OPERATION

20. Normally, the adjustment of springs *d* and *d'*, Fig. 7, is such that track shoes *a* and *a'* are held sufficiently clear of the rail to pass over any obstruction that would not actually stop the car. Under this condition, the regular brake shoes *b* and *b'* hang well away from their respective wheels. The instant the operating controller is placed on a brake notch, or the brake controller is advanced to an operating notch (according to which system of control is used), track-shoe coil *c* takes a current, the value of which

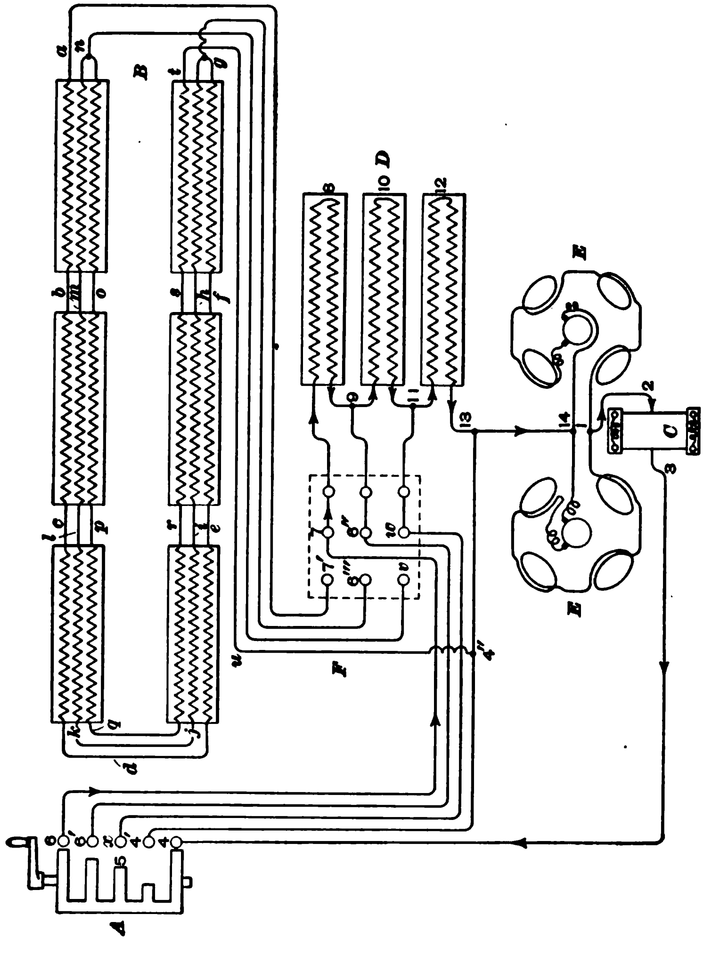


FIG. 9

depends on the electromotive force applied and the amount of resistance in circuit, and the track shoes are drawn down on to the rail because of the magnetic attraction between the energized shoes and the rail.

The energizing of shoes *a* and *a'* produces four distinct effects that contribute directly or indirectly to the retarding of the car:

1. The increase of the pressure of the wheels on the rail due to the downward force exerted on the side bar of the truck; the amount of the downward force tending to hold the car wheels harder to the rails depends on the stiffness of springs *d* and *d'*; but whatever its amount, its tendency is to increase the adhesion between the wheels and rails, thereby increasing the maximum braking force that can be applied to wheels without causing them to slide.

2. The direct retarding force that is due to the friction of the track shoes on the rail, increasing the resistance to be overcome by the car's momentum.

3. The direct retarding force that is due to pressure of the brake shoes on their wheels.

4. The retarding effect due to the motors acting as generators with no source of mechanical power except the momentum of the car.

Assume the brake current to be applied while the car is moving to the left, Fig. 7. In this case the friction between the rail and track shoes tends to bring the shoes and the rear wheels closer together, thereby pushing on right-hand push rod *e*, and, therefore, on the lower end of brake lever *g*, which, using the right-hand end of connecting-rod *k* as a fulcrum, forces shoe *b'* to its wheel. The instant shoe *b'* touches its wheel, the point of connection between the shoe and lever *g* becomes stationary and then acts as a fulcrum or center around which lever *g* turns farther, its upper end thereby forcing connecting-rod *k* to the left and exerting a force on the upper end of the left-hand lever *h* connected to it. As the lower end of the left-hand lever *h* is connected to track shoe *a*, the result of the upper end of *h* moving to the left is to force left-hand shoe *b* to the left against its wheel. The stronger the current in coil *c*, the greater the magnetic attraction between the track shoes and the rail, the greater the drag, and hence the greater the force with which the brake shoes are pressed to the wheels.

21. In Fig. 9, *A* represents the brake-circuit contacts of either a regular operating controller or a special brake controller; *B*, the car heaters; *C*, the brake coils; *D*, the resistance coils under the car; *E*, the car motors; and *F*, the change-over switch, the position of which decides whether heaters *B* or starting coils *D* are to be used as resistance to regulate the value of the brake current. When switch *F* is thrown to the right, the starting coils serve this purpose; when it is thrown to the left, the heaters serve the same purpose. Assume the switch to be to the right and the controller to be on the first notch. In this case the current takes the path *1-2-3-4-5-6-7-8-9-10-11-12-13-14*, as indicated by the arrowheads. On moving the controller to the second notch the current path becomes *1-2-3-4-5-6′-6″-9-10-11-12-13-14*.

Each succeeding step cuts out a starting-coil section until, on the last notch, the current path is *1-2-3-4-5-4′-4″-13-14*. The two motors are then in parallel across the brake coil, a condition seldom required, except when the car is merely creeping along. Suppose switch *F* to be moved to the left: with the controllers on the first notch, the current path is *1-2-3-4-5-6-7-7′-a-b-c-* . . . *t-u-4″-13-14*. On the last notch, all heaters are entirely cut out, the two motors then acting as generators in parallel across the brake coil.

22. **General Considerations.**—As in the case of most electric brakes, the greater the speed of the car, the greater will be the electromotive force generated, and hence the braking current obtaining on any given braking notch. In other words, maximum braking force is applied at maximum speed when the likelihood of skidding wheels is at a minimum. As the speed of the car decreases in response to the application of braking force, the electromotive force, and hence the current and braking force, decrease. In other words, the braking force decreases as the tendency of the wheels to skid increases.

THE AMERICAN ELECTRIC BRAKE

23. The **American electric brake** has several features not found on other electric brakes. At speeds above 4 miles an hour, the braking current is due to the generator action of the motors and to a small line current. At lower speeds, the braking current is supplied from the line, a special relay automatically determining which source of power is to be used. The braking pressure applied to the regular car-brake shoes is due to a solenoid with a plunger, so designed that the pull is practically constant throughout its travel. The braking current is applied through a brake controller standing beside the regular controller, the two being so connected electrically that abuse of the car equipment is prevented. The brake coil is divided into several sections, the acting combinations of which depend on the position of the brake-controller handle. A governor is provided, which graduates the current flow through the brake coil so as to effect a uniform rate of retardation. The governor also acts to prevent an excessive flow of braking current and consequent damage to the motors. With the brake applied, the regular car controller cannot introduce operating current, and with the power controller applied in full, application of the brake controller will interrupt the motor current before any braking force acts. On account of a special separate field-coil excitation feature, the braking ability is independent of the position of the reverse handle and of the direction of motion of the car. Should the brake be applied without the power controller having been thrown to the off-position, it is necessary to return the power controller to off-position before the brake can be released and motor current again introduced.

ELECTRIC SIGNALS

INTRODUCTION

24. Electricity is used for operating signals of various kinds in electric-railway work. At one time, modern cars were provided with an electric-bell system whereby passengers could notify the motorman and conductor of their desire to leave the car at the next crossing or stop. In many cases, however, these signal systems have been discarded, owing to their being too frequently out of order and to their being misused by some passengers. The signal bells were operated by means of push buttons let into the side posts of open cars and the window frames of closed cars.

Where connecting cars or trains are not stopped within sight of each other, an electric-bell system of some kind is usually installed to enable the starter at one point to notify the starter at the other point to hold his car or train for transfer passengers.

By far the most important use to which electric signals are put, however, is that of preventing collisions between cars running on the same track either in the same or in opposite directions. Such signals are usually operated by the conductors of cars, but may be automatically operated by the cars themselves through the agency of an electric contact established by the passing car. On high-speed cross-country lines, the telephone is much used for keeping cars in touch with a centrally located official called the **train despatcher.**

TRACK SIGNALS

25. The **track-signal system** to be considered first is called the **manual system**, because it must be operated by hand. In this manner, it is distinguished from the more elaborate systems operated by the cars or trains themselves, and is therefore called **automatic signal systems.**

A simple, cheap, manual signal system is generally used on single-track surface trolley roads as a means of preventing collision on stretches of single track that connect switches or turnouts. For example, in Fig. 10, the stretch of single track *C* between the two sidings *A* and *B*, which are provided to enable cars to pass each other, may be a mile or more long or may include curves or hills that prevent the motorman of a car resting on one siding from seeing a car on or near the next siding. Without some means of knowing from either siding whether or not there is a car approaching, or perhaps stalled, on the single track ahead of the siding, all cars would have to proceed so cautiously, in order to avoid collision, that operation would be unprofitable.

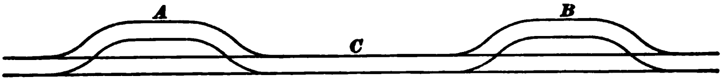


FIG. 10

MANUAL SIGNAL SYSTEM

26. Description.—The signal generally takes the form of a light that shows red to block a car and white (or not at all) to signify that the track is clear. If, on approaching a signal point, a red light shows, it means that the stretch of single track running to the next switch already contains a car, and that all approaching cars must wait until the signal shows clear before passing it. Fig. 11 is a diagram of connections for an 8-lamp signal system, and Fig. 12 shows the actual arrangement of the lamps. In Fig. 11, K_1 and K_2 are two simple two-way switches. One of these switches is placed at each end of the stretch of single track to be protected. The two switch blades are connected by means of a

No. 10 B. & S. gauge iron wire, strung on the line poles. Two 16-candlepower incandescent lamps *Ra*, *Ra* having red

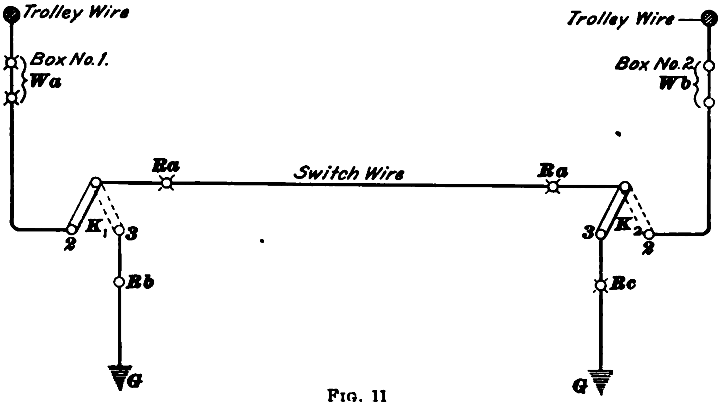


Fig. 11

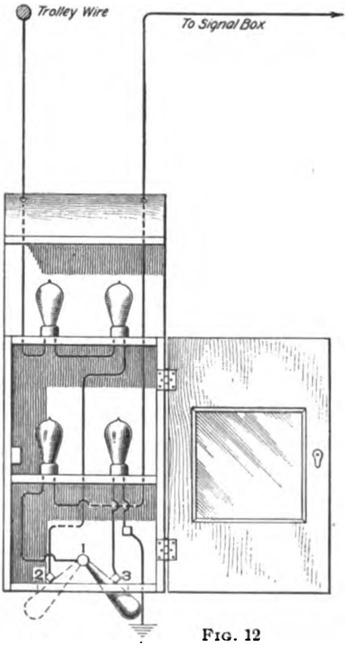


Fig. 12

globes are connected in the iron-wire circuit. Each switch has a trolley connection that includes two white lamps *Wa* or *Wb*, and a ground connection *3* that includes a red lamp *Rb* or *Rc*.

When the two switch blades are in the full-line position, the two white lamps *Wa* and the single red lamp *Ra* light in the No. *1* signal box at, say, the west end of the stretch of single track; only the two red lamps *Ra* and *Rc* light in the No. *2* box at the east end. If the two switch blades occupy the dotted positions, current from the trolley connection at the No. *2* box takes the path trolley–*Wb*–*2*–K_2–*Ra*–*Ra*–K_1–*3*–*Rb*–*G* and lights the two white lights *Wb* and red light *Ra* in the No. *2* box and the red lamps *Ra* and *Rb* in the No. *1* box. If both switch blades are on No. *2* point, or both are on No. *3* point, none of the signal lamps can light, since in the first case both ends of the lamp circuit are connected to the trolley wire, and in the second case both ends of the switch wire are connected to ground, and the trolley connecting wires at each box are left disconnected at terminal No. *2*.

27. Fig. 12 shows a common form of signal box. It has two parts, an open part for the white lamps and a closed part for the red ones. The white lamps are on top and outside, but are protected by a hood and wire cage (not shown), and the lamp sockets are of the waterproof type. In the door and two sides of the closed part of the box are glass windows. If the lamps within have red globes, the glass may be uncolored.

The signal boxes are kept locked and every inspector has a key. Inside of every box is kept an extra lamp or two to replace, without delay, any that may burn out or otherwise become inoperative. The trolley and ground contacts of the two-way switches should be at least 7 inches apart, to minimize the probability of a short circuit by arcing. The closed part of the signal box need have no lining except a coat of thick shellac from the bottom of a shellac pot. The switch handle extends through an opening in the bottom of the box; the handle must always be either at the extreme right or the extreme left end of its travel when the signal system is in service—never in an intermediate position, because this would rob one box of its trolley connection and the other box of its ground connection, thereby rendering that particular section of the signal system entirely inoperative.

28. **Operation.**—Suppose that, on reaching the No. *1* signal box, the crew finds all lights out. This means either that a fault is rendering the system inoperative, or that the blades of both switches are resting on contacts of the same polarity; that is, both are either on trolley or on ground points. In the event of the latter condition existing, it means that a car bound in the same direction as the car under consideration has passed out of the block at the other end, or that a car recently passed on a siding and bound in the opposite direction has passed off the block at the approaching end; in either case the lamps have been extinguished by the conductor to clear the stretch of track for the next car.

Finding all lamps extinguished and the block apparently clear, the conductor of the car at the No. *1* box throws the switch blade to the opposite side of the signal box. If, before the switch was thrown, the No. *1* switch blade rested on the No. *2*, or left-hand, side of the No. *1* signal box, the switch blade in the No. *2* box at the other end of the stretch of single track must rest on the No. *2*, or right-hand, side of the box; otherwise the lamps would light. On throwing the No. *1* switch blade to the opposite side of the No. *1* box, this box shows two red lights, but the box at the other end shows but one red light and two white ones.

No matter what may be the position of the two switch blades, if the lights are extinguished and their extinguishment is not due to a fault, throwing either of the blades to the opposite side of the signal box will light a red lamp at both ends of the block. In the absence of instructions to the contrary, a car must not pass a red light to enter a block. When the conductor throws the switch, lighting the signals at both ends of the block, his car has the right of way through the block and no car may enter either end until the block is cleared. On arriving at the next siding, or stretch of double track, the conductor must again throw the switch, thereby extinguishing all lights and clearing the block so that a car may enter at either end.

29. The next stretch of single track constitutes a second block protected by two more signal boxes. Before entering any block that is clear, the conductor must block other cars by throwing the switch; and on leaving the block at the other end, he must throw the switch at that end to *clear* the block for other cars. Naturally, time tables are so arranged that cars meet at a siding as nearly as possible simultaneously, so that delay at signal boxes may be avoided.

As far as closing the block to other cars is concerned, by the arrangement described, all the lamps might be of the same color, because "lights" (the lighted lamps) block both ends of the single track, and "no lights" (the unlighted lamps) open both ends, if the system is in good order. The red and white lights, however, have the advantage of not being readily mistaken for lights from other sources.

30. Precautions.—The most likely sources of trouble in such a signal system are open circuits, caused by loose connections, broken wires, and broken or burned-out filaments. Such failures can be rendered much less frequent by using flexible wire for all connections and soldering all joints. The signal boxes should be supported on independent posts, so that the connections may not be subjected to line vibrations. The inside of all signal boxes should be inspected occasionally, and any lamps burned out or loose in their sockets should be replaced or adjusted; the lamp fuses must be kept intact, and the switch blades must not be allowed to get loose enough to be jarred out of contact. Since unlighted lamps are accepted as an indication of a clear track, it is extremely important that the system should be kept free from open circuit. A conductor can readily tell if the clear-track signal is due to the position of the switches or to an open circuit. In each case, before entering a block that shows clear, move the switch to the other side for a moment, and then back again. If the lamps light when the position of the switch is changed, it shows that the "no light" or clear-track signal was due to the position of the switch blades and not to a fault. If the lamps will not light in either position, there must be trouble, and the conductor must be governed by the local rules covering such a condition.

AUTOMATIC BLOCK SIGNAL

31. The automatic block-signal system now to be described is the one installed on the elevated railroad in Boston, Massachusetts, and is adaptable to any double-track service where expense of installation is secondary to safety. The system is unique in that one line of rail of each track is reserved for signal-circuit purposes, and is divided into insulated sections or blocks. The remaining line of rail of each track serves as a ground return for the train-operating currents, in the usual way, the track rails being bonded together and to the steel elevated structure at frequent intervals to increase the current capacity of the return part of the circuit. The device of using one of the track rails as a signal-circuit conductor is much more practicable on an elevated railroad than it would be on a surface road, where there is no metal structure to be connected in parallel with the remaining return rail, and where the cross-ties, being embedded in earth, cannot be relied on as signal-circuit insulators as well as those on an elevated road. Great care is taken to prevent any electrical communication between the signal-track rail and the ground-return track rail, except in so far as they may be connected through conductors necessary to the signal system. Insulation separators are used at switches, crossings, and any other places where the two track rails would ordinarily be connected. The bonds between abutting ground-return track rails and the bonds to the structure must be substantially installed and properly maintained.

32. The signal system itself comprises a combination of electrical and compressed-air apparatus. A 100-volt

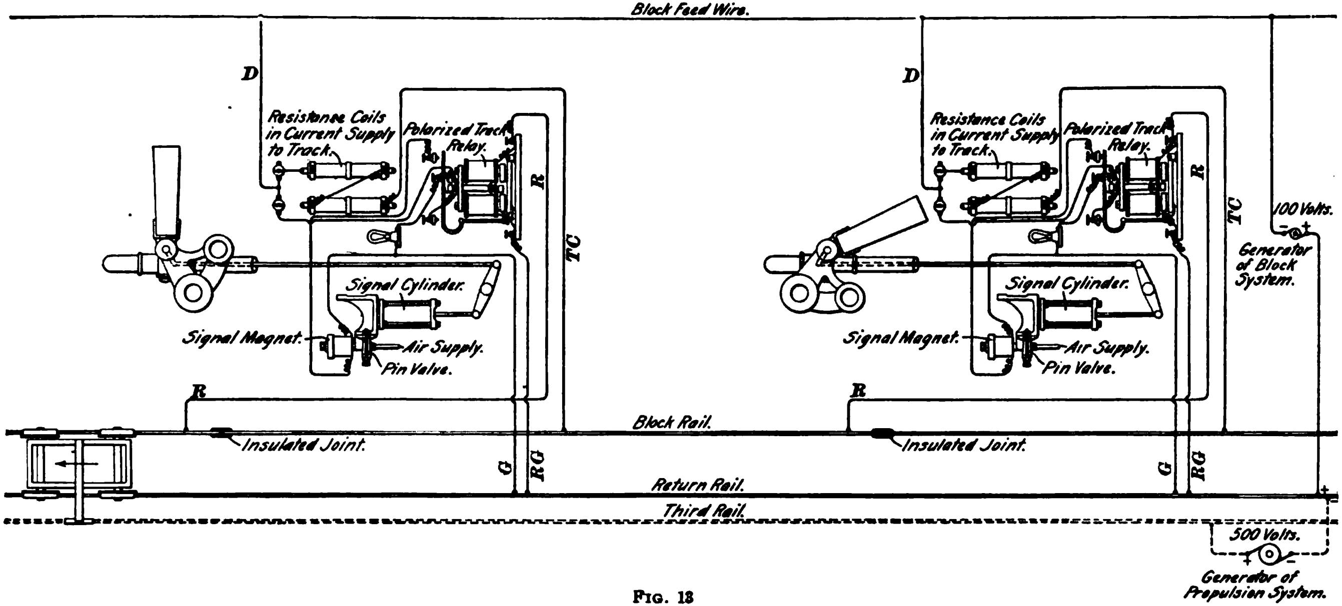

Block Feed Wire.
D
Resistance Coils in Current Supply to Track.
Polarized Track Relay.
R
TC
Signal Cylinder.
Signal Magnet.
Air Supply.
Pin Valve.
R
Block Rail.
Insulated Joint.
G
RG
Return Rail.
Third Rail.
D
Resistance Coils in Current Supply to Track.
Polarized Track Relay.
R
TC
100 Volts.
Generator of Block System.
Signal Cylinder.
Signal Magnet.
Air Supply.
Pin Valve.
R
Insulated Joint.
G
RG
500 Volts.
Generator of Propulsion System.

FIG. 13

motor-generator, driven from the railway power circuit, furnishes the current for the signal devices that operate the air valves controlling the admission of compressed air to the signal cylinders and the exhaustion of the compressed air from them. The electrically controlled air cylinders automatically operate the semaphores (railroad signals) and dependent safety devices. Since the signal-current supply is primarily dependent on the same generators as the train-current supply, when the line is dead the signal service is dead also, so far as indicating safety is concerned.

The supply of compressed air for operating the semaphores and dependent devices is obtained from motor-driven air compressors located at terminal stations, and is delivered to the pneumatic operating cylinders by a pipe line extending the full length of the elevated structure.

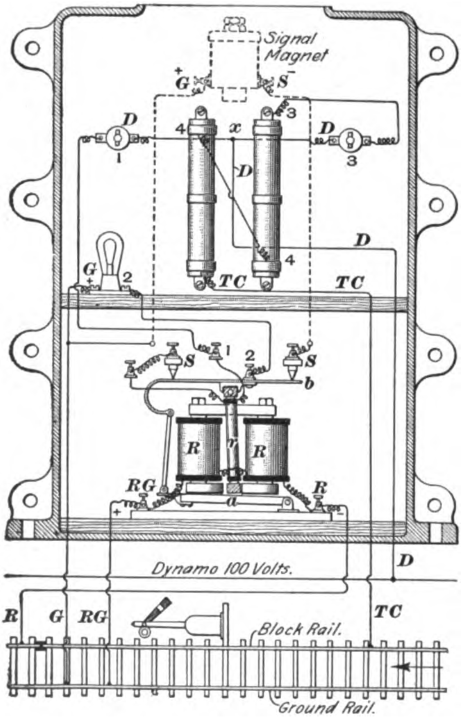


FIG. 14

33. Description and Operation.—The general connections and principles of operation can be understood by the aid of Figs. 13 and 14. Fig. 13 shows the scheme of track circuits for a complete signal section or block; Fig. 14 shows more clearly the connections within one of the signal-operating boxes. In Fig. 13, the 100-volt signal dynamo is shown connected between the ground-return rail on one side and the supply wire, or ***block***

feed-wire, on the other side. The block feed-wire extends the full length of the system, a tap connecting it to each operating box, as indicated at *D* in Figs. 13 and 14.

Fig. 14 shows that tap *D* connects to the stretch of circuit *D–D–D–x–D*–switch *3–3*–resistance coil–*4–4*–resistance coil–*T C–T C–T C*–block-signal track rail. Each resistance coil has a resistance of 100 ohms, the two coils in series, therefore, provide a total resistance of 200 ohms. The block feed-wire, or signal-current supply wire, then, taps to the block track rail at each signal-operating box through a resistance of 200 ohms.

34. The two electromagnets *R*, *R* at the bottom of the signal box constitute what is called a *relay*. When coils *R*, *R* are energized, they attract their armature *a* up to the position shown in Fig. 14, thereby causing the attached spring contact maker *b* to touch contacts *S*, *S* and close the circuit of which contacts *S*, *S* are a part. Beginning at tap *x*, near the top of the two resistance coils, the path to the right leads through snap switch *3* and the two resistance coils to the block rail. The path to the left leads through snap switch *1*–post *1*–swinging electromagnet *r*–the left-hand post –contact *S*–spring contact maker *b* (provided it touches contacts *S*, *S*)–contact *S* on the right–signal magnet (by way of the dotted path)–track–ground rail.

When the signal magnet gets current, which it cannot get unless relay magnets *R*, *R* are energized so that spring contact maker *b* closes the signal-magnet circuit between contacts *S*, *S*, the signal magnet opens a valve that admits compressed air into the operating cylinder of the semaphore, thereby causing the semaphore to set at clear or safety.

Figs. 13 and 14 will be considered now in order to determine under what conditions the relay operates to close the signal-magnet circuit and thereby keep the semaphore at safety. In Fig. 14, coils *R*, *R* of the relay are in series and are permanently connected between the ground rail and the block rail, of the section or block to be protected, by way of the path, ground rail–*R G–R G–R–R–R–R*–block track rail.

Assuming that there is no train on the complete block shown in Fig. 13, the semaphore to the rear of the block, the one indicated near the right-hand box in Fig. 13, will be at *safety*. The signal to the rear of the block to be protected has its relay coils connected across the block rail and track ground-return rails of that block; and the signal at the forward end of the block, Fig. 13, also has a permanent connection between the block feed-wire and block rail. As long as there is no train in the block, current from the return rail flows through the relay coils of the rear signal box, along the block rail, through the resistance coils of the forward signal box to the block feed-wire, thereby keeping the armature of the relay in the rear signal box in its upper position, where spring contact *b*, Fig. 14, keeps the signal-magnet circuit closed. This, in turn, keeps open the air valve that admits the compressed air to the control cylinder that is effective in keeping the semaphore and its connections set to safety.

The instant that a train enters the block, thereby short-circuiting the relay coils by connecting the block and track ground rail by means of the car wheels and axles, the armature of the relay drops, pulling down spring contact arm *b*, Fig. 14, and opening the circuit of the signal magnet, so that the magnet can no longer hold open the valve that controls the admission of air to the cylinder that retains the semaphore and its attachments at safety. Accordingly, the instant a train enters the block the semaphore at the entrance of the block goes to danger.

For example, in Fig. 13, a car or train has passed off the complete block and has just entered the block to the left on which a car is indicated. The instant the train passed off the complete block, the short circuit being removed from the relay coils of the rear signal, the semaphore at that end at once went to clear. Simultaneously, however, the block and track rails of the next section—the section on which the train is indicated in Fig. 13—being short-circuited by the axles of the train, and the relay of the signal box at the entrance to that block becoming dead, its dependent semaphore at once moves to danger.

In any given signal box, the current that energizes the relay coils in that box and keeps the signal-magnet circuit closed and the semaphore at safety when there is no train in the section, is due to the block feed-wire connection of the signal box at the beginning of the next block. That stretch of circuit that connects the block feed-wire to the block rail at every signal box and includes the two 100-ohm resistance coils always carries current, because when the circuit to the track rail is not completed by a train on the block, it is completed by the relay coils of the next signal box.

35. The signal magnet, then, can get current only when there is no train in the block, because only then are the relay coils energized, so that they can pick up their armature and cause spring contact *b* to close the signal-magnet circuit. So long as the signal magnet is energized, it holds open a valve that admits compressed air to the live side of the semaphore piston, which pushes the semaphore to the clear, or safety, position. As soon as the entrance of a train to a block short-circuits the relay of the protecting signal box, thereby opening its signal-magnet circuit, a valve opens, releasing the air and permitting the semaphore to move to danger. The semaphores are held to safety by air admitted by the signal magnet, and fall to danger as soon as the air is allowed to escape.

36. Features of Safety.—In Fig. 14, *r* is a swinging electromagnet, the winding of which is connected in series with the signal magnet. The passage of current through the winding gives its pole piece at the lower end a well-defined polarity. This pole is attracted to the poles of the relay magnets *R*, *R*, and ordinarily the relative polarity of the relay magnets and swinging magnet is such that the swinging magnet takes up the position shown in Fig. 14, where its pole is attracted to the right-hand relay-magnet pole. In Fig. 13, the third rail, or the contact rail from which the trains derive their motive power, is connected to the positive side of the power station. The contact rail is thus positive. The negative side of the power-station generator is connected to the ground-return rail. The positive side of the 100-volt dynamo that supplies the current for the signal system is, however, connected to the ground-return rail, while its negative side is connected to the block feed-wire.

Suppose that a train entering the complete block, Fig. 13, should run on ice or sand on the ground-return rail, but not on the block rail, so that the relay coils *R*, *R*, Fig. 14, are not short-circuited by the axles, and the coils still take current with which to keep the signal-magnet circuit closed and the semaphores at clear. Under such a condition (Figs. 13 and 14), when the power is applied to the train in the block, current, instead of entering the temporarily insulated ground-return track rail after having passed through the car motors, follows the block rail to the relay, and passes through the relay in the opposite direction to that ordinarily taken by the current from the 100-volt signal circuit. The reversed current reverses the polarity of the relay stationary pole pieces, while the polarity of the swinging pole piece, which is energized from the 100-volt dynamo, is the same as before.

The result of this is that, although the reverse current does actually operate the relay and tend to energize the signal-magnet circuit and keep the semaphore to clear with a train in the block, such a dangerous condition cannot actually happen, because the reversal of polarity of the relay magnets *R*, *R* causes the swinging pole pieces of *r* to move over to the left-hand relay pole piece, thereby springing contact maker *b* away from right-hand contact post *S*, which leads to the signal magnet. The signal-magnet circuit is now open and the semaphore is set at danger.

As soon as the left-hand movement of the swinging pole piece causes spring contact *b* to spring away from the right-hand contact post *S* and open the signal-magnet circuit, the current that ordinarily passes through the signal magnet now passes through the lamp by way of post *2* mounted on spring contact maker *b*. Were no lamp or its equivalent provided to bridge the open circuit in the signal-magnet circuit, all current flow through swinging magnet *r* would cease, its pole piece would become weak, and its attraction for the relay pole piece would not be sufficiently strong to hold the signal-magnet circuit open and the signal at danger.

37. From the fact that the current passed through swinging coil *r* gives well-defined polarity to its pole piece, the device as a whole is known as a **polarized relay.** Should the polarized member of the relay be omitted, and a train happen to run into the block when there is ice or sand on the ground-return rail, as soon as the power is applied the relay will be operated by the reverse current, and the semaphore will be kept at safety. Again, should the signal-service dynamo and the power-station dynamo both have their negative ends grounded, the polarity of the stationary-relay pole pieces will be the same, whether excited from the 500-volt railway current or from the 100-volt signal current, and therefore there will be no agent tending to pull swinging magnet *r* to the opposite side, as just described. The connection of the block-signal dynamo, therefore, must be as indicated in order to realize the benefits of a polarized relay.

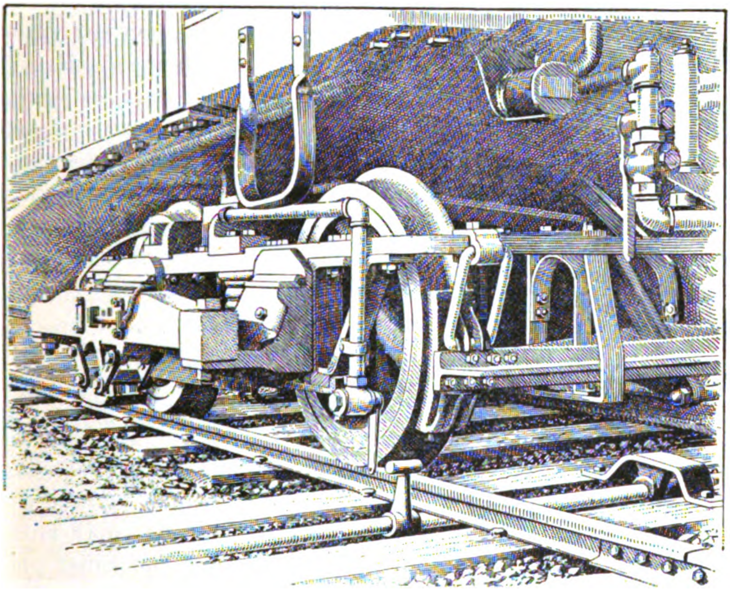


FIG. 15

38. Automatic Train Stop.—Fig. 15 shows the device for automatically stopping a train that, through the carelessness, indisposition, or sudden death of its motorman, runs past a semaphore set to danger. The same piston that operates the semaphore operates the **automatic train-stop** device. The operation of both is substantially as follows: As soon as a train runs on to a block and short-circuits the main relay coils, the signal-magnet circuit, thereby rendered temporarily inoperative, can no longer hold open the valve that admits air to the control cylinder, which then exhausts its air into the atmosphere, allowing gravity to set the semaphore to danger. Simultaneously, a tripping arm is raised near the track rail, as indicated in Fig. 15. Should the train for any reason run into a block, the semaphore of which is set at danger, the raised track trip arm will engage the downward projecting handle of an emergency air-brake valve and set the brakes, thus automatically stopping the train.

ABSOLUTE AND PERMISSIVE BLOCKING

39. Absolute blocking means that no car under any circumstances is allowed to enter a block, or section, the signal of which is set at danger. **Permissive blocking** means that, subject to certain conditions, usually including a time limit fixed by the operating company, a car may enter a block of which the signal is set at danger, but must proceed with great caution.

40. The strong feature of an absolute block system is that, so long as the system is in good working order, the danger of collision is at its minimum. But even when a first-class system is installed, absolute protection against collision is not realized. Assume, for example, that a motorman operating an automatic air-braked train should drop dead while approaching, on a down grade, a block whose signal shows danger. The train would continue down the grade and run past the danger signal, and the automatic train stop would operate to apply the brake; but if the triple valve on the automatic air-braked train should stick, or a brake rod snap—and such things do happen—there would be nothing to prevent collision with the car ahead. Of course, these assumed conditions are mere possibilities where efficient inspection is maintained; but where human lives are at stake, however, it is the growing tendency to regard even remote possibilities as probabilities, and to take all reasonable precautions to prevent their occurrence.

The only absolute method of providing against collision under all conditions is a liberal use of derailing switches, terminal derailing switches being automatically operated in conjunction with the danger signals. A **derailing switch** is a switch so disposed that under certain conditions a car will be led off the track. The derailing switches at the ends of a block are connected to the semaphore mechanism in such a manner that when the semaphore is at danger the derailing switch is open and the main-line rail broken. A train, under control, approaching the block, may not enter it unless the semaphore shows a clear signal, because only then is the derailing switch closed and the main-line rail unbroken. Should a train or a car with defective brakes run past a semaphore set at danger (the automatic train stops could not, of course, operate the brakes), the car or train would be derailed.

The main objection to absolute blocking is that a crippled or derailed car stalled in a block may tie up the road for some time before the cause of the delay is located and removed. The probability of such a condition arising on a double-track road, however, is small, because trains operated in opposite directions are controlled by independent systems of signals. Also, in most cases of train service, each train contains more than one motor car, so that the probabilities of entire helplessness are very much reduced.

41. Only on low-speed services, in which the blocks are very long, should permissive blocking be allowed. Even then, in the absence of any despatching system, auxiliary signals should be adopted, so that the last of several cars going through a block in the same direction may be the only one to clear the block on passing out.

42. A consideration of Fig. 13 suggests another remotely possible danger. Suppose that a west-bound train is in the position shown; it has just left the middle block, so that the semaphores are in the positions indicated, the receding block being clear, and the approaching block closed. Now suppose that the train that has just passed out of the block backs into the block again, touching the block rail at exactly the same instant as a second train entering the block at the rear end. The motorman of each train will naturally assume that the movement of the semaphore to danger is due to the contact made by his own train, and accordingly will suppose his train protected when in reality there are two trains on the same block with no warning of such a condition. The chances of such a complication are slight, but on single-track roads conductors of cars running in opposite directions have been known to operate the signals at almost the same instant.

TELEPHONE SIGNAL SYSTEM

43. The **telephone system** of directing the movement of cars is probably the most reliable manual system in use. It is especially adapted to interurban single-track roads. Generally, its operation is as follows: Telephones are installed in locked boxes at all sidings, spurs, and other meeting places. These telephones connect to a central station presided over by a despatcher, who starts all cars from the sheds or terminals by telephonic orders to the conductors, and appoints meeting places for cars traveling in opposite directions and designates the sidings where expresses shall pass locals. All orders received by a conductor are repeated back to the despatcher to minimize the chances of mistakes. The despatcher has before him a miniature reproduction of the road or division of which he is in charge.

As the arrival of a car is announced by its conductor over the telephone at the point of arrival, the despatcher moves a peg representing that car to a hole on the board representing the point from which the car has been reported. He then gives the conductor instructions as to where the next car must be met, or as to where he must lay over to allow an express or a special to pass him; he also gives the running time, or the time to be consumed in running to the designated place.

44. A conductor, on arriving at a designated meeting place, telephones the time and place of arrival to the despatcher who, as soon as conditions permit, gives him his **clearance** to proceed to the next meeting or passing place. Under no circumstances is a conductor allowed to run past a telephone without calling up the despatcher for orders. The conductor may be as well informed as the despatcher in regard to the running time and meeting places of regular cars in good order, but he cannot be posted on the movements of freight, mail, special, and crippled cars, and if he runs past a telephone station without reporting he does so at a great risk. On some roads, conductors are provided with portable telephones which, by means of a hooked contact fastened to a long pole, can be cut into the telephone line wire and communication established with the despatcher from any point along the road. This arrangement is very useful in case of a complete breakdown, which might otherwise cause an unnecessarily long delay to traffic.

MISCELLANEOUS SIGNALS

CAR SIGNAL BELLS

45. Fig. 16 is a diagram of the signal-bell connections on a car. The bells *M*, *M* are located under the two car hoods. An electric battery *V* consisting of two or more dry cells in series is installed in a protecting box located either above or below the car floor, according to whether the car is of the closed or open type. Contacts should be so arranged that the simple operation of inserting the cells in the box and closing its lid will automatically establish the connections necessary to render the battery active as soon as a push button *B* is pressed. Such an arrangement saves much time in changing cells, which should be done as soon as weak action of the bells indicates a weak battery. As the push buttons are all in parallel, a pressure on any button will cause the signal bells on both ends to ring. Any signal given by a passenger will attract the conductor's attention.

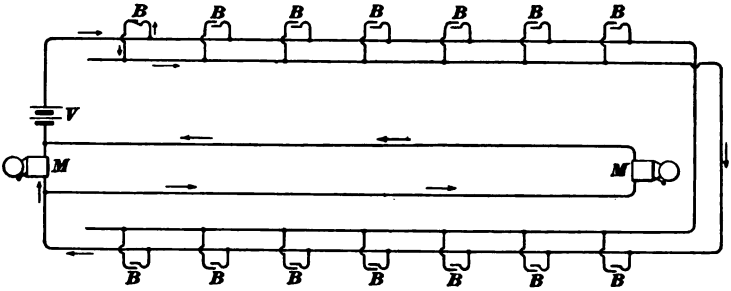


FIG. 16

The conductor, on ascertaining the passenger's wishes, transmits the proper signal to the motorman by pulling the regular bell rope.

46. A motorman is supposed to give the electric bell signal no attention further than to get his car under control in readiness for the regular signal from the conductor, because passengers are liable to give signals that are not only confusing, but dangerous, in that, unknown to them, some one may be getting on or off the car. On an open car that has no platform seats, or on a closed car that has cross-seats, there need not be as many push buttons as seats, because two inside seats face each other. On an open car that has platform seats, a push button is located between the end windows.

In the diagram, Fig. 16, are four wires running the full length of the car. As a rule, these wires are installed when the car body is built, it being then much easier to locate the vertical push-button taps in the posts. It is difficult to install a push-button system on a completed car without considerable expense. If it must be done, the two bell wires may be run over the car roof and the four battery wires in floor moldings, the push-button taps being run to the buttons in concealed grooves or molding. As the voltage is low and the circuit metallic return, ordinary bell wire may be used. Two of the long push-button wires and one bell wire can be dispensed with by grounding one side of every push button and the bells on the side farthest from the battery.

DOUBLE-CIRCUIT STARTERS' SIGNAL

47. Trolley voltage instead of battery voltage may be used on car signal-bell systems, but it is then necessary to use more expensive high-resistance bells, or an extra high resistance in series with the bells, to limit the current to a small value. In such cases, however, there is the objection that, in damp weather, a passenger is liable to get a shock when pressing a button.

On a starters' signal-bell circuit, however, a much louder, and hence heavier, bell is used, and it is then desirable to employ trolley voltage in conjunction with a lamp circuit to limit the signal current. Also, on such a circuit, as only two contact buttons or switches are used, there is much less liability to trouble from poor contacts, due to repeated arcing, than on a car bell circuit, where from twelve to twenty-four push buttons are required.

48. Suppose that surface cars and elevated trains make connections at certain intervals that are not very frequent during the non-rush hours; the elevated-train starter is on the elevated structure, and the surface-car starter is on the street. On account of the infrequency of the trains, it is desirable that either starter may be able to signal the other to hold a car or a train for passengers.

Perfect signal service can be established between the two starters by installing either a double- or a single-circuit signal system. Fig. 17 shows the connections of the double- or independent-circuit system. *T* is the elevated-railroad contact rail, and *t* the surface-railroad trolley wire. Switches *K* and *k*, or other forms of contact makers, are ordinarily held open, in the dotted position, by a spring or by gravity, and may be closed by hand pressure; *L* and *l* are two sets of five lamps in series; *M* and *m*, two solenoids containing iron plungers *O* and *o*, which ordinarily, from gravity, rest on metal gongs *N* and *n* beneath them. Both gong frames are grounded. One end of each solenoid is connected to its plunger, as indicated.

The circuit through which the surface starter signals the elevated starter is *t–k–l–m–o–n*–ground; that through which the elevated starter signals the surface starter is *T–K–L–M–O–N*–ground. To notify the elevated starter to hold a train,

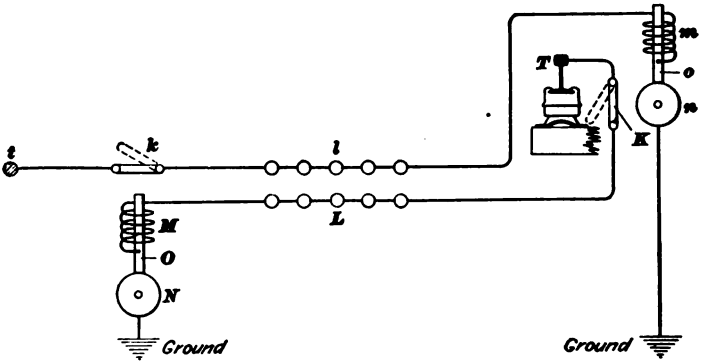


Fig. 17

the surface starter closes contact *k*, thereby energizing solenoid *m*, which immediately lifts its plunger *o*. The instant the plunger rises, however, it interrupts the signal circuit, and solenoid *m*, becoming dead, drops its plunger, which strikes the gong. In striking the gong, the plunger closes the circuit; the coil *m* is again magnetized, thus drawing up the plunger, opening the circuit and dropping the plunger against the gong, making another signal. The operation of the surface signal is exactly the same. In either case, the starters will be able to signal as many taps as they desire; in this way one starter can tell the other what train he wishes held.

SINGLE-CIRCUIT STARTERS' SIGNAL

49. The principle of the single-circuit starters' signal is exactly the same as that of the single-track manual signal previously described. Switch *k*, Fig. 18, has a trolley and a ground connection, and switch *K* has a third-rail and a ground connection. When both switch blades rest on the lower contacts, the signal circuit is dead. If both blades are in their upper positions, there is a small current flow through the lamps and bells, assuming that the electromotive force between the third rail and the ground is higher than that between the trolley wire and the ground. The electromotive force represented by the difference between these two values forces a small current through the high-resistance circuit; not enough, however, under ordinary conditions, to operate the bells.

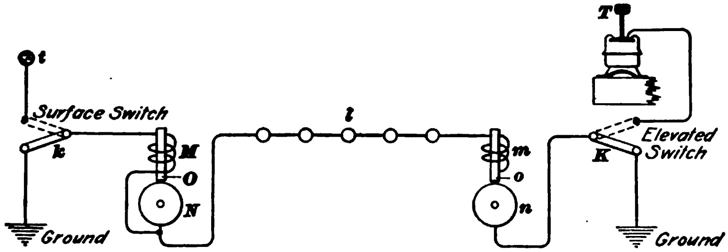


FIG. 18

For either starter to signal the other, he need but push the switch blade at his end over to the opposite contact. In this case, the solenoids *M* and *m* being connected in series, one bell rings when the other does, so that each starter can hear on his own bell the signal given on the distant bell. Only one of the bells need have the interrupting device; the other bell automatically opens and closes the circuit through both bells.

MECHANICAL INSTRUCTIONS

INTRODUCTION

1. General instructions are divisible into two classes: *mechanical instructions* and *operating instructions*. **Mechanical instructions** apply principally to employes that keep the cars in working condition. The operating instructions apply principally to employes that handle the cars when in service. The two classes cannot be kept rigidly apart, for the motormen, conductors, inspectors, and other employes are often called on to make slight repairs necessary to enable a car to proceed to its destination or, at least, to a siding. On the other hand, mechanical, or shop, employes must often go out on the road and render the assistance that operating employes are not equipped to give.

Mechanical instructions that apply to one electric-car system are often impracticable on another. For instance, on some roads, the same crew has charge of the same car practically all the time. On other roads, one car may be successively handled by several crews in the course of the working day. On some roads, cars operate from 10 minutes to 1 hour apart, so that, in case of trouble, the crew, if qualified to do so, can locate and correct troubles that could not be investigated and corrected were the headway short. For example, on lower Broadway in New York, where cars operate at intervals of from 15 to 25 seconds, and where much of the clearance between cars is taken up by vehicles of various kinds, practically the only thing to be done to a disabled car, except within limits to be defined, is to couple it to its follower and push it to the nearest turnout, siding, or barn, or to a section where traffic is less congested.

In such exceptional service, the duties of the crew are limited to the closing of a switch or breaker, the renewal of a fuse, the temporary hitching together of two wires to close an open circuit, which has become evident, or the cutting out of a motor by means of one of the cut-out switches. In extreme cases, to avoid a long delay, it is customary to derail a car and leave it at the side of the road until night, when it can be put in condition safely and without interference.

The points to be considered now concern the management and repair of car apparatus; and in order to avoid an incomplete treatment of the subject, faults previously discussed have been, in some cases, referred to again.

OPERATION UNDER SHORT HEADWAY

METALLIC-RETURN SYSTEM

LOSS OF CURRENT

2. Car Lamps Lighting.—In case no flash occurs in the controller when thrown on and off, turn on the lamp switches. If the lamps light, it means that they get current although the motors do not, and that therefore the open circuit must lie between the two points where the two ends of the lamp circuit tap the wires leading from the plow. The positive ends of the lamp circuits tap the positive conductor on the positive side of the positive ground switch or breaker, and the negative ends of the lamp circuits tap the negative conductor on the negative side of the negative ground switch or breaker. An open circuit in the stretch of circuit including the two ground switches or breakers, the two fuses (when such are used), and the two overhead switches or breakers can cut off current from the motor circuit without cutting it off from the lamp circuits. In such a case, look for a blown main fuse or an open breaker or ground switch that may have been jarred to the off-position. The position of the breaker handle shows whether it is on or off. If a breaker or switch is found open, close it. If a main fuse is burned out, renew it. As a rule, but one fuse or breaker will operate, but it is possible for both fuses or both breakers, or one fuse and one breaker, to operate; accordingly, when inspecting these devices, inspect them all, although an open circuit may have been found in the first one inspected.

3. Car Lamps Not Lighting.—On closing the lamp-circuit switch, should the lamps fail to light, one of three conditions is indicated: (1) The line may be temporarily dead; that is, some power-station safety device may have operated to cut off current from that particular section of road. (2) The lamp circuits themselves may be defective. (3) A plow lead may have pulled loose, or a shoe fuse burned out.

If the line is dead, no car on that particular section will move, nor will the lamps on any of those cars light. If, then, the lamps on any particular car fail to light, while those on other cars in the immediate vicinity do light, or if near-by cars operate in a normal manner, the trouble must be on the affected car and failure of its lamps to light must be due to a fault in the lamp circuits, or to a loose plow lead or blown shoe fuse. Where two lamp circuits are protected by the same switch and fuse, the fuse may be blown or the switch blade may fail to make contact. Where two lamp circuits are independent, the only fault that can affect the operation of both is a fault in each.

It is reasonable to assume, when neither lamp circuit will operate and no neighboring cars are moving, that the line is dead. The conductor rails are discontinued at curves, crossings, and section terminals; if a car stops with its shoes in one of these breaks, the lamps will not light and the car must be pushed forwards until the shoes again engage the conductor rails.

CAR RUNNING AWAY

4. Controller Drum Stuck.—It is possible for any controller drum to stick as a consequence of disorder in its notching gear, or of the welding of some finger to its corresponding drum tip by a heavy flash; but on a modern controller neither of these conditions is at all likely to arise. If, on moving the controller drum to an operating position, it sticks, so that it cannot be returned to the off-position, knock off the overhead switch. If there is no overhead switch or breaker on that end, and a crowded car cuts off communication with the conductor, apply the brake as hard as possible. This will increase the current to a value that will blow a fuse or a breaker.

5. Combination of Grounds.—If a motorman on a car equipped with a K8 controller finds that his car does not respond to the off-position of the controller and the usual application of the brake, he may know that faults exist on one conductor rail and at some point on the car wiring that allow at least one motor to take current when the controller is at off-position. Under such a condition, knock off the No. 2 breaker; if that breaker is not on the motorman's end of the car, and the conductor's attention cannot be attracted, set the brake as hard as possible so as to blow the fuses or breakers. As a final resort, pull the reverse handle back to off-position. Certain reverse-drum contacts are a part of the local circuit established by the two faults; the reverse drum and fingers are not designed to break a current, but this action may be taken in case of an emergency. With some of the later styles of controllers for metallic-return systems, both sides of the motor circuit are cut out when the controller is at off-position; hence, this runaway action can be stopped by the controller.

BRAKING BY REVERSAL OR BY MOTOR CURRENT

6. Line-Current Reversal.—To bring the car to a sudden stop, proceed as follows: Apply the brakes; set the reverse handle for the opposite direction of car motion;

simultaneously with the movement of the controller to the first or second notch, sand the rail and ease off the handbrake; keep on sanding the rail, easing off the brake and advancing the controller as fast as the reversing effect takes hold. The objections to fully releasing the brake on applying the reversed current are: If the brake is reducing the speed, no man is willing to dispense with that retarding force until he feels another taking hold; full release of the brake removes restraint from the wheels, and a too rapid increase of reversing current, caused by rapid notching, will spin the wheels backwards. Gradual release of brakes as reversing current is applied secures the effect of both the line-current reversal and the brakes, one increasing in intensity and the other decreasing, until the car actually begins to back. A precaution of great help under all conditions of reversal is to *keep sanding the rail until danger is passed.* Line-current reversal, however, is made impracticable by any open circuit that is common to both motors on all notches, or by the line being dead.

7. Motor-Current Braking.—In any case where line-current reversal is impracticable, the generative ability of the motors must be utilized, the manner of doing so depending on the equipment in hand. Unless there are provided special facilities for electric braking, it is necessary that a car should have at least two motors, in order that the generative ability of either may be available for stopping the car.

1. With *rheostatic control and two motors in parallel,* throw the power handle to the off-position and set the reverse handle for the opposite direction of motion to that of the present car motion. (This supposes that there is no device installed on the controller to prevent braking action, as is the case in some mining locomotive controllers.)

2. With *series-parallel control and two motors,* throw the power handle to the off-position and set the reverse handle for the opposite direction; then move the power handle to the first parallel notch.

3. With *four motors and either rheostatic or series-parallel control*, throw the power handle to the off-position and set the reverse handle for the opposite direction.

EXAMPLE 1.—A motorman operating a car equipped with two motors and rheostatic control, undertakes to effect a line reversal. The reverse handle is moved over for the opposite direction and the power handle is moved to an operating position; but he advances the power handle too fast, and thereby blows a fuse or a breaker, rendering line reversal impossible; what must he do?

SOLUTION.—Let everything remain as it is; the car will be braked by the generator action of one of the motors.

EXAMPLE 2.—A motorman operating a car equipped with four motors and either rheostatic or series-parallel control, has gone through the operations necessary for line reversal, but finds that the motors fail to reverse; what must be done?

SOLUTION.—Leave everything just as it is; the speed will be checked by the generator action of two of the motors.

EXAMPLE 3.—A motorman operating a car equipped with two motors and series-parallel control, finds, on taking the proper steps to secure a line reversal, that the reversal cannot be made; what must he do?

SOLUTION.—If the power handle is on a parallel notch, leave it there; but if it has not been advanced beyond a series-position, it must be advanced to a parallel notch before the generator action of either motor can become effective in checking the speed of the car.

EXAMPLE 4.—A motorman ascending a grade on a car equipped for two-motor series-parallel control, finds, on applying the brake to make a stop, that it will not hold, and the car begins to roll backwards down the grade; what must he do?

SOLUTION.—Leave the reverse handle in its former position (pointing forwards) and apply the power as usual. If the line is not dead, the line current will reverse the direction of rotation of the motors and start the car up the hill again. Under such conditions no stops should be made to take on or let off passengers. The car should be kept going until it reaches a level stretch of track, where it will stand without the assistance of either the line current or brakes. The brakes should then be temporarily repaired, or the following car should push the crippled car into the car barn.

EXAMPLE 5.—In example 4, the motorman, on trying to apply the power, finds that, because of some fault, the line current cannot reach the motors, and thus does not prevent the car from backing; what should be done?

SOLUTION.—Since, up to the time of throwing off power to stop, the current was urging the car up grade, the reverse handle must still point up grade; therefore, do not disturb it, but move the power handle to the first parallel notch to obtain the effect of motor-current braking.

8. General Remarks.—For emphasis, it may be stated, that on four-motor equipments, although not necessary, it is advisable to move the power handle to a parallel notch after the reverse handle has been moved to the proper position; this will avoid confusion where two-motor and four-motor equipments are operated on the same road. The purpose in not moving the controller past the first parallel notch is to lessen the tendency to blow a fuse or a breaker if the power should return during motor generation (supposing that the overhead switch has not been opened). The fuse and breakers are not in the local motor-braking circuit, but are in the circuit through which trolley current reaches the motors, and this trolley current will be much less if the controller is on a parallel-resistance notch than if on the parallel-running notch.

When controlling a car on a down grade by means of the line reverse, the brake being out of order, the reversed current should be applied every 20 to 100 feet, according to the grade. If the speed is being controlled by motor-current braking, the car cannot be stopped by this agency alone, for stopping would stop generation and the car would roll on again. A car restrained by generation alone will descend a grade slowly enough to be stopped by putting a block of wood or a stone under a wheel. At the top of a long grade it is well to hold the faulty car until its follower arrives. Then connect the cars and proceed carefully down the hill, using the brake on the good car. On approaching long grades, it is sometimes well to throw off the power and pull the reverse handle back, to be ready for reversal, should occasion arise. This precaution is practicable on two-motor series-parallel equipments; but on most four-motor equipments it is not, because the pulling back of the reverse switch for the opposite direction qualifies the motors to act as generators. In case the power drum and reverse switch are in proper position for motor-current braking, as soon as the car speed reaches a value necessary for the motors to pick up, the more powerful ones will do so, and the motor-braking action will reduce the speed to a low value.

GROUNDS

9. Cut-Out Switches Ineffective.—If a ground occurs on a car while it is on a section having one of its conductor rails grounded, and the cut-out switches will not correct the trouble, leave the circuit-breakers open and have the car pushed by the following car to a section with conductor rails free from grounds; or, if necessary, pushed to the car barn.

10. Cut-Out Switches Effective.—Where smoke or some other indication of burning designates the ground as a motor ground, and headway permits such procedure, cut the motors out, one at a time, and try the car. Instructions for the operation of cut-out switches in the controllers are generally pasted inside the controller door. Should they be missing or unreadable, proceed as follows: Push one cut-out switch up or to the left (according to the type) as far as it will go and try the car; should it operate normally, close the door and run on one motor to the nearest relief point. If, however, after having cut out one motor or, on a four-motor car, one pair of motors, the car fails to operate normally, the wrong motor or pair may have been cut out. Accordingly, restore the first switch tried to normal position and move the other one up or to the left; then try to operate the car. A car should never be tried with both cut-out switches up or to the left, as the starting coil is likely to be burned out. Always cut in the first switch (down or to the right) before cutting out the other (up or to the left).

GROUND-RETURN SYSTEM

LOSS OF CURRENT

11. Line Dead.—In case of the power being off the line, lamp circuits in good order will give the same symptoms as on a metallic-return system, and no other car fed by the same feeder will be able to operate. While waiting for the power to return, the lamp switches should be turned on so that the returning glow of the lamps will indicate the presence of current, and a controller should be thrown on and off at intervals to preclude the possibility of being misled by a defective lamp circuit. Under no circumstances should a motorman put the controller on the first notch, seat himself inside the car, and await its starting as a sign of the return of power. This rule applies to any and all systems.

12. Open Circuits.—Assuming that the line is alive and that the lamp circuits on the affected car are in order, failure of the lamps to burn and of the motor circuit to take current must be due to an open circuit common to both. Such an open circuit may be due to the trolley wheel being off the wire or resting on ice or a line breaker, to a broken or loose ground connection, to dust or sand on the rails, or to dead rails. See that the trolley wheel does not rest on a line breaker. If it does, swing the pole and touch the wheel to the wire long enough to kick the car clear of the breaker; then restore the pole to its former position and be ready for the proper signal.

Should a car get stuck on account of ice on the wire, conditions are serious, unless the wheel is of the ice-cutting type or the ice is local only. Wheels of the ice-cutting type, called **sleet wheels**, are generally provided when ice is expected. In the absence of a sleet wheel, the trolley wheel must be removed entirely, allowing the wire to slide in the harp crotch, which will then act as a scraper and clean the wire.

On some roads, harps are used altogether instead of sleet wheels. To start, it may be necessary to scrape the ice off for about 2 feet; after the car gets started, the arc formed between the wire and the harp contributes to the cleaning of the wire. Care must be taken at switches and crossings to prevent the harp from catching, as the forks of the harp project considerably above the level of the trolley wire.

13. The loose connections most likely to affect both the lamp and motor circuits are due to the roof wire breaking or pulling loose from the trolley stand, or to the car ground wire becoming loose. A broken or loose roof wire is revealed by inspection or by working the wire up and down by hand to ascertain whether or not the wire is broken inside the insulation. If the roof wire is too short to permit hooking it around the connector, or twisting its skinned ends together, twist a couple of fuse wires to each end and then twist the fuse wires together. On modern equipments the probability of an open-circuited ground wire rendering both motor and lamp circuits dead is small, because the lamp circuit taps the car ground wire, which is flexibly connected to both motor frames. Only faulty inspection will allow both motor ground taps to become defective. Defective ground taps can be detected by sight and by trying with the hand the wires secured under the motor-frame bolts.

Occasionally, on a ground-return system, a car previously operating in good order fails to start after a regular stop, and the first serious intimation of its condition is that a passenger gets a shock while stepping on or off. Such a condition is generally caused by dust on the rail, but can be caused in damp weather by an accumulation of sand applied by the motormen to secure prompt starts and stops at slippery places. From habit, they sand such places after it has ceased to be necessary, and the rails become coated with crushed sand that will not conduct current well. Sufficient current may get through to light the lamps, but not to operate the motors. Sand or dust insulates the wheels from the rails, and any one standing on the ground will be shocked on touching any car or truck part that is ordinarily grounded, because current passes through the lamp or heater circuit to the car ground wire, thence through the motor frames, axles, wheels, brake rigging, dash irons, grab handles, stanchions or gates, and through the human body to the ground.

A car may not take sufficient current to start on dust or sand, but it will keep going when once started, because the wheels drag arcs that cut through the dust or sand, and the low resistance of the arcs passes sufficient current to keep the car under headway.

Cars stalled on dust or sand can be started as follows: Throw off the lamp and heater switches and one or both hood switches, according as they are in series or parallel; lay the edge of the switch iron flat on the rail 6 inches behind a car wheel and slide it back and forth, slicing off the dirt or sand clear up to the wheel; keeping the iron pressed down on the rail, jam it between the rail and wheel, or let the conductor do it; then close the switch or breaker and start the car. Keeping the iron jammed firmly down on the rail, follow the wheel a couple of feet. Should it be necessary to throw off the power before reaching clean rail, the operations must be repeated. If the operator always keeps the switch iron jammed down on the rail, he can get no shock, but should the iron touch the wheel alone, a shock is certain, unless the hands are protected by dry gloves or their equivalent, or the ground beside the rails is dry. Sweaty gloves will conduct a current as readily as those made wet by rain or snow.

Motormen generally refer to a car stuck on sand or dust as being *grounded;* the trouble is that the car is not grounded, and the object of pushing the switch iron between the rail and the wheel is to ground it. As a rule, sand gives trouble only on single-track roads, where it is dropped by cars running in both directions and therefore both rails are sanded.

14. Classification of Open Circuits.—A motorman can ascertain whether an open circuit is so located as to disable both motors, and whether operation of the motor cut-out switches will do any good, by advancing the controller handle to a parallel notch. As long as the motors are in series, an open circuit anywhere in the motor circuit will kill both motors. As soon as the power handle reaches a parallel notch, however, where each motor has an independent path, the motor whose circuit is not impaired will work. Therefore, if advancement of the handle to a parallel notch causes one motor to work, find out, by looking at the car wheels when the power handle is thrown over, which motor is not working; then cut it out with its cut-out switch.

15. Dead Rail.—A dead rail is a rail with its bond wires broken, so that there is no electrical connection between it and abutting rails. If a car stops on a dead rail, it cannot start, because the dead rail opens the circuit. To close the circuit, run a switch iron down in the joint between the dead rail and one of the abutting rails. In modern trackwork, a dead rail is of rare occurrence, because all rails have cross or zigzag bonding in addition to the joint bonding.

CAR RUNNING AWAY

16. Stuck Drum.—The only condition under which a ground-return car can run away on a level track is when the controller sticks on an operating position. On old-time controllers, this sometimes happened as a result of heavy arcing and faulty design of the fingers; but on modern controllers such a condition is not likely to arise.

Should a drum stick on an operating position, throw off a hood switch or breaker and apply the brake. In case operation of the breaker on one end has failed to open the circuit, owing to a breaker on the rear end being in parallel with it, the excessive current caused by braking the car may blow the rear circuit-breaker and interrupt the current.

BRAKING BY REVERSAL OR BY MOTOR CURRENT

17. The precautions to be observed when resorting to reversal or generation are the same as those considered in connection with a metallic return car. In reversing, advance the controller gradually. In generating, advance the controller to a parallel notch. In both cases see that the reverse handle points in the opposite direction to the motion of the car.

GROUNDS

18. General Remarks.—A single ground fault affects operation because one end of the motor circuit, usually the No. 2 field, is grounded to the motor frame and the two grounds form a shunt that cuts out part of the motor circuit. The extent to which a ground fault affects operation, and the possibility of cutting it out, depends on its location. There is little probability of a ground on car-roof devices, they being so far removed from the grounded parts. The liability of such parts to ground is limited to lines that pass underneath metal structures, such as elevated-railroad structures, steel bridges, steel-braced culverts, or structural-steel car houses. With such surroundings, trouble is sometimes caused by the trolley getting off the wire, with the side of the pole bearing against the wire, and the wheel in contact with a grounded part of the structure. In such cases a short circuit occurs, accompanied by much display but little harm, beyond burning the parts that were in active contact. To prevent short circuits, the overhead wire in such exposed places is installed in inverted wooden troughs. The current through such a fault is generally large enough to operate a station breaker, but reaches none of the car control or safety devices, because from the trolley it passes through part of the pole directly to ground. To reach a ground fault anywhere else on the car, the current must pass through one or two switches or breakers, according to their connection, and the fuse. If the breakers are in series, one or both will operate; if in parallel and both happen to be closed, the main fuse may blow before both breakers operate. The fuse alone must be depended on if switches are used instead of breakers.

19. Cut-Out Switches Ineffective.—If a fuse or breaker blows as soon as the wheel touches the wire, or on placing a controller on the first notch, it is probable that the ground is so located that it cannot be cut out by either of the cut-out switches. If there is no time to see whether a brake rod is rubbing the starting coil, or whether the lightning arrester is short-circuited, and to correct such a fault, the only resource is to tie down the pole and be pushed to a relief station.

20. Cut-Out Switches Effective.—If the fuse or breaker does not act until the controller handle has been moved over the first few notches, it is probable that the fault can be cut out by one of the cut-out switches. The motors should be tried, one at a time, in order to ascertain which is the defective motor, and the car then run in on the good motor.

CHARGED PARTS

21. Charged Controller.—When simultaneous contact with any part of the controller and the car step, platform, or brake handle gives a shock, the controller is charged. To become charged, some high-voltage controller part must be accidentally connected to the controller frame or shaft, and the frame must be at least partly insulated from the ground. If the controller frame is connected to the truck rigging, it cannot be charged, because any connection to a high-voltage controller part would burn itself out at once. Most controller frames are grounded through the dash rail, brake, and truck rigging. If this connection becomes defective, so that it conducts current very poorly, copper dust, moisture, or defective insulation in the controller may charge the frame. The high resistance of the ground connection would prevent any short circuit. On all General Electric ground-return controllers, the ground connecting post that takes the car ground wire is connected to the frame, and a person in contact with some other grounded part and touching the controller frame can get no shock, because the controller frame and the person are both connected to the ground.

When an internally grounded controller becomes charged, the charge can generally be removed by improving the controller and motor ground connections, that is, by tightening the bolts and screws that hold them. Where a controller that depends entirely on the dash rail for support becomes charged, the charge can often be removed by tightening the angle-iron bolts that hold the frame to the dash rail. Where a controller that has no frame ground connection at all becomes charged, or where tightening the angle-iron bolts in the above case proves ineffective, the charge can be temporarily removed by connecting the controller ground connecting post to its frame with a small wire. First, however, the trolley should be pulled down and the breaker closed; and the trolley should not be replaced until the connection is complete, because, should the internal trouble be a short circuit or a defect easily developed into one, the temporary connection will blow like a fuse and possibly burn the operator. If, on replacing the trolley after making the connection, the temporary wire does blow, or the overhead breaker operates, it means that the fault that causes the charging is so serious that it should be attended to by the repairmen at the car barn. Under such circumstances, passengers should not be allowed to enter or leave at the faulty end of the car.

On a dry day, the motorman will have no serious trouble in avoiding shocks, if he confines his hand to the wooden knob on the power handle, keeps his feet off iron bolts running through the car floor, and, as far as possible, avoids holding the brake and power handles at the same time. On a wet day, gloves are necessary; if the conductor's gloves are not available for changing, the motorman should use his own gloves, one at a time, on his controller hand, the other glove being kept dry. Some motormen use the lower part of their rubber coats as a protection for the controller hand.

22. Charged Floors.—In wet weather, parts of a car floor may become charged, due, as a rule, to a live bolt head. Suppose, for example, that a starting-coil-hanger bolt head is flush with the floor line. Such bolts are insulated from the starting coil by insulating bushings, which occasionally become defective, allowing the bolt to touch the live coil. The bolt is then alive, and simultaneous contact with its head and a ground will cause a shock. In wet weather, umbrella drippings saturate the floor around the bolt head, and quite an area may become charged. Even though the bolt may not extend clear through the floor, water soaking through the floor may charge a small area. In either case, a grounded part within the charged area will permit a minute but steady current flow from the charged part to the grounded part. Any one standing in such a way as to span part of this high-resistance path is likely to get a shock. Damage suits have resulted from such conditions. A charged bolt and a grounded bolt or part, so disposed as to permit direct and simultaneous contact with both, will give a serious shock. In one case, a conductor reached from the platform to take a fare from a woman seated inside the car; the instant he touched the coin, both received a shock. The woman had one foot on a charged floor bolt, and a current passed successively through her, the coin, the conductor, and the wet platform to the ground.

23. Charged Fixtures.—Register riggings sometimes get charged by a bolt or screw extending through and cutting into a live wire in the bulkhead. Where the register is operated by cords or straps, passengers are little liable to shock, but the conductor is likely to get a shock when he turns the register back, unless he stands on a seat while doing it. Where, however, the register is operated by metal rods and pulls, the conductor is liable to a shock every time he rings up a fare. There are circumstances under which he can shock himself and a passenger from whom he is taking a fare. For example, if the rear platform is wet or has grounded bolts, on one of which a passenger is standing and the car floor is dry, or the conductor has on rubber shoes, on taking hold of the register pull, the conductor will get no shock; but if he retains his hold on the pull while taking a fare from a passenger standing on a grounded section of the platform, both will get a shock.

OPERATION UNDER LONG HEADWAY

INSPECTION AND TEST

24. Where a car that has been operating normally unexpectedly loses its power, an inspection will often reveal an irregularity no more serious than an open breaker, a blown fuse, or a displaced trolley wheel. Any one of these irregularities can be quickly remedied. Operating one of the cut-out switches may correct the trouble. If the trouble can be temporarily corrected without much trouble, it is well to do so, and then continue running the car, unless it is necessary to run it to the car barn for further repairs. If the trouble is serious enough, the faulty car may be pushed to the car barn by its follower.

The following articles will give an idea of how the less evident troubles are located, either in the car barn or on cars operating under long headway, where the locating of irregularities may devolve on the crew. A ground-return system will be assumed, because most systems are such, and all faults except grounds affect the operation of all systems in the same manner.

THE LAMP-TEST CIRCUIT

25. A lamp-test outfit is a convenient device for locating faults. It consists of five lamps mounted in keyless sockets on a paddle-shaped piece of wood and connected in series. From one side of the first and last sockets run two wires, called *test lines;* if the sockets have good lamps in them, and one test line is held on the trolley wire T and the other on the rail R, as in Fig. 1, the lamps

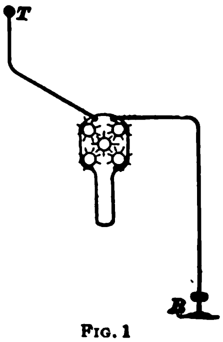


Fig. 1

will light, provided that every part of the circuit is in good order.

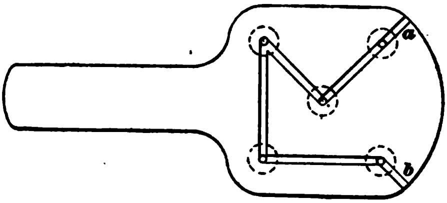


FIG. 2

26. Description.—The paddle can be made as follows: Take a piece of 14″ × ¾″ maple and shape it to hold five lamp sockets symmetrically disposed far enough apart for the globes to clear one another. Having located the sockets, bore a ¼-inch hole under the center of each and connect the holes by grooves to take the lamp cord for connecting the sockets in series. Install the sockets on the opposite side of the paddle from the grooves, as indicated by the dotted circles in Fig. 2. Connect the sockets in series by flexible cord run in the grooves. The test lines can be run directly from the positive side of the first lamp and the negative side of the last one, but it is preferable to install two connecting posts, as indicated at *c*, Fig. 3. The second post is directly behind *c*. One post connects to the wire in groove *a* and the other post to the wire in groove *b*, Fig. 2. The unconnected sides of the two end sockets are connected to these posts, to which the test lines also connect. This device avoids the possibility of an undue stress pulling the test line loose at the lamp socket. After the sockets are connected and the two end connections brought out, a piece of ¼-inch maple of the same shape as the paddle is screwed to the back to protect the connecting wires. The whole is then given a coat of thick shellac and allowed to dry, after which the end wires are soldered to the posts and the long, flexible, test leads attached. Each test lead must have a solid copper

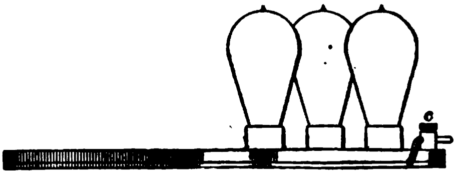


FIG. 3

point on its contact end. When not in use, the test leads are wound around the handle.

27. Precautions.—There are two precautions to be observed in using a test-lamp circuit: If it has been in use a long time, the test-line contact points become oxidized, and sometimes the current will not pass through them, so that, though the rest of the test circuit is in good order and the power on, the lamps will fail to burn when they should. To avoid such trouble, the contact points should be cleaned often with a piece of sandpaper or a file. The points generally give warning of poor condition by failing to make contact except when held in a certain position. The next thing to make sure of is that the contact points are properly held. When holding them on a commutator, if the points are sharp and clean, as they should be, it is easy to rest one point on mica instead of a copper bar, in which case the lamps will not burn. Do not rest the test point in any one place, but move it about until good contact is assured. Again, in holding the test points on the brass parts of motors or on parts of switchboards, it is easy and misleading to get the test point on some varnished or lacquered part. The test point should, if possible, be held on a part that is used as a surface contact. If this cannot be done, partly unscrew a screw and hold the point on the shank of the screw. Motors, rheostats, etc. often have their frames covered with asphaltum or other insulating compound; so, when using these parts as a ground, always be certain that you have a ground connection before doing any testing.

In tracing up a fault of any kind with a lamp circuit, hold the ground test line to a dead ground after each test, in order to insure by the lighting of the lamps that the lamp circuit is all right.

OPEN CIRCUITS

28. When a car fails to start on the first notch and there is no flash in the controller when it is thrown on and off, there is either an open circuit or the line is dead. The first thing to do is to fasten one test line to the trolley wire near the wheel, and then touch the other test line to one of the rails on which the car stands. If the lamps light, it shows that there is power on the line and that the car does not rest on a dead rail. If the lamps do not light, touch the ground test line to some abutting rail or a rail on another track; if the lamps light then, it proves that the car is standing on a dead rail. If, on touching the test line to other rails, the lamps still fail to light, the indications are that there is no power on the line. Before deciding on this, be certain that there is no local switch that cuts the power off the span of trolley wire under which the car stands.

The trolley wires in a car house are sometimes divided into sections controlled by switches placed outside the building. This is a wise precaution, especially where a shop motor is used, for then, when a thunder storm comes up, the shop-motor section can be cut out; or, in time of fire, the involved section can be cut out and the others used for running cars out of the house.

29. Assuming that the test satisfactorily indicates the presence of power on the line, throw a controller to parallel to see if both motors are affected on that end; assuming that they are, try the same thing on the other controller.

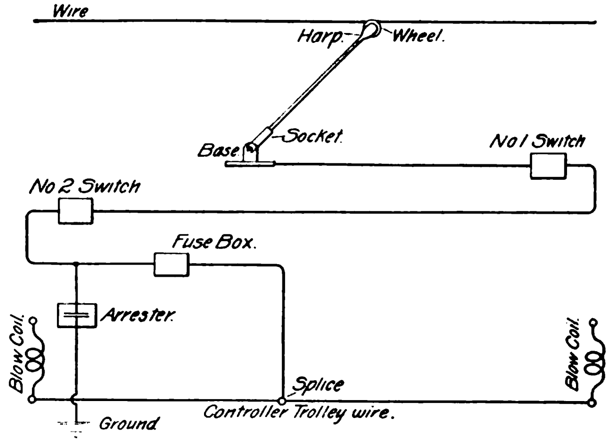
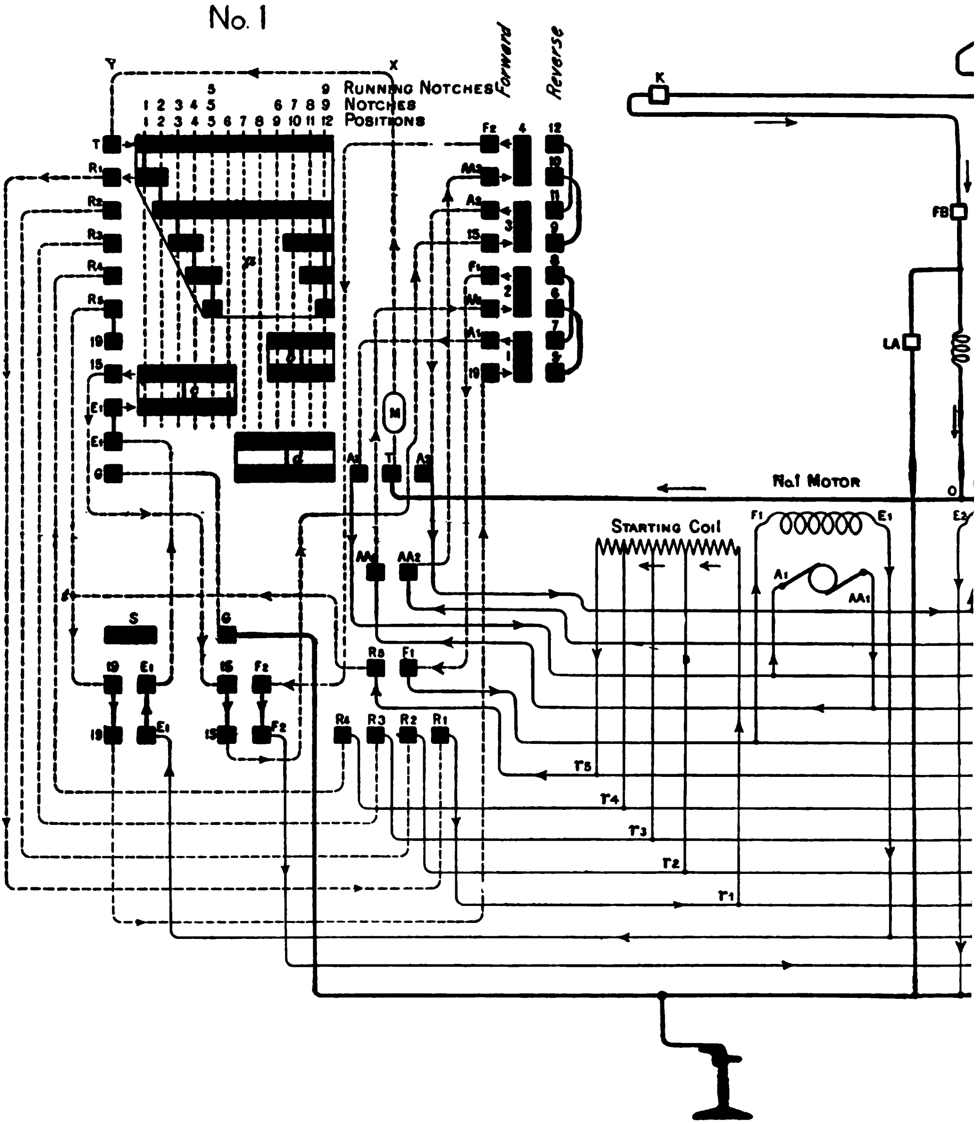


FIG. 4

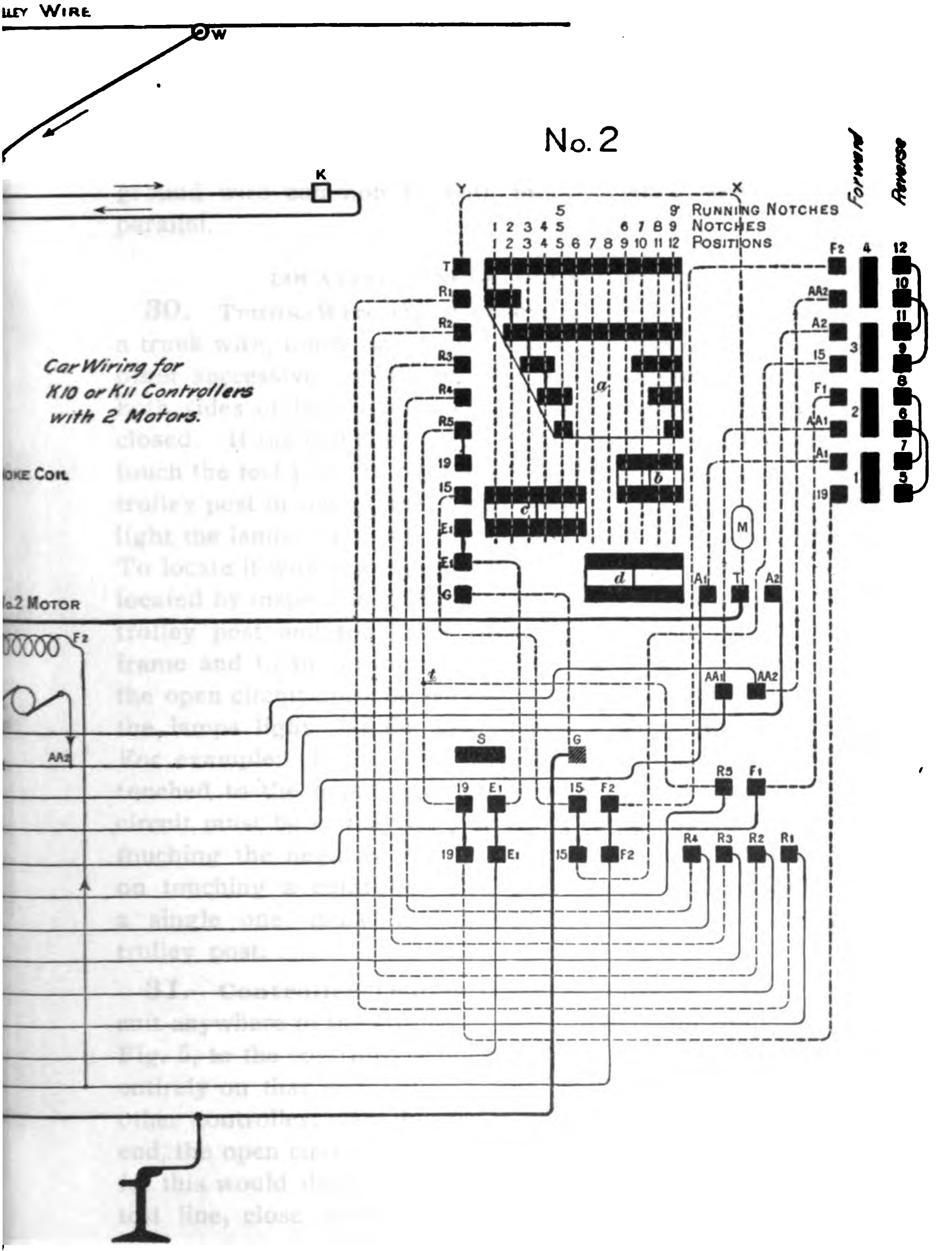
Tr



No. 1
Y
X
Running Notches
Notches
Positions
1 2 3 4 5 6 7 8 9 10 11 12
Forward
Reverse
T
R1
R2
R3
R4
R5
19
15
E1
E2
G
S
F2
F1
AA2
A2
AA1
A1
M
No.1 Motor
Starting Coil
K
FB
LA
O
T5
T4
T3
T2
T1
R4
R3
R2
R1
R5

Fig. 5

No. 2


Car Wiring for K10 or K11 Controllers with 2 Motors.

Assuming that the car fails to take current on all notches on both ends, the break in the circuit must lie between the trolley wire and the splice, Fig. 4, where the wire from the fuse box connects to the wire that runs the full length of the car from one controller trolley connecting post to the other, or in the ground wire common to both motors, when they are in parallel.

LOCATING SINGLE OPEN CIRCUIT

30. Trunk-Wire Open Circuit.—To locate a break in a trunk wire, touch one test point to the track rail and the other successively to the wheel, harp, pole-socket foot, and both sides of both hood switches or breakers, these being closed. If the test lamps light on all these points of contact, touch the test point to both sides of the fuse box and to the trolley post in one of the controllers. If these contacts all light the lamps, the open circuit must be in the ground wire. To locate it with the test circuit (though generally it can be located by inspection), connect one test point to a controller trolley post and touch the other successively to a motor frame and to the ground post in a controller. In any case, the open circuit must be between the contact point on which the lamps light and the next one, on which they do not. For example: If the lamps respond until the test point is touched to the negative side of the No. *1* switch, the open circuit must be in the No. *1* switch. If the lamps light on touching the negative side of the fuse box, but fail to light on touching a controller trolley post, the open circuit, if a single one, must lie between the fuse box and the trolley post.

31. Controller-Trolley Open Circuit.—An open circuit anywhere in the stretch of circuit extending from tap *O*, Fig. 5, to the controller trolley finger *T* will disable the car entirely on that end, but will not affect operation from the other controller. As the car operates normally from one end, the open circuit cannot be on the positive side of tap *O*, for this would disable both ends. Accordingly, ground one test line, close both switches or breakers, and touch the other test line successively to T–M–X–Y–finger T. If the lamps respond to all these contacts, inspect finger T to see if it will touch the drum when the drum is turned to on-position.

It is the custom in repair shops, when it is certain that the open circuit is not between the trolley wheel and the last hood switch or breaker, to fasten one end of the test circuit to the trolley side of the lamp switch and test as usual with the other end. This is a good idea, because both switches can be left open while the test is being made, and there is no danger of the car starting when one of the controllers is put on the first notch. Also, there is no danger of the tester making a short circuit by touching two fingers or two connecting posts at the same time when feeling around in the controller with the test line. To further guard against such a mishap, the exposed part of the test points should not be over 1 inch long, the rest of them being encased in a hard-rubber or fiber tube 6 or 8 inches long.

In the test just considered, instead of grounding one test line, it is standard practice to hook one test line over the lamp switch, open both hood switches or breakers, and explore with the other test line, the controller under test being on the first notch.

32. Car-Wire Open Circuit.—A car-wire open circuit cannot affect operation on both ends because each controller uses only part of every car wire. If operation is normal on one end, but the car will not start on the series-notches on the other end, hook one test line to the lamp switch, open one or both hood switches or breakers, put the controller on the final notch, and with the other end touch the controller connecting posts in the order in which the current reaches them. In this figure, the order is T–R_1–R_5–A_1–$A\,A_1$–F_1–E_1–A_2–$A\,A_2$–F_2–G. An open circuit in a No. 1 field car wire, for example, would prevent the test lamps from lighting until contact is made with connecting post E_1.

33. Tap or Device Open Circuit.—An open circuit in a device or one of its taps is located in the same manner as one in a car wire, and gives practically the same symptoms, but it affects operation from both ends. For example, with an open circuit in the No. 1 field or one of its taps, the car would not start in series on either end, and the test lamps would not light in either controller until contact was made with post E_1.

LOCATING TWO OR MORE OPEN CIRCUITS

34. One of the most annoying conditions to be encountered is that due to two or more open circuits on a car. Some car-barn men become marvelously expert at locating a single open circuit within narrow limits by operating both controllers and noting the action of the car, and in many cases this method suffices. Where irregularity in action, however, is due to more than one open circuit, time can often be saved by the use of a test circuit. Suppose, for example, that each of the motors represented in Fig. 5 has an open circuit. In such a case, the car would be entirely inoperative from either end, and the tester would suspect an open circuit between the trolley wire and the trolley cable tap, for only there can a single break disable a car entirely. A man of experience with double breaks will, when he has failed to locate any break in the trolley circuit, throw up both cut-out switches and turn one controller on and off. If it flashes, the open circuits are in the motors, because cutting out both motors has cut out both open circuits. Suppose that the car ground connection is also broken. Here the test with the cut-out switches would be misleading, because failure of the controller to flash would indicate that the motors were in order when such is not the case. Conditions are further complicated where one motor has one break in it, and the other motor has two breaks.

35. Any complications of open circuits can be straightened out with a test-lamp circuit. Suppose, for example, that the trolley wheel has been separated from the wire by a piece of paper; that the pole has been thickly japanned and allowed to dry before being put in the socket; that the car wheels are standing on paper; that pieces of mica have been slipped under a set of brushes on each motor; and that the connecting strip has been removed from between the E_1, E_1 fingers on the No. *1* controller, and from between the R_5, *19* fingers on the No. *2* controller. As the helplessness of such a car would suggest open circuit in the trolley or ground connection, the first step would be to locate any such breaks. On exploring the circuit, the lamps will light only when one test point touches the trolley wire and the other point the rail. In such a case connect one test point to the rail and explore from the trolley wire downwards. Suppose that on touching the trolley wire the lamps light, but that on touching the trolley wheel they do not, thereby indicating an open circuit between the wheel and wire. This break can be eliminated by taking out the piece of paper. The tester would not suspect a second break so close to the first, but to save another possible trip to the roof, he explores down to and through both hood switches or breakers. On testing the pole, the lamps light, but on touching the socket, they do not, thereby indicating an open circuit between them. In this case, the break is due to the japan, but a similar fault has been caused by using cardboard as a lining to make the socket clamp the pole tightly. Such open circuits can be removed by substituting a standard pole with a clean base.

After testing the trolley-foot connection, the tester passes below and tests both switches or breakers while closed, to insure that they and their connections are intact. Assured of this, the test line can be touched to the *T* post of one of the controllers, both of which are as yet at the off-position. If the lamps light, no trolley break that can affect operation from both ends exists, and it is well now to test from ground back toward the trolley line. The safest connection for this is to attach one test line to the lamp switch. The hood switches or breakers can then be opened. On touching the free test point to the rail, the lamps light; but on touching a wheel, truck, or motor part, they do not, thereby indicating an open circuit between wheels and rails. In this particular case, the open circuit is due to the paper under the wheels, but it might have been due to sand or dust on the rails; in one case known, it was due to paper-cored car wheels; the lamps would light on applying the test point to the tire of the wheel, but not when applied to the motor frames or truck parts, unless the brakes were applied, thereby bringing these parts into metallic connection with the wheel tires, which rested on the rails. Open circuits due to paper under the wheels can be corrected by pushing a nut or a bolt under a wheel. Touching the test line to the *G* post of both controllers will show whether or not the trunk ground connection is defective. If the test lamps do not light when either *G* post is touched, there is an open circuit in the main ground connection, or two open circuits in the ground car wire.

36. Having corrected the trunk wiring open circuits, if there are any, the tester tries to run the car to see if it will take current from either controller on any notch; in this particular case, it will not. The circuit is clear from the trolley wire to the controller *T* posts and from the *G* posts to ground, so that disability must be due to two or more open circuits between the *T* and *G* posts. Accordingly, open the breaker (or breakers, if they are in parallel), cut out both motors by means of the cut-out switches, and place the No. *1* controller on the first notch. As both motors are cut out, open circuits in them or their connections will not affect the lamp indications. Next, move the test line along the stretch of circuit (bearing in mind that the cut-out switches are up) $G–15–15–c–E_1–E_1–E_1–S–19–t–R_2–R_1–R_1–a–T$. The lamps will light on all points from post *G* to and including upper finger E_1, but will not light in response to contact with lower finger E_1, showing that the open circuit must lie between the two E_1 fingers. Inspection will show that the flat copper strip that ordinarily connects these fingers has been removed. This test might also have revealed an open circuit in the starting coil, or in some of the R_1 or R_2 connections. The missing E_1 strip can be temporarily supplied by connecting the two E_1 fingers with a fuse wire.

Next, cut in the No. *1* motor and try the car. Trial will show that the car cannot yet take current. Opening the overhead switch or breaker, again placing the controller on the first notch, and with the No. *1* motor still cut in, move the test line along the stretch of circuit G–*15*–*15*–c–E_1–E_1–E_1–E_1–post F_1–reverse finger F_1–*2*–finger AA_1–post AA_1–post A_1–finger A_1–*1*–finger *19*–*19*–*19*. In this case, the lamps will respond to all contacts until connecting-board post A_1 is touched, showing the presence of an open circuit between the AA_1 and A_1 posts, that is, somewhere in the No. *1* armature connections. Next, touch successively the AA_1 brush holder, the commutator, and the A_1 brush holder; if contact with the AA_1 holder lights the test lamps, there is no open circuit in its car wire or cable tap. If the lamps fail to light when the test point is touched to a commutator bar, indications point to an open circuit between the AA_1 brush holder and the commutator; it may be caused by a stuck, broken, or absent brush, shellac on the commutator, a bit of wood or (as in the present case) a piece of mica under the brush. Inspection will show if the open circuit is due to any of these faults. Having located this open circuit and removed its cause, try operation from that controller again. In this particular case, the car will operate on one motor from that end because all open circuits that could affect the No. *1* motor have been corrected. Next, open the breaker, cut out the No. *1* motor, cut in the No. *2* motor, and apply the test line to stretch of circuit G–E_2–F_2–F_2–F_2–F_2–*4*–AA_2–AA_2–AA_2–A_2–A_2–A_2–*3*–*15*–*15*–*15*–*15*. In this case, the lamps will light until the test point passes the open circuit, which is in the No. *2* armature circuit; having located the open circuit exactly, as already described, remove the cause and again try the car. The car will now operate as usual from the No. *1* controller.

37. Once normal operation is secured from one controller, the work attending the test of the other is much less, for it is certain that no open circuit exists in any motor or motor tap, or in the starting coil or any of its taps, or in any of the main trunk connections. Testing of the No. *2* controller is limited to open circuits between its T and G posts, or in the car trolley wire running from the trunk trolley wire to its *T* post. Tests conducted as on the No. *1* controller, between those limits, will reveal any breaks in the stretches of circuit covered by the tests.

Assuming that the open circuit in the No. *2* motor has been located and its cause removed, the car can be tried from the No. *2* controller. A trial under the assumed conditions will show that while both motors work on the series-notches, only the No. *1* motor is in action on the parallel notches. Normally, on the parallel notches, the No. *2* motor takes current through fingers R_8, *19*, and *15*; if the connecting strip between R_8 and *19* has been removed, the No. *2* motor cannot take current. Therefore, throw off the overhead switch, open the No. *1* cut-out switch so that it does not touch either *s* or *19* and E_1, and advance the controller to the sixth notch, or ninth position. Beginning at the ground post with the lower test point and working backwards toward the trolley on the No. *2* motor circuit, the lamps will light when the test point touches post F_2–F_2–F_2–*4*–*A* A_2–*A* A_2–A_2–A_2–*3*–*15*–*15*–*15*–*15*–*b*–finger *19*. When the test point touches finger R_8, which hangs in the air on the ninth position, the lamps will not light, as the strip between fingers R_8 and *19* is missing, and the No. *1* motor circuit is interrupted by the No. *1* cut-out switch blades hanging in the air. The lamps, therefore, indicate an open circuit between fingers R_8 and *19*. Restoration of the connecting strip will enable the car to operate normally.

38. Distinction Between Starting and Taking Current.—Aside from the conditions due to grounds or open circuits, a car can take current without starting. The test as to whether or not current flows on the first notch is to throw the power drum on and off and listen for the sound of the flash due to breaking current. There are times when a car takes current in a regular manner on the first notch, but, owing to low voltage or poor rail return, the current is not sufficient to start it. Again, an inexperienced man about to start on a down grade releases his brake and applies his controller simultaneously. He may have the impression that the current started the car when in reality the grade started it, and his impression may not be corrected until he has occasion to make an emergency reversal stop and finds that there is no current with which to do it.

GROUND FAULTS

39. Comparison of Grounds and Open Circuits. The symptoms of ground faults differ in two respects from those due to open circuits. A ground fault permits current flow in the circuit of which it is a part, while an open circuit does not; a ground fault will affect all branch circuits in metallic connection with the grounded part, while an open circuit will not. For example, an open-circuited car wire can affect operation from but one controller; a grounded car wire will affect operation from both. The test-lamp circuit is the handiest of the devices for locating ground faults. Any one familiar with the wiring diagram of the car under test can locate any ground within narrow limits without disconnecting a wire.

40. Distinguishing Grounds From Metallic Short Circuits.—A metallic short circuit is a short circuit in which no ground fault is involved. For example: should the motor armature terminals rub together and touch where the terminals hang together at the motor, the resulting short circuit would be a metallic short circuit. To distinguish a ground fault from a metallic short circuit, disconnect the motor and controller ground wires, and then advance the controller a notch or two and throw it off. A flash will show the fault to be a ground through which current can reach the rail, even when the regular ground connections are disconnected; no flash shows the fault to be a metallic short circuit.

SECTIONING OF WIRING DIAGRAM

41. A study of any wiring diagram will show that the wiring and other devices are naturally divided into several sections. A ground on any given section will cause certain symptoms, regardless of the part of the section on which the ground fault develops. It is convenient to consider this sectioning in locating grounds between certain limits.

42. Designation of Sections.—The **pole section** extends from the trolley wheel to the positive terminal of the first hood switch or breaker. A ground on this section will not affect a car fuse or breaker, but may operate some safety device at the power station as soon as the wheel is put on the overhead wire. Such a ground is usually accompanied by more or less demonstration, which reveals its location. A ground of this kind may take place on an overhead-trolley car operating under a metal structure or between the third rail and shoe fuse of a third-rail car.

43. The **breaker and fuse section** extends from the negative side of the first safety device to the trolley fingers of both controllers. This includes the lightning arrester connection. Assuming that breakers are used and not hood switches, a ground anywhere on the negative side of the No. 1 breaker will cause it to operate when the wheel touches the wire. If two breakers in series are used, the ground will operate the more sensitive one, or possibly both, and if the breakers are in parallel, it will operate whichever one is closed; if both are closed, both may operate; but if they do not, a station breaker is likely to open. Where hood switches are used in conjunction with a fuse, only the station breakers are any protection against grounds occurring on the positive side of the fuse: with the hood switches closed, such grounds will cause a demonstration when the wheel touches the wire. A ground on the negative side of the fuse box will blow the fuse. Grounds likely to blow a breaker or fuse before the controller is placed on the first notch are generally due to a faulty lightning arrester, or to that part of the trolley wiring that is under the car coming in contact with a grounded part, or to grounding of a magnetic blow-out coil in a controller. Any ground that causes a fuse or breaker to act before the controller is placed on the first notch is in the main trunk trolley connections, and must be removed before the car can proceed on its own motors.

44. A ground on the **drum sections,** which include both power and reverse drums, has the peculiarity that it cannot affect operation as long as the defective drum is at off-position; that is, a grounded drum in one controller will not affect operation from the other. In what way the fault will affect operation from the defective controller depends on the location of the fault. A ground on any casting used only in parallel will not affect series-operation. A ground on the *a* casting, Fig. 5, will cause the fuse or breaker to operate on the first notch; a ground on the *c* casting will not cause the fuse or breaker to operate, because the counter electromotive force of the No. *1* motor prevents excessive flow of current. Casting *c* is not active on the parallel notches.

45. The **starting-coil section** includes all resistance wires and connections and wires or devices marked *R*, *r*, or *19*. The action produced by a starting-coil section ground depends on its location. For example, a ground on the r_1 end of the coil will cause a fuse or breaker to act on moving the controller to the first notch; if the ground is on the r_5 end, however, the fuse or breaker may not operate until the controller has been advanced two or more notches, thereby decreasing the resistance through which the current must pass to reach the fault.

46. The **No. 1 armature section** includes all wires and connections marked A_1 or AA_1. A ground anywhere on this section, except on the armature itself, will cause the fuse or breaker to act as soon as advancement of the controller cuts out part of the starting coil. A ground on the armature itself causes the same action, but may be accompanied by bucking if it occurs while the car is under headway.

47. The **No. 1 field section** includes all wires and connections marked F_1 or E_1, and a ground on it will cause symptoms that depend on the location of the ground. For

example, a ground on the positive side of the No. *1* field causes the same action as a ground on the No. *1* armature section; a ground on the negative side of the field will permit the car to operate with the No. *1* motor on the series-notches; and if the ground is no farther along the circuit than either E_1 finger, the car may operate on the parallel positions, as upper finger E_1 hangs in the air on these positions, and the effect of the ground is not felt on the positive portion of the No. *2* motor circuit.

48. The **No. 2 armature section** includes all connections marked A_2 or AA_2; a ground on the positive or negative sides of the No. *2* armature will allow the car to operate on the series-notches, but the fuse or breaker will operate on the parallel positions. A ground on the No. *2* armature itself will cause it to operate with a jerky motion on the series-notches, and the fuse or breaker will act on the parallel positions.

49. The **No. 2 field section** includes all connections marked F_2, E_2, or G. Grounds rarely occur on this section, because all of it is at nearly the same potential as the ground.

50. Marking of Sections.—In connection with Fig. 5, the stretch of circuit W–K is the pole section; K–K–FB–LA connection $-O-\left\{\begin{matrix}T-M-T\\T-M-T\end{matrix}\right\}$ is the breaker and fuse section. The drum sections on both power and reverse controllers are marked *a–b–c–d* and *1* to *12*. The resistance section comprises R_1–R_2–R_3–R_4–R_5–r_1–r_2–r_3–r_4–r_5–*t*–*19*–*19*–*19* on both controllers and the connecting car wires. The No. *1* armature section is the stretch of circuit, reverse finger–A_1–A_1–A_1–AA_1–AA_1–AA_1. The No. *1* field circuit comprises reverse finger–F_1–F_1–F_1–E_1–E_1–E_1–E_1–E_1. No. *2* armature section includes A_2–A_2–A_2–AA_2–AA_2–AA_2; No. *2* field section, F_2–F_2–F_2–F_2–E_2–G.

LOCATING GROUND FAULTS

51. Complete Tests.—With the pole down and all switches and breakers at the off-position, move all power and reverse drums to off-position to isolate the several controller sections from one another. Connect one lamp-test line to the overhead trolley wire (where it is certain that the fault is not between the wire and the controller trolley fingers, as would be indicated by all breakers remaining closed when the wheel is on the wire; the test line may be attached to the lamp switch), and with the other test line explore from a point near the first test line to the ground, along the path taken by the current on the first notch, frequently touching the exploring test point to a part that is known to be grounded, in order to insure that the test circuit is intact. Suppose that the test lamps light on touching the test point to main fuse *F B*; disconnect the fuse and test on both sides of it. Suppose that the positive side shows clear and the negative side ground; disconnect both controller trolley wires and test both the wires and the posts from which they were taken. If the posts show clear, but the wires show ground, the controllers are in order, but the lightning arrester is probably short-circuited, or the car trolley wire is rubbing a brake rod or other grounded part; to find out which, disconnect the arrester and test both sides of the disconnection. If, however, the controller trolley wire shows clear and one of the controller *T* posts shows ground, the fault is in that controller; most probably, it is a grounded blow-out coil, but to be certain, disconnect the coil entirely and test it and the terminals to which it is connected.

Suppose that a ground does not show until contact with an *R* finger indicates the fault to be in the starting-coil section. A ground on the starting coil, or on any of its wires, will light the test lamps if the test point is touched to any wire, finger, or post marked with an *R* or with the number *19*, on either end of the car. To determine if the fault is in the starting coil itself, or in one of its wires, fingers, or posts, the starting coil must be disconnected from the car wires. The test point is then put on the coil alone and on each of the *R* connecting posts. If the fault is not in the coil, it must be in one of the car wires or its connections. Having located a suspicious wire, disconnect it at both ends and test it, as well as the two posts out of which its ends come. This will show if the fault is in the wire or not. If the R_3 connecting post shows a ground, the wires, fingers, and posts must be disconnected, one at a time, to find out if the fault is in one of the internal wires, a power finger, reverse finger, or on the No. 1 cut-out switch.

If any wire, finger, or post marked A_1 or AA_1 lights the lamps when it is touched, either the No. *1* armature itself, one of the brush holders, or one of the wires running to them is grounded. To find out if it is the armature itself, draw the brushes and touch the test point to the commutator: if the lamps light, the armature is grounded; if they do not, the fault is elsewhere. Drawing the brushes separates the A_1 and AA_1 car wires and they can be tested, one at a time. As soon as a grounded car wire is located, it must be disconnected at both ends, so that by separate tests it can be found out whether the fault is in the car wire itself, or in one of the fingers, posts, or internal controller connecting wires.

52. Shop Method.—When a car is turned in for a ground, it is generally marked up for blowing fuses, breakers, or for bucking; by noting the action of the car the ground can be approximately located, but usually the lamp test is used to locate it exactly. Shop men apply the test about as follows: Making one end of the lamp circuit fast to the trolley, and with both drums of both power and reverse controllers at the off-position, the test point is run up and down the power drum and reserve finger boards; then all drum castings or tips are touched with the test point. Considering Fig. 5, the lamps should not respond except when contact is made with fingers *G* and F_2, both of which are grounded, *G* directly and F_2 through the No. *2* field. Should the lamps respond to contact with any other finger than those permanently grounded, that finger is part of the section on which a ground fault exists and the fault can be exactly located in the manner already described—by disconnection and test of the disconnected parts.

CROSSES AND WRONG CONNECTIONS

CROSSES

53. Definition.—By **a cross** is meant a short circuit caused by insulation breaking down and letting current take an irregular path to the ground.

54. Blow-Out Coil Crosses.—In Fig. 5, the blow-out coil leads come out on opposite ends of the coil. This may or may not be the case; where the leads come out on the same end, they sometimes get into contact with each other; and even if they do not come out at the same end, there is likely to be a cross in the coil, because the inside end must be brought out from the bottom layer. In doing so it passes every other layer, and unless the insulation is good, there may, in course of time, be a contact. The effect of a short circuit in the blow-out coil is to cut out some or all of the turns of wire in it, with the result that very little magnetism is produced and the controller burns badly when thrown to the off-position.

55. Starting-Coil Crosses.—A short circuit in the starting coil causes the car to jump badly on some notches, while it fails to respond on others. If the trouble is in the coil itself, it will be felt on both ends of the car; and if it is between two of the car wires or in the controller, it will be felt on both ends also. Suppose the R_1 and R_2 posts to be touching in the No. 2 controller; when the No. 1 controller is used, the current will pass through this short circuit instead of through the first section of the starting coil. To find out if the short circuit is in the car wires, disconnect the starting coil entirely and test with a lamp circuit between each resistance wire and every other resistance wire. The lamp circuit has one of its ends connected to some trolley connection. When the coil is disconnected and the controllers are at the off-position, the resistance wires, posts, and fingers do not touch each other anywhere unless there is a cross between them. To locate such a cross, run a small wire from the ground post of the controller to one of the resistance wires, and touch each of the other resistance wires with the test line. Ground each wire in turn, and touch all the others until the test lamps light; this they will do as soon as the test line touches the wire that is crossed with the grounded one. After deciding which two wires are crossed, they must be disconnected from the controllers and tested again, to decide if the cross is in the hose or in one of the controllers.

56. Drum Crosses.—No casting on the drum is supposed to touch any other casting; to tell whether it does or not, use a wire from the ground as one test line to touch each casting on the drum, while the lamp test line is at the same time touched to every other casting on the drum. The test lamps will not light unless the two test lines touch the same casting or two castings that are crossed.

57. Arc-Guard Crosses.—If the arc guards are kept clean and renewed when they should be, it will be a long while before they give trouble. But, as a rule, this care is not given them, and being made of vulcabeston, the constant flashing in course of time carbonizes them so that they carry current, and then trouble results. To avoid burning, the contacts must be kept in good condition; wear in the fingers must be taken up by means of the adjusting screws provided for that purpose; their pressure on the drum must be strong enough to insure good contact, but not strong enough to produce excessive wear. If the fingers are so adjusted that they drop about $\frac{1}{16}$ inch when the shoe leaves a drum tip, the tension will be about right. Another important point is to keep the finger tips in line, so that when the current is broken on several fingers at once, they will all break at the same time, and no one of them will get more arcing than the rest.

Good alinement, also, to a great extent, does away with burning on the notches. Nothing helps the action of a controller drum more than a little vaseline. When the drum tips are dry, the drum turns stiffly, because there is friction between the shoes and the tips. Do not put on much vaseline, but put it on the drum tips and spread it over very thinly with a stiff brush. Keep the dust and copper cuttings out of the controller by blowing it out. Do not poke a metal-nosed bellows into a controller without first throwing off an overhead switch. Keep the drum-shaft bearings well oiled and do not forget that grease helps the action of the index roller. Go over the connections in the controller, once in a while, to see that there are no loose wires and screws. When the hole in the controller handle becomes badly worn get another handle.

If these details are attended to so that the controller works properly, the arc guards are not so apt to burn. The guards should be thrown back and inspected once in a while; if they show ordinary burning, scrape the burned part off. If a slight hole has been started by burning, scrape the guard well, give it a thin coat of shellac, and lay a piece of thin, clean asbestos over the hole; when this asbestos burns away, put in another piece. If there is a hole through one of the arc guards, and there is no new guard on hand to put in its place, the hole may be stopped up with a paste made out of shellac and equal parts of powdered asbestos and plaster of Paris. Press the paste into the hole and light it with a match. When all the alcohol in the shellac is burned out, it leaves the paste hard and firm. Those arc guards that are next to the fingers carry the main-motor current, when the motors are in parallel, such as the *T* finger and those guards that are next to the fingers on which the change from series to parallel takes place, such as the *19* and E_1 fingers, are the most liable to give trouble from burning.

58. Field Car-Wire Crosses.—A cross between the F_1 and E_1 hose wires, or between the F_2 and G hose wires, will cut out the field of one motor, but leave its armature in circuit. The cross may cause no noticeable trouble so long as the motors are in series, because the counter electromotive force of the good motor holds the current down to a safe value; but as soon as the motors are thrown into parallel, where both are across the line, the one with its field cut out takes an enormous current and blows the fuse or operates the breaker. There are several other faults about a car that will cause this same symptom, so the only thing to do, in order to locate the two wires between which the cross exists, is to disconnect the motors and test each motor wire with every other motor wire. As a rule, when any such cross takes place in a hose, the large current that flows through it burns the hose and so betrays its location. There are numerous places where crosses occur from time to time in the car wiring or controllers, and each system of control may have its own peculiar way of indicating the existence of a cross.

WRONG CONNECTIONS

59. Blow-Out Coil.—Confusion of the controller blow-out coil leads does not affect the running of the car, but may affect the ease with which the magnetism blows out the arc. The direction in which the arc is deflected depends on the direction of the blow-coil lines of force and on the direction in which the current flows through the arc. At the factory, the coils are so connected that the heaviest arcs are blown against the best protected places. Suppose, for example, that the arc on the trolley finger is deflected downwards; if the coil leads become interchanged, the lines of force due to the coil are reversed, but the current through the arc remains in the same direction as before, so that the arc is deflected upwards. In being deflected upwards, it may be blown against an end plate on the power drum or some unprotected part on the controller, and cause trouble. On some fingers, also, the current flows toward the drum; on others, it flows from it. Two such fingers might be next to each other; in such a case, the blow coil may be so connected as to blow the two arcs away from each other. The effect of reversing the blow-coil connections would be to reverse the direction in which both of these arcs were blown, and thereby blow them together; this would tend to burn opposite sides of the same arc guard, and would soon make a hole through it. In several instances, continual trouble with blow-out controllers was found to be due to the fact that the coil was connected in backwards.

Before undertaking to wind a blow coil, the winder should acquaint himself with all details of an old coil; and a car wireman, before putting in a coil, should connect it in series with an old coil and compare their polarities.

60. Controllers or Motors.—If, in installing a new controller, the tags on the car wires are too unreliable to go by, the wireman can save time by connecting the wires into the controller and trying the car afterwards. It is assumed that he can tell whether a wire is a field or an armature wire, but he cannot tell whether it is positive or negative. It is the custom among wiremen to adopt some mark that can be made with the pliers; if the marks on the tags are too dim to be seen clearly, they mark each wire as it is taken out of the old controller to save time in connecting the new one. Suppose that after the car is connected it starts normally on one end, but on the other end backs when the reverse handle points forwards; this means that the F_1 and E_1 wires or the A_1 and AA_1 wires have exchanged places on the No. 1 motor controller connections, and that the A_2 and AA_2 wires on the No. 2 motor controller connections have exchanged places; the error must be in the controller, for were it in the motors, both ends of the car would be wrong. The way to right matters is to reverse either the field or the armature car wires on the No. 1 motor controller connections and the armature car wires on the No. 2 motor controller connections in the controller. If the car starts in a direction opposite to the indications of the reverse levers on both ends, the field or armature leads on the motors themselves must be reversed.

If, on throwing a controller on and off, the gears click and the controller flashes, the motors are probably opposing each other; in such a case, try them, one at a time, to see which is right, and do this on both ends of the car. If they are right on one end, do not disturb the connections there or at the motors, but reverse the field or armature controller wires on the faulty end. If trial at both ends shows that the two motors oppose each other, and both trials convict the same motor, the reversing should be done at the motor itself; but if one motor is wrong when tried from one controller, and the other motor is wrong when tried from the other controller, the irregular motor must in each case be reversed in the controller in which it is irregular. If both motors start wrong on one end and one starts wrong on the other end, the motor that starts wrong on both ends must be reversed at the motor itself; but the one that starts wrong on but one end must be reversed in the controller on that end. Do not reverse any of the motor terminals, unless the motor runs wrong on both ends. If the two field and two armature terminals on one or both motors become interchanged, it will make no difference in the running of the car.

61. Field and Armature Terminal of Same Motor. A common mistake is to get a field and armature terminal on the same motor interchanged. Suppose this happens to the A_1 and F_1 car wires in the No. *1* controller of Fig. 5. In this case, the car will start forwards on the No. *2* motor; but as soon as the controller is put on the parallel notch, the motor fuse blows, on account of the rush of current through the No. *1* field, which is thrown across the line. With the No. *2* motor cut out, the car will not start forwards at all. If the reverse switch is thrown, the car will start on the first notch, as usual, even if the No. *2* motor is cut out. Confusion of the F_2 and A_2 motor wires causes the same action on that motor. If a car will back up on both motors, cut in, one at a time, but if it will go ahead on only one of them, there is probably a confusion between the positive field and armature wires on the affected motor. Next, suppose the E_1 and AA_1 wires to be interchanged; in this case the indications are the same as for the interchange of A_1 and F_1 wires when the reverse lever is forwards, except that the No. *1* brushes will flash when the power drum is thrown to parallel. The car will not start forwards on the No. *1* motor. When the reverse lever is thrown, the car will start on the first notch on either or both motors.

62. Interchange of Leads Between Two Motors. Suppose the $A A_1$ and $A A_2$ wires to be confused. In such a case, with both motors cut in and the reverse lever forwards, the car will not start on the series-notches, but will blow fuses, because the current passes through the No. 1 armature and the No. 2 field to ground. Nor will the car start on either motor alone, for in either case there is an open circuit. With the reverse lever thrown and both motors cut in, the car will run on the series-notches on the No. 2 motor alone; as soon as the drum is thrown to parallel, the No. 1 motor is picked up as if nothing were the matter.

Next, suppose the A_1 and A_2 wires to be confused. With the reverse lever forwards, the car runs on the series-notches on the No. 2 motor alone; on the parallel notches, both of the motors work. The car will not run on either motor alone. With the reverse lever thrown, the motor fuse blows on the series-notches, because the current passes to the ground through the No. 1 armature and the No. 2 field. The car will not back on either motor alone because of open circuits at the cut-out switches.

Finally, suppose the F_1 and F_2 wires to exchange places. With the reverse lever forwards and both motors cut in, there is a short circuit through the No. 1 armature and the No. 2 field, and the car blows fuses on the series-notches. The car will not start on either motor alone, because there is an open circuit in one case and a short circuit in the other. With the reverse lever thrown, the motor fuse blows on the series-notches, as before. Also, the car cannot start on either motor alone with the reverse switch thrown, on account of the open circuit in one case and the short circuit in the other.

63. Interchange of *T* and *G* Wires.—Assuming that the ground post of the controller is not itself grounded to the controller frame (as it often is on modern equipments in order to make it impossible for the controller frame to become charged as a result of the insulation of some wire becoming defective), an interchange of the trolley and ground wires kills all controller circuits until the seventh position is reached; because the trolley wire, instead of leading through the blow coil to the top finger, leads directly to the bottom finger, which hangs in the air until it makes contact with casting *d* on the seventh position. On this position, current takes the path $T–G–G–d–E_1–E_1–E_1–E_1–F_1–F_1–F_1–2–AA_1–AA_1–AA_1–A_1–A_1–A_1–1–19–19–19–t–R_2–r_2–r_2–R_2–R_2–a–T$ (finger)–$M–T$ post to the ground. On the eighth position, the same combination exists, so that on these positions the car runs on the No. *1* motor. On the ninth and subsequent positions the No. *1* motor is operative as before, but has in series with it the No. *2* motor, which, however, cannot do its full share of work until the twelfth position is reached, because on position *9* it has in parallel with it the last three sections of the starting coil; on position *10* the last two sections of the starting coil, and on position *11* the last single section.

Assuming that the controller ground post is itself grounded to the controller frame through a small fuse, and that the frame is connected to the ground, as soon as the pole touches the wire this small fuse blows, leaving the car in the same condition as that just discussed. If, however, the ground post is grounded to the controller frame by means of a heavy connection that can carry more current than is necessary to blow the car's main fuse or hood circuit-breaker, one of these safety devices will act as soon as the pole touches the wire, and the car will thereby be rendered dead on all notches.

64. Interchange of Resistance Wires.—Interchange of resistance wires will cause irregularity in notching and according as the interchange involves car wires or the starting-coil taps, the irregularity will affect operation from one or both ends. For example: interchange of the R_1 and R_2 car wires in the No. *1* controller, Fig. 5, will cause the car to start on the first notch with a jump, because the current enters the starting coil at r_2 instead of r_1; but on the second notch, the speed will fall to what it should be on the first notch, because the current must pass through the whole coil; on the third notch, the car will jump again. This interchange will affect operation only from the No. *1* controller, assuming that the No. *2* controller connections are correct. If the r_1 and r_2 starting-coil taps are interchanged, the action will be the same as in the last case, but operation from both ends will be affected. Interchange of the R_1 and R_2 car wires or of the r_1 and r_3 taps will cause even more violent jumping. In case of confusion of starting-coil connections, some of the controller drum tips will show burning on the ends opposite those that usually burn.

BLOWING FUSES

ON CURVES

65. Sometimes, on double-truck cars, the fuse or breaker blows only when the car is rounding a curve; this means probably that the car-wiring hose has shifted its position in some way, or that wear in some parts of the car or truck, or some unusual depression of the springs, allows the wheels to cut into the hose when the truck rounds a sharp curve. If the fuse does not blow until the second, third, or fourth notch is reached, the indications point to a ground on the No. 1 motor, and such a ground can be corrected by means of the No. 1 cut-out switch. The reason for this is that if the fault is on the No. 2 motor, the counter electromotive force of the No. 1 motor prevents the fuse from blowing as long as the two motors are in series, and it is only when a parallel notch is reached that the fuse will blow. Use the cut-out switches and try the motors, one at a time, to find out which is the faulty one; after this is done, the faulty one can remain cut out and the car run to the house on the good one. If, however, there is time to spare, lift the trap doors and inspect the motors: the trouble may be as evident as a motor terminal rubbing the frame or suspension bar or two terminals rubbing each other. Also, inspect the controller to see that there are no loose connections.

WHEN PASSING FROM SERIES TO PARALLEL

66. If the fuse blows between series and parallel positions, indications point to a ground on the No. 2 motor. Grounded brushes or a faulty commutator may cause this action. Such faults may not show themselves on the series-notches, because the electromotive force impressed on the terminals of each motor is comparatively low; but, as soon as the drum is thrown to the parallel positions, the higher electromotive force impressed on the faulty motor terminals is apt to develop the fault.

ARMATURE RUBBING POLE PIECES

67. If the car persists in blowing fuses at irregular intervals, it may be due to the fact that the armature bearings are down and the armature core is rubbing the pole pieces, in which case the brushes spark badly and a grinding noise is heard. Armature clearance should be frequently and regularly inspected, so that bearings can be renewed before excessive wear causes rubbing. Notwithstanding efficient inspection of clearance, armatures are sometimes let down on the pole pieces as a result of a box becoming hot. In such cases, cut out the affected motor and, if practicable, either knock off the pinion or loosen the caps, lift the armature with a rope sling, if necessary made from the trolley rope, and block up the bearings.

CLINGING BRAKE SHOES

68. Fuse blowing may be due to the fact that the brakes do not release, in which case the shoes ride the wheels all the time, the wheels and shoes get very hot, and a peculiar scorching odor is given off. Clinging shoes may be caused by weak release springs. On single-truck cars using brake slides, if the release springs on one end get weak the stronger release springs on the other end will pull out the weak springs and force the shoes near the weak springs against the wheels, thereby adding considerably to the work of the motors.

HOT BOXES

69. No other single fault throws so much extra work on the motors as a hot box. It is equivalent to a powerful brake, and where the box gets so hot as to freeze, the wheels on that end of the car are *locked* and cannot be turned. A hot box in its first stages emits an odor of burning oil and even a whistling noise, either of which symptoms should be taken as a warning to give the box attention or run the car slowly to the nearest relief point. A locked journal-box can sometimes be relieved with cold water, but in this there is danger of cracking some cast-iron part by sudden contraction. A motor-axle box can sometimes be unlocked by easing off the capscrews. When an armature box becomes locked, if the pinion cannot be removed, the car must be skidded in, that is, run in with some of the wheels sliding on the rails. In any case where a car is skidded in, the motor on the affected end should be cut out.

DIRTY MOTORS

70. An accumulation of carbon dust on the brush yoke will cause flashing over, which will blow fuses or breakers. Oil in the bottom of a motor rots the field-terminal insulation, and carbon dust floating on the oil will cause a short circuit. If a field coil is wound on a metal shell, the mixture of oil and dust will short-circuit the winding to the edge of the shell. In winter time, snow and salt thrown into the motor by the car wheels will do the same thing. There have been cases where all the cars on a road would begin to blow fuses much oftener than they should; but this, of course, could be caused by making the mistake of giving out a smaller fuse than usual.

LOW VOLTAGE

71. A cause of fuse blowing difficult to locate, because in many cases it comes on so gradually that it is never suspected, is due to low voltage on the line. If the ground-return part of the circuit, for any reason, becomes defective, or if the number of cars has been increased, the voltage becomes low all over the line, and the blowing of fuses will gradually increase. The direct cause of blowing fuses is the motorman's unconscious abuse of the equipment. The running time for the cars is made when the voltage is well up. The motorman can run in series here and coast there, start the car a notch at a time and still make his time; perhaps there is even a layover of 10 or 12 minutes at the end of the line; this gives him a good chance to look over the controller fingers and do a little adjusting, if necessary; to keep the brushes and brush springs in good condition; to feel the motor bearings and connections; or do a number of other things that are small in themselves, but that in the end decide whether a car will run smoothly or not. If, however, the voltage on the line becomes gradually lower, there is no time for series-running or coasting to rest the motors. At the end of the line the motorman gets no time to examine things. The motors get no rest, and neither does the fuse; consequently, trouble with the fuses is the result.

WINDINGS ROASTED

72. The first symptom of a roasted, short-circuited, or wrongly connected field is frequent operation of the fuse or breaker and sparking of brushes when the motors are in parallel. In time, it will be impossible to throw to parallel without operating a fuse or breaker. A short-circuited, wrongly connected, or roasted field coil will eventually roast all parts in series with it; so will a roasted armature. The roasting may reach a degree where the fuse or breaker will act if the controller is moved past the first notch. In either case, chronic fuse blowing will be preceded by excessive brush sparking. In many cases, a glance inside the motor case will show a belt of solder around the case and in line with the commutator connections. This solder has been melted out of the commutator connections by the excessive current and thrown on the casing by centrifugal force. Under such circumstances, the motor is said to *throw solder.*

FUSE OR BREAKER DISORDER

73. Chronic fuse or breaker operation may be due to the fuse being below standard size or the breaker being out of adjustment. Both of these conditions should be investigated regularly, and the standard size of fuse or adjustment of breaker maintained.

OPERATING INSTRUCTIONS

RULES OF GENERAL APPLICATION

INTRODUCTION

1. No system of rules and regulations exists that will apply to all roads; every road has its own written or understood code based on its own peculiar conditions. A set of standard rules that would cover all points of importance could be made to apply to all roads in the United States, but until such time as the managers of all the roads can agree on a standard code, by which they will all abide, a discussion of a particular code would be useless. Some managements believe that it is well for a crew to know as much as possible about the equipment it is to operate, and even go so far as to establish schools of practical instruction where the men are required to qualify to certain physical and mental standards before being allowed to conduct or operate a car in service. Others think that a crew's qualifications should be limited to a knowledge of how to handle the brake, how and when to renew a fuse, and how to cut out a defective motor. Still others assert that a crew's duties should be confined to operating the controller and brake handles and looking after the passengers.

The members of the car crews and the mechanical department are all directly responsible to the operating department. In case of emergency, a crew may be called on to perform duties ordinarily performed by the mechanical department, or vice versa. Each should, to some extent, understand the work of the other. For example, if traffic is being delayed by a derailed or disabled car, it should be the business of the crew to replace the car or make temporary repairs, if possible, rather than to await help from the mechanical department.

2. There are several reasons why a crew should understand the equipment it is to operate:

1. In many cases, the proper use of a piece of tape, wire, or string, a pair of pliers, or a screwdriver will enable a disabled car to proceed before its follower or an inspector can get to the scene of trouble. If a man knows enough about his car to tell from its action where the trouble is and to remedy it, so that the car can proceed, the knowledge is valuable to the man himself, to the public, to his immediate superior, and to the company.

Those employed directly in the operation of cars or trains should not feel that their efforts must be limited to making time with a car that is in good condition, but should endeavor to become qualified to prevent their car getting in such bad condition as to make running on time impossible.

2. If the rules of the road do not allow the crew to make an inspection, it will still be of great help to the shop men if the crew can tell from the action of the car the cause of the trouble.

3. Inspectors are advanced to their positions from the ranks. If a man is familiar with quick methods of repairing and moving crippled cars, although he may have few chances of using his knowledge, the fact that he has it is sure to become known in time, and will increase his chances of promotion.

4. A man whose mind has been trained or developed by schooling is apt to retain his presence of mind in times of emergency, and, all other things being equal, is better qualified to meet requirements in cases of accident than is the untrained man.

3. In course of time, a standard code of rules will probably govern every road in the United States. It is to this end that the American Street Railway Association appointed a committee to formulate rules and regulations to govern its members. The following general discussion is based on the work of this committee and on the rules of some of the more important roads. The object is to give some general idea of what may be expected in the way of duties and discipline.

QUALIFICATIONS OF CAR OPERATORS

4. **Physical.**—For car work, men should attain a certain standard of weight and height; they should be strong enough to pull at least 200 pounds on a brake handle in cases of emergency, and tall enough to manipulate the overhead switches. Some small men, however, are strong and extremely active and may be able to fulfil these requirements. Many roads do not have a rigid standard of physical stature.

Both motormen and conductors should have good hearing and good eyesight; good hearing may often prevent accidents at grade crossings, and good eyesight is essential to read signals correctly as well as to see unusual obstructions in time to avoid striking them.

Applicants should be sound in heart and lungs. An unsound man is liable to become disabled at any time; and if such an accident should happen to a motorman on a car that has a curtained front, so that he is not in sight of the conductor or passengers, the situation would be very dangerous.

5. **Intellectual and Moral.**—All applicants for positions as motormen or conductors must be able to read in order that they may intelligently obey rules, bulletins, etc., as well as detect worthless tickets, transfers, etc. offered to them on the road. They must be able to write in order to make out reports, take names and addresses of witnesses in cases of accidents, etc. They must be able to add, subtract, multiply, and divide, so as to keep a correct account of fares collected and make proper reports.

About the only moral qualification required by most roads is that the applicant shall be honest. Most managers, however, naturally prefer to hire men whose reputation for both honesty and sobriety is good, and they will hesitate long before putting a man of known intemperate habits in a responsible position.

PREPARATION

6. Breaking In.—A successful applicant may be put in the shop for a few days; he may be put through a regular course of school instruction, or he may be placed directly on a car under the tuition of an old employe, who breaks him in. In all cases, the applicant is broken in before he is given a car.

All preparatory work is done on the applicant's own time, and the sooner it can be determined whether or not he is likely to be a success in the line of work chosen, the less will be his expense. Where a preparatory school is provided, the man's prospects are soon known. If the man has access to an easy course of reading, showing the duties and responsibilities of the position to which he aspires, he can, in most cases, decide for himself without a trial. He should not, however, become discouraged by the large number of rules or the apparent severity of some of them. The exercise of a little good judgment and a desire to do what is right will prompt a man to obey more than one-half of these rules. The instinct for self-preservation will make him obey the more important ones.

7. Examination.—If, when being broken in, the applicant shows but little aptitude for the work, his tutor will refuse to recommend him, and this will result in his rejection. Should he be turned in, he may be examined by an inspector before he is allowed to take out a car. The inspector sees that he has the proper knowledge of the rule book; that he understands all signals and signs; that his knowledge of the equipment is up to the standard prescribed by the company. Prospective conductors are examined in their knowledge of their duties both to the company and to the public.

ASSIGNMENT

8. Unless regular positions are open at the time, all accepted applicants are placed on the *extra list;* that is, they are given no regular or certain work, but must be ready for duty at any time between the hours named by the depot master. If any regular man is temporarily off duty for sickness or other cause, the man whose name stands nearest the head of the extra list is called to take his place; dinner and supper trips run while the regular men are at meals, the running of extra cars during rush hours, etc., furnish irregular work for the men whose names are on the extra list. Vacancies in the regular force are filled from the extra list, the name at the head of the list always being first called, the other names being advanced as those from the top are removed.

9. Dress and Appearance.—After a man has been assigned a number and a place on the extra list, he is provided with a badge, which must always be worn while on duty and for which he must make a deposit; the deposit is refunded when the badge is returned. He must provide himself with the uniform prescribed by the company. This uniform can be obtained under such lenient payments, as a rule, that its purchase is no hardship. The winter clothing of motormen must be of close texture. The clothing of conductors must have deep well-reenforced pockets; and in the side change pockets, it is well to have a mouth lining of chamois skin to prevent wear and also to retard the hands of pickpockets. The uniform buttons are the property of the company and must be turned in when a man ceases to be an employe.

Conductors and motormen should make an effort to appear as neat and clean as possible. They should assume their responsibilities thoroughly imbued with the idea that their positions offer a field for the cultivation and exercise of gentlemanly instincts.

10. Penalties.—The penalties for breaking rules depend on the offense, on the offender's previous record, on the judgment of his superiors, etc. The maximum penalty is discharge; whether or not this is imposed for the first offense depends on local rules covering such cases. Offenders are sometimes put at the foot of the extra list or given some period of suspension, according to the gravity of the offense. Even though no direct penalty is imposed, infraction of rules is sure to work indirectly against a man in preventing desired promotion or in the failure to hold the confidence of his employers.

TREATMENT OF PASSENGERS

11. Safety.—Assuming that the applicant has successfully stood the physical, intellectual, and moral examinations, and that he has become an employe, he should hold in mind several points that will be a help to him on any road, whatever may be its local rules. Above all things, the safety of the passenger must be considered. Every company has rules regarding this fact and the crew should observe them to the letter. Should a condition arise that is not covered by any rule, discretion, in the absence of a ranking officer, must be used. Any infraction or neglect of a safety rule is a serious offense, for it complicates the company's position should a damage suit arise.

12. Comfort.—The comfort of the passengers must be considered. Drafts are unavoidable, on account of the frequency with which doors are opened and closed, but the crew can help matters a great deal by at least keeping the front door closed. If it is feasible, encourage the passengers to enter and leave by the rear door; the rules of some roads make this compulsory, and in all cases, the crew must be governed by the rules in force. Make an effort to keep the temperature of the car agreeable to the passengers, if the rules of the road will permit. On some roads, the crews are forbidden to turn on the heaters, the management preferring to have the heating of cars attended to by other employes.

13. Accommodation.—Railroads are designed primarily to meet the convenience of the public, and the feeling of the public toward the management depends on the amount of accommodation afforded. In fact, the management and the employes are servants of the people. In wet weather, stops should be made at points where passengers are not obliged to wade through mud and water in passing to or from the car. By making friends of the passengers in a quiet way, the crew makes a good public reputation for the company, as far as its passengers are concerned, with the result that public favor is enlisted on the side of the company in cases of accident.

14. Judgment and Courtesy.—Practically, the only employes who come into direct contact with the public are the members of the car crews, and their appearance, dress, and manners are bound to give the public a favorable or an unfavorable opinion of the company. Street-car crews are brought into contact with many kinds of people. Occasions arise that severely try patience, but at such times the crew should remain quiet. The tirades of an angry passenger are, as a rule, the outcome not of any personal feeling against the crew itself, but of chronic resentment against railroads in general and that one in particular; no attention should be paid to any disparaging remark that may be made by a passenger; unless it has been caused by some remissness on the part of the crew, in which case the fault should be immediately remedied, as far as possible, and a quiet apology of some kind made. This will usually work a revulsion in the feeling of the offended passenger, and will, at least, make him less likely to take umbrage on the next occasion.

On the other hand, street-car employes often meet some of the best people in the land. If a crew gains a reputation for treating its passengers with courtesy and consideration, and for running its car on time, desirable passengers who have to make frequent or regular trips will endeavor to get that particular car; they then feel sure of receiving good treatment and, if need be, of making important connections elsewhere.

CONDUCTORS AND MOTORMEN

15. Responsibility.—Conductors and **motormen** are responsible to the superintendent or to a division superintendent; to him they report, and from him they receive all their general instructions. They are to some extent, however, subject to the orders of the depot masters, the inspectors, and the starters. The depot master has charge of the extra list and assigns men from it, as already explained. Inspectors and starters also, in some cases, are in charge, and car crews are bound to obey their orders. Men having regular runs or those called for extra runs must report to the starter at a stated time before their car is to start. All extra men must report according to the orders given them by the depot master, and each man must remain available for duty until the time assigned him has expired or until he is excused. No one is excused until his name appears on the excused list, except in case of sickness, when the starter must be informed in person or by special messenger. The depot bulletin board must be frequently consulted, and all new rules or instructions carefully noted. The official badge must never be worn except by the person to whom it is assigned. Employes are held strictly responsible for all company property entrusted to them. Each conductor is held accountable for all the company's money coming into his hands, and he should report to his superiors any persistent attempt to induce him to use such funds irregularly, or any attempt to take them from him.

ROAD DUTIES

16. The conductor is in charge of the car and the motorman must obey all reasonable orders regarding its conduct. If the motorman persists in breaking the rules of the company, thereby interfering with the proper conduct of the car, it is the duty of the conductor to report him. Under no circumstances should the motorman and conductor be away from the car at the same time, unless regularly relieved. In the absence of the conductor, the motorman is held responsible for the car and must inform the conductor as to the passengers that have entered it during his absence. Both the conductor and the motorman must be on the lookout for passengers. The motorman must not run by passengers unless instructed to do so by the conductor; he should then tell them to take the following car, at the same time pointing to the rear. Conductors and motormen are not usually allowed to sit while the car is in motion. While on duty, they must not shout or signal to crews on passing cars, nor must they carry on unnecessary conversation with each other, or any one else. Information concerning the affairs of the company must be given to no one save an officer of the company, who is authorized to receive such information. Reading while on duty is dangerous and is therefore strictly prohibited.

Passengers should be requested to wait until the car stops before attempting to get on or off; and some gentle but firm restraint should be imposed if necessary to enforce this request, especially if it seems quite evident that its violation might result in an accident. The attention of alighting passengers should always be called to approaching cars or other vehicles, which they might not otherwise see, especially cars approaching on the other track.

17. At Grade Crossings.—A motorman must bring his car to a stop not nearer than a specified distance from the nearest rail of a steam crossing, the distance being greater on a down grade than on a level or up grade. He must not proceed with the car until the conductor has gone on the railroad tracks, looked both ways, and given him the signal to start. The motorman should also be alert, and if he has reason to think that there is danger ahead, he should not proceed until he is certain that the track is clear. Before starting, he should look back to see that no one is getting on or off the car.

When derailing switches are used, the motorman should have the car under perfect control when approaching them.

Unless the switch has a special attendant, it is the conductor's duty to hold it closed while the car is passing; and in doing so, he must be careful that the switch does not open before the hind wheels are over.

18. On Platforms.—No one but those named in the instruction book should be allowed to ride on the front end of a closed car. If there is no room inside and a passenger persists in riding outside, do not try to throw him off, but appeal to the nearest inspector or officer, unless the rules solve the problem otherwise. Throwing a passenger off a car often results in serious complications; and if it is necessary to put him off, it is much better that an officer should do it.

19. Signaling.—If, for any cause, the motorman should stop the car without a signal from the conductor, and a passenger should wish to get on or off, the conductor must give the signal to stop just as if the car were in motion, but whether this signal is given or not, the motorman must wait for the conductor's signal to start. Motormen and conductors should familiarize themselves with the foot-gong signal intended to notify the conductor on a transfer or connecting car that the signaling car has transfer passengers for him. The conductor signals to his motorman, who repeats it to the car ahead.

20. Time, Conduct, Etc.—Each conductor and motorman should provide himself with a reliable watch, which should be kept to the depot standard time. Each car must run according to the time table, making each point at the time indicated on the time card. If a motorman should diminish the receipts by running ahead of time or by failing to stop for passengers, or should be guilty of any conduct that will hurt the record of the car, the conductor should give him due warning; and if such conduct is persisted in, should report him.

21. Precautions.—Before leaving the car house or the end of the route, conductors and motormen must see that the destination and route signs are properly turned; that the fender is on the front end; and, if at night, that the headlight is burning on the front end. When the car is run into the car house for the night, knock off the overhead switches, remove both controller handles, and dispose of them as the rules may require. Some roads require the crew when putting away a car, to switch off the car lights and pull down the trolley pole; others require that both be left on.

If the power leaves the line while the car is on the road, do not put the controller on a notch and sit inside the car to wait for the power to return; fatal accidents have resulted from this practice. The car lamps will generally tell whether or not the line is dead; if there is any reason to believe that the lamp circuit is out of order, try the controller at frequent intervals.

RULES OF SPECIAL APPLICATION

RULES FOR MOTORMEN

22. Starting Out.—Before starting out, the motorman should see that his car has the necessary supplies for the trip; that the sand box is full and that the sand rigging is in working order; that fuses are properly installed and that three or four extra fuses are on hand; that the car has a drawbar and pin; and if the road is long it will be well, if possible, to carry a few feet of rope, a small amount of wire, an extra trolley wheel, etc. Experience will very soon reveal what extra parts are most likely to be needed. Before the trolley is placed on the wire, preparatory to starting, the motorman should see that one or both overhead switches are at off-position and that the motor cut-out switches in both controllers are in proper position, so that both motors or both pairs of motors will operate when either controller is used. He should also see that both controllers are at off-position, and, after the trolley is in place, should close the overhead switch, set the reverse handle to point in the direction it is desired to go, and on receiving the proper signal from the conductor, he should release the brake and turn the controller handle to the first notch. If the car fails to start on the first notch, and no flash is heard on throwing the handle back to the off-position; see if the trolley wheel is on a line breaker, or if a circuit-breaker or switch is open, or if a fuse is blown. If none of these devices account for the failure, try the second notch of the controller, then the third, and so on up to the last series-notch, keeping the brake well in hand. With some types of controllers, if one motor is cut out, a car will not start with the controller on any series-notch. If the car fails to start on any of the series-notches, and the local rules will permit further trials, try the first parallel notch; if the car then starts, it is evident that one motor is cut out or open-circuited, leaving the circuit open on all series-notches. Unless the cause of the failure can be easily found and removed, the matter should be reported and another car taken.

23. Stopping and Starting.—The motorman should stop and start his car as smoothly as possible, and under no circumstances, should he start without the proper signal from the conductor. In stopping a car apply the brakes gradually, so as not to throw standing passengers. Release the brake a little just before the car ceases to move, otherwise the stop will be so abrupt as to be disagreeable. In endeavoring to make an emergency stop, apply a little sand first and then set up the brakes, but do not slide the wheels, or the stop will not be as quick as it would if they were allowed to roll on sanded rails. Moreover, sliding the wheels flattens them, especially if the rails are sanded. If the wheels begin to slide, loosen the brakes a little until the wheels roll, apply sand, and then apply the brakes again.

As a rule, do not apply the brakes while the current is on, nor the current while the brakes are on. There are some exceptions to this rule; for example, if the rails are so slippery that the wheels slide as soon as the current is turned on, a slight pressure of the brakes will retard their speed until they can grip the rails and start the car. There is less friction between rapidly sliding wheels and the rails than there is if the wheels turn slowly. Sometimes, also, when starting up grade, it is necessary to place the controller handle on the first notch before releasing the brakes; otherwise the car will roll backwards before the motors can start. Stops must not be made on curves except to avoid accidents. In starting or accelerating, never, unless it is absolutely necessary, throw the controller from series to parallel when on a grade or curve where the motors are taking a heavy current.

24. Never use the reverse switch to make a stop, except in case of great danger; and when using it for this purpose, do not throw the controller handle past the first notch until it is felt that the speed of the car is being checked. In such an emergency, throw off the current and throw the reverse switch with one hand while applying the brakes with the other. Then put the controller on the first notch and gradually release the brakes. When the reversed motors begin to check the car speed, move the controller handle another notch, but not until the brakes are released. If the reverse current is continuously applied with the brakes fully set, the wheels are held so that the motors cannot reverse them, thus defeating the object it is desired to obtain. If the controller handle is advanced too rapidly after throwing the reverse switch, there is danger of blowing the fuse, stripping a pinion, or breaking a motor frame. In order to avoid blowing a fuse in such an emergency, some managements instruct the men to use the generating power of the motors in preference to reversing them, as the fuse is not then in circuit.

25. **Coasting.**—In descending a grade, the car must be allowed to coast with the power off; it must be kept under perfect control and must not be allowed to go down faster than an empty car could be driven up the grade. The practice of making up time by running rapidly down grade, either with or without power, is dangerous; if the power is on, the motors may buck and give trouble; and if the car is coasting too rapidly, there is always danger of derailments or of collision. Coasting on level ground or on light grades, or at safe speeds down heavier grades, is economical, and should be done in preference to running on resistance notches to kill time. When ascending grades, use the series-notches as much as possible, even if there is no rule requiring this, because the motors then take much less current than on the parallel notches, and they are much less apt to give trouble.

26. Curves and Crossings.—Some roads prohibit cars passing one another on curves. In fact, on many roads, the curves are such that the cars cannot pass one another on them. In such cases, the car on the outer or longer rail usually has the right of way. Where two lines cross at grade, whether they belong to the same company or not, there is always some understanding as to the right of way, and all crews should be thoroughly familiar with it. If the two lines belong to the same company, main-line cars usually have the right of way; if to different companies, the agreement may be, perhaps, that north-bound cars on one line have the right of way over east-bound cars on the other, but that they must give way to west-bound cars. Such agreements are often based on local traffic or grade conditions at the point of crossing. In any event, it is a general rule for all cars to come to a stop before crossing another line either steam or electric.

27. Switches, Etc.—Never run, at full speed, over a switch pointing in the opposite direction; slacken the speed of the car to a point where, if the car should run off the track, little harm could result. Curves, crossings, and switch points must be taken at about the speed of a man walking leisurely. If two cars going in opposite directions reach the switch at the same time, both should slow down until they are past each other. Under no circumstances should the speed be accelerated when taking a switch, nor until absolutely certain that all wheels have taken the proper rails, and that the trolley is safely past the frog. Failure to observe this precaution has resulted in numerous derailments and damage to equipment. The motorman should familiarize himself with the location of all frogs and line breakers, and should reduce or throw off the current when passing them.

28. Obstructions.—If the streets are torn up for any purpose, or if piles of building or paving materials, or vehicles of any kind, are near the track, such obstructions should be passed with great caution, especially with open cars carrying passengers on the running board; otherwise these passengers are liable to be knocked off or hurt. Double-track roads using the guard-rail on open cars allow no one to ride outside the rail. The motorman should never attempt to run over stones or other obstructions large enough to make a derailment possible. If a rain storm floods portions of the track, the power should be shut off, if possible, while the car is passing through the water; but if power must be used, the speed of the car while running through the water should be as low as possible.

29. Cripples.—If a car stops or fails to start when the controller is in a running position, throw the controller to the off-position; locate the trouble before trying to start more than once from each controller. Ascertain whether the line is dead by turning on the car lamps or by noting if any other cars are moving. If the trouble is in the car instead of on the line, see whether a fuse is blown or a circuit-breaker is open; if so, the cause of the blow-out is probably a ground, and it should be found and removed, if possible. If a second fuse blows or a breaker opens on attempting to start, and the blow-out occurs on a series-notch, cut out No. 1 motor; if the blow-out does not occur until a parallel notch is reached, cut out No. 2 motor. Motormen should thoroughly familiarize themselves with the process of cutting out or in a motor or a pair of motors. If the cause of the blow-out is not thus found, and if it cannot be found elsewhere, summon help from the repair department, tie down the pole, and wait to be pushed in, or until the repairmen come.

The trouble may not be due to a ground, but possibly to an open circuit between the car wheels and the rails, due to the presence of dust or sand on the rail; or the failure may be due to a dead rail; or possibly to an open circuit in one of the motors. If the rail is dusty, ground the wheel to the rail with a switch iron, applying the iron to the rail first to avoid a shock. If the rail is dead, wedge the switch iron between the dead rail and one of those next to it. An open circuit in either motor will kill the car on all series-notches, but the car will start on the first parallel notch. If the trouble is a ground, there will be a flash when the controller is thrown on and off; with an open circuit there will not be.

30. Inspection.—Motormen should familiarize themselves with the devices entrusted to their care, so that they may be able to look after them properly and be qualified to meet the various emergencies that occur on the road. Unless otherwise advised, a motorman should feel that any available information in regard to the devices and their operation is at his disposal. He should also know that any information that he can give in regard to irregular actions on the part of his car will be a help to the repairmen. A motorman can often forestall some serious trouble by lifting the traps and giving the devices and connections a casual inspection whenever a suitable opportunity occurs. He should frequently inspect the sand box and replenish the supply when necessary. He can detect loose or exposed connections; chafing and rubbing motor leads; bad brushes, yokes, and commutators; loose brush holders and oil rings; open motor shells and gear-cases; loose, bent, or cracked suspensions; missing nuts, bolts, or springs; worn axle collars and brake shoes; bent truck rods and brake levers; hot starting coils and shunts; hot motor or motor bearings. Any of these conditions, if neglected, may soon result in serious trouble. If repairs cannot be made at the time, the remainder of the run can be made with due caution, and an intelligent report can be made.

One of the worst breakdowns that can happen to a car is for a suspension rigging to give way, allowing a motor to drop on to the street. Such an accident is especially dangerous if it occurs while the car is going at a high rate of speed. If cars do not get shop inspection regularly, it is essential that the crews inspect the suspension riggings at regular intervals.

31. Circuit-Breakers.—On metallic-return systems, circuit-breakers are sometimes used in conjunction with switches and fuses, and sometimes circuit-breakers alone are used. In either case, the two circuit-breakers on a car are wired in series, so that in time of trouble either or both of them may operate. They are placed under the car, where they take the place of the ground switches and fuse boxes, and where the noise of their operation cannot be heard. On ground-return systems, it is the usual practice to connect the circuit-breakers in series, but they are sometimes connected in parallel. Only one, however, is used at a time, the other remaining open. They are mounted overhead under the car hoods; and the motorman should see that the circuit-breaker in use is always the one on the front end of the car, the rear circuit-breaker remaining open; the active circuit-breaker is then where its action will not alarm passengers standing on the rear platform and where the motorman can quickly close it if it does open.

32. Handles.—A motorman must not leave his post of duty without taking the controller handles with him; and if straight air is used in conjunction with the hand-brake, he should retain the operating handle in his possession, even if his absence is to be but momentary. In removing the handles, remove the reverse handle first, then the power handle, then the air-brake handle; in replacing them follow the reverse order, replacing the air-brake handle first, then the power handle, and finally the reverse handle. This order of handling insures the motorman's possession of the reverse handle, which is the key to the motive power of the car, and insures his control of the air brake so long as he may be at his post. Never use any of the handles to turn switches; use a switch iron.

33. Car Speeds.—A motorman must so regulate the speed of his car that it will be as nearly uniform with the time card as possible. He must not wilfully or carelessly lose time on one part of the road in the expectation of making it up on another. If time is unavoidably lost, the motorman should make it up gradually by running a little faster for the rest of the run. The conductor can help him by hastening the entrance and egress of passengers and by signaling promptly.

A motorman can increase his usefulness to his company, and at the same time earn a pleasing distinction, by acquiring a fairly accurate knowledge of car speeds and the distances required to bring a car to an emergency stop when it is running at any of the several speeds in common use on the road. Testimony of this sort is often required in damage suits, but that usually given is so apparently ignorant guesswork that, as a rule, it has little weight.

34. Precautions.—When the car is in motion, all responsibility for safe running rests with the motorman. Appliances are provided for controlling the car promptly and they must be intelligently used to avoid accidents. Keep cool, exercise good judgment, take no risks, comply strictly with the company's rules, unless there seems to be very urgent reasons for non-compliance; these, with a proper knowledge of the way to use the controlling and safety devices provided, will go far toward avoiding accidents.

The moment a person or a vehicle of any kind is seen on the track, the motorman must get his car under perfect control at a reduced speed. Never take any risk in so important a matter, and do not approach the obstruction closer than is allowed by the company's rules. On nearing a wagon going in the same direction but on the other track, proceed very carefully, as the driver is very apt to turn in ahead of you; even if the foot-gong is sounded, the driver may forget that he is on the right track and, without looking, turn in ahead of the car.

The motorman must always sound the foot-gong when approaching cross-streets and roads along the line; also when approaching a standing car, or when wishing to call attention to the movement of his own car. Should the signal be unheeded, it must be repeated as often as is necessary.

No car should be run past a standing car faster than allowed by the local rules, usually 4 miles per hour; and in passing another car, the gong should be sounded to warn persons against moving from behind one car in front of the other. Motormen must comply strictly with the rules covering the spacing of cars; and where high speeds are in vogue, no car should start up a long steep grade until the car already on the grade has reached the top, unless derailing switches are used, in which case each car must be run so that there is always a derailing switch between it and the one ahead.

The motorman must pay strict attention to all *slow* and *stop* signs. A red light in the middle of the track at night, or a red flag in daytime, means danger. On hearing the gong of a fire-department vehicle, or an ambulance, or the company's repair wagon, the car should stop until it has passed. The motorman must be certain that the proper headlight burns at night and that neither the headlight nor car lamps burn in the daytime, except in dense fogs. All car lamps should be tried before dark to see that they are in working order. The headlight bulb and glass should be kept clean and the headlight lid closed.

RULES FOR CONDUCTORS

35. General Conduct and Responsibility.—The conductor must use no rude or obscene language while on duty, nor should he permit such language to be used in his car if possible to prevent it. He must be civil and attentive to all passengers, giving especial attention to ladies, children, infirm and elderly men, but must not place hands on passengers, unless to help them or save them from injury. An attempt should be made to keep standing passengers well up toward the front of the car, unless the doors in both ends are in use. The conductor should find seats for as many passengers as possible; by politely and quietly requesting a passenger who may be thoughtlessly occupying too much room to move up a little, he may make room for another to be seated; often, a nod to a standing passenger, at the same time pointing to a possible seat, is sufficient to make those seated near by move a little and make room. When not otherwise engaged, the conductor's place is on the rear platform.

The conductor is responsible not only for his own conduct, but to some extent for that of his passengers; he must use every effort to prevent drunken or disorderly persons from annoying other passengers. Good tact is of great value in such emergencies, and by the use of it very disagreeable scenes can often be avoided. The conductor has charge of the car and is responsible for its welfare, as well as for the proper treatment of passengers. He should under no circumstances leave his post of duty without notifying the motorman to take charge during his absence.

Each conductor, before taking out a car, is provided with a punch, pads of transfer slips, and with tickets on roads where the conductors are authorized to sell tickets. Before starting on a trip, he should see that he has all these and on his return should promptly turn in all company property according to rules.

36. Records.—Each conductor is also given a day card, on which must be entered his name and that of his motorman; also the record of his register, and the number of transfers and free passengers at the end of each half-trip, together with whatever other information may be required by his instructions. The record of the day card is very important, and the conductor is responsible for it, so that before handing it in, he must be certain that it contains no inconsistencies. If it becomes necessary to change cars during a day's work, both car numbers, the time of making the change, the reasons therefor, and any other connected facts that may be of interest later on, should be entered on the day card.

GENERAL DUTIES ON THE ROAD

37. Before starting out with a fresh car, the conductor must see that the lamp circuit and signal bells are in good order, and that the car has a lamp plug, if such a device is used. He must also take the reading of the register, and before giving the signal to start he must see that the brake on the rear end is not set.

Never give the signal to start the car when a passenger is getting on or off, and try to prevent passengers from leaving or boarding the car while it is in motion, using great caution to prevent their being run down by another car or vehicle when leaving a car. Aged, infirm, and afflicted persons should be allowed to seat themselves before the signal is given for the car to start. The rear door, brake, and controller should be kept as free from obstruction as possible. When the platform becomes too crowded, non-smokers should be politely requested to step inside. In making change inside the car, the conductor should face the rear platform. Inside front and rear gates must be kept closed on double-track lines, unless the rules state otherwise. Any disorder in chains, gates, guard-rails, or their fastenings should be promptly reported. Each conductor is expected to keep the inside of his car neat and clean.

38. When on a stand at crowded terminal points, and when approaching passengers at night, the conductor should announce clearly and distinctly the route and destination of his car. While on the road, he should announce the names of cross-streets, depots, ferries, public buildings, and all transfer points, even where there is no rule requiring him to do so. A conductor can add to his popularity and prospects by making all announcements in a loud, clear tone.

If any person should get an electric shock, however light, by touching any part of the car, the condition should be reported at once to an inspector or starter. During a thunder storm, turn on the car lamps, unless there is a rule against it, or unless the rules require that the cars stop running, in which case, tie down the pole.

39. Never allow a car to be run with the pole turned the wrong way. When a car is being towed, tie down its pole. The trolley should not be pulled from the wire when the current is flowing. Never swing the pole while the car is in motion, and do not put the trolley on the wire until the motorman is at his post, unless sure that one of the hood switches is turned off. Should the trolley come off while the car is in motion, grab the rope and pull down the pole; signal the motorman to stop, and do not replace the trolley until the car has come to a standstill; after replacing it, see if any one is getting on or off the car before signaling to start. The conductor should not allow passengers to handle the rope, and he should see that no passenger is in a position to be caught in a loop of the rope should the trolley leave the wire. The conductor should not operate the car for the motorman unless the company's rules permit him to do so. He should familiarize himself with the location of streets, public buildings, cemeteries, hospitals, asylums, and churches, and the manner of reaching them, so as to be able to answer promptly any questions that may be asked concerning them.

Conductors are not allowed to take charge of any article put on the car, nor assume responsibility for it, unless such article is delivered from some authorized officer or other employe of the company, or consigned to one. Each article of value left on a car by a passenger must be deposited with the starter, and attached to each must be a card bearing the conductor's name, the car number, date, place, trip, and time of finding it. No form of peddling should be permitted on a car, except perhaps the selling of newspapers; the rules of some roads permit newsboys to enter the cars. In case of an accident, however trivial it may seem to be, the conductor must carefully fill out the accident blank provided for that purpose.

All roads have rules covering the privileges of smokers. Usually passengers are allowed to smoke on the three rear seats of open cars. Rules in regard to closed cars differ; on some roads smoking is permitted on the rear platform, on others, it is not permitted at all. Whatever the rule may be, the conductor must see that it is observed.

40. When putting up the car for the night, the conductor must see that the rule in regard to the car lamps is observed and that the trolley pole is turned in the proper direction for running out the next morning. Any irregularity that has been noticed in the line, track, or action of any car should be reported to the starter, even if it has already been reported to an inspector on the road and noted on the day card.

FARES

41. The register must be set to *Up* or *Down*, *In* or *Out*, according to the direction in which the car is going, and according to special instructions referring to the direction designated. Fares must be promptly collected from every individual, except those exempted by the rules. Firemen and policemen in uniform and employes wearing badges, are generally exempted from paying fare. The number of free passengers that shall be allowed to ride on a car at once, except when going to a fire or a wreck, is generally specified in the rule book, and the rule must be enforced. All in excess of the prescribed number must pay their fare or take a car following. Employes riding free must not occupy seats to the exclusion of passengers who have paid fare. Conductors must be familiar with the passes and cash-fare tickets issued by the company and must, as far as possible, have in mind the numbers of pass books and badges that have been called in. The depot bulletin board gives a list of those wanted and should one of them be presented as a fare, it is the duty of the conductor to take it up. Fares should not be collected when the car is approaching railroad crossings, curves, switches, or transfer points if the conductor's attention is needed elsewhere.

If a passenger finds that he is on the wrong car and demands the return of his fare after it has been registered, the conductor must use his judgment about refunding it, unless there are specific rules covering such cases; but if the fare is refunded, a record should be made on the back of the day card, stating date, trip, and time of day, and all subsequent fares should be registered as usual. Should a conductor find that he has rung up more fares than he has received, the mistake must be settled at the office.

When, on account of a disabled car or damaged track, passengers are transferred to another car at any place other than a regular transfer point, the number of passengers transferred must be noted on the back of the day card, together with the cause, time, date, and numbers of both cars. No fares are to be collected by the conductor to whose car the transfer is made. The conductor must remain in charge of a disabled car until relieved, and must see that all passengers have received the transfers asked for, so far as the rules of the road permit.

42. If the company's rules do not permit the issuing of transfers for transfers, that is, successive transfers on the same continuous trip, there is generally some rule requiring the passengers to ask for the desired transfer at the time of paying his fare. Some such rule or its equivalent is usually necessary, because after collecting a number of fares and transfers, it would be very difficult for the conductor to remember who is entitled to transfers and who is not. If a conductor attempts to remember this and persists in his views when a passenger disagrees with him, it makes an opportunity for innumerable disputes, some of which will result in disagreeable scenes and all in making enemies for the road. By quietly asking each passenger paying a cash fare if he wishes a transfer, and issuing it then if one is desired, the rule can be enforced without difficulty.

EJECTIONS

43. Never eject a person from the car unless it seems necessary for the comfort or safety of other passengers, or unless the justice of the action is very apparent. If there is any doubt whatever as to the justice of a passenger's position, give him the benefit of the doubt, but note all the facts on the day card. If a passenger is making himself obnoxious or very disagreeable to others, or is endangering their safety or destroying the company's property, or if he arbitrarily and unreasonably refuses to pay fare, it is the conductor's duty first to remonstrate quietly but firmly and to use all the tact at his command to abate the nuisance or collect the fare, and failing in this, to call an officer; if no officer is at hand, it is sometimes a conductor's duty, as a last resort, to eject a passenger. The motorman's assistance should be enlisted if it is needed, and no more force should be used than is absolutely necessary. Every care should be taken not to injure the passenger being ejected, or any of the others, and names and addresses of witnesses should be taken to sustain the action.

DUTIES OF HIGHER OFFICIALS

INSPECTORS

44. General Duties.—**Inspectors** are among the most valuable employes of a large railroad system; their duties, in general, are to assist the superintendent or manager in the proper management of the road; to him they report, and from him they receive their instructions. Each inspector must be alert to discover the needs of the public, such, for instance, as are involved by entertainments, picnics, exhibitions, or gatherings of any kind to be held along the portion of the line over which he may have charge; and he should keep his superintendent informed, so that provision can be made to handle unusual crowds satisfactorily. The inspector must at all times aim to improve the service, and must recommend to his superintendent any changes that will effect improvements. To each inspector is assigned a portion of the system, and all cars, car crews, etc. in his section are under his supervision.

45. Rules, Time Tables, Etc.—The inspector must keep himself thoroughly familiar with all rules, special instructions, etc., affecting the running of cars or the conduct of car crews. Rules are not always clearly worded, and the inspector must be prepared to explain all uncertain passages and to give a temporary decision where the rules apparently conflict in any way. In times of emergency, he may even be required to give special instructions not covered by any rules. He should report at once to his superintendent all real or apparent discrepancies in the rules, so that, if necessary, the rules may be revised. Each inspector should provide himself with copies of rule books, etc., which he should keep available for ready reference. The inspector must do all in his power to see that the rules and regulations are complied with, and he must report any gross infractions.

Inspectors must keep thoroughly conversant with the time table in force, and must see that all cars are run as nearly as possible on time, and that the cars over any line are properly spaced. They must recommend to the superintendent at any time such changes in time tables as may seem best to them for the improvement of the service.

46. Relations to Car Crews.—Each conductor and motorman, when operating a car, is subject to the orders of the inspector in charge of the section of track over which the car may be running. The inspector has authority to relieve either member of a car crew when unfit for duty, on account of sickness or for any other reason; he must therefore be qualified to take charge of either end of a car. He should make note of the appearance and conduct of the men on duty as well as of the appearance of the cars, and should insist on neatness and cleanliness of men and cars and on an invariably courteous treatment of the public; he should see that the cars are heated, lighted, and ventilated according to rules, and that signs, fenders, seats, etc. are properly arranged and in good condition.

On entering a car, the inspector should count the passengers and compare the number with the number of fares registered; if there are more passengers than there are fares registered it would appear that the conductor has not collected or rung up all the fares, and an explanation should be demanded. All unnecessary conversation with other employes of the road should be avoided while on duty. An inspector should use every reasonable effort to gain the good will and cooperation of the men under his charge, and should impress on them the fact that he desires to help them in the performance of their duties. He should have a correct list of badges, passes, etc. that have been called in, so as to be able to sustain a conductor who may take one up or to advise him of a mistake he may be making in so doing. An inspector in charge of a section should not attempt to give general orders; his orders apply only to the operation of cars while under his supervision, and if it can be avoided he should give no order not in harmony with general orders.

47. Blockades, Accidents, Etc.—Unless called elsewhere, an inspector should remain near that portion of his section, where traffic is most dense, or where blockades seem most likely to occur. He should be familiar with the location of all fire-alarm boxes in his territory; and if an alarm sounds, he should go at once to the scene and be prepared to keep the cars moving as soon as circumstances will permit. He should make a special effort to keep mail, express, or parlor cars moving. He must also be familiar with the location and operation of all section switches on the line, so that he can promptly cut out a section if necessary. If a blockade occurs, the inspector assumes charge until the arrival of a superior officer; and when it is relieved, he must send on the cars one at a time, keeping them as far apart as he thinks the circumstances will permit. If the cause of the blockade is likely to last some time, as in case of a fire, the terminal depots of the affected line must be notified at once. The superintendent, also, should be notified in order that he may give the necessary instructions as to the running of the cars on other lines, and, if necessary, have the power cut off from the affected section.

If the power should become low during storms, or for any other cause, the inspector should instruct the crews to turn off the heaters, or at least to run them on the first notch, unless the rules of the road forbid this. The crews should also be instructed to effect any other economies possible, as in economical running, use of lights, etc.

48. If an accident occurs, the inspector must go at once to the scene and assist the conductor to obtain and record all possible information that may be of use to the company, including names of witnesses. He must assume charge, if necessary, and must avoid all unnecessary delays. An inspector must see that every accident, no matter how trivial, is reported at once to the proper department of the company. If any one is injured, everything possible should be done to make the person comfortable; an ambulance or other medical aid should be summoned at once, if necessary. All company rules governing accidents must be closely followed, and the inspector must see that conductors' records are properly made out.

No employe should, under any circumstances, give out any information concerning a blockade or an accident to any one but a duly authorized representative of the company, except to state approximately how long a blockade may last.

The inspector must see that conductors do not give the signal to start while passengers are getting on or off the car, and that motormen under no circumstances start the car until they have received the proper signal from the conductor to do so.

49. **Cripples.**—If a car is crippled, the inspector must use every means in his power to avoid delaying the cars behind it. If the car can run but cannot make its time, let it run in, stopping only to let off passengers; if it is dead, let its follower push it to the nearest turnout, or, possibly, to the car house, where it will be out of the way. If the car must be pushed in, see that the two cars are safely coupled together, then politely ask the passengers of the disabled car to transfer to the good car, so as to put the weight where it is needed and leave the view through the crippled car unobstructed. When a car is being pushed, it should be done cautiously and slowly, allowing it to help if it has a good motor, and using its brakes to aid in stopping; but if the car is completely disabled, or "dead," tie down its pole. Inspectors should see that every car on the road has a pin and drawbar.

50. Precautions.—Every inspector should carry a pair of pliers, a screwdriver, a small wrench, a roll of tape, and some extra fuses. If the line is a long one and his assignment is at some distance from the car house or depot of supplies, he should keep at one or more convenient points two or three spare trolley wheels, a wheel and pole complete, a few extra lamps, 10 feet or more of No. 10 flexible, rubber-covered wire, a piece of rope, an extra drawbar, and a few extra motor brushes of each kind; with this equipment, he is ready for almost any emergency. He should be familiar with the motors and connections of the equipments used on his division, and should be able to locate any open circuits or grounds that may occur on them. He should see that every motorman has a switch iron and bell button; that switches and grooved rails on curves are kept clean; and that the rail is kept well sanded at grades, junction points, crossings, and terminals, where it is slippery.

DEPOT MASTERS

51. Some of the duties of the **depot master** are very similar to those of an inspector. The depot master is under the supervision of a superintendent, to whom he reports and from whom he receives instructions. The depot and all company property in and around it, as well as all persons employed therein, are entrusted to the care of the depot master, and he is responsible for the proper performance of all depot duties. He must see that enough good cars are kept on hand to fill the time table; that the cars leaving the depot are clean and in good order; that the fenders are in good shape; and that all cars carry the proper signs to indicate their destination and routes. He must see that the depot does not run short of signs; and in case of route changes or innovations, that the proper signs are obtained, and that those signs that are not in use are properly stored away.

52. The Depot.—The depot master must see that the depot is kept in an orderly manner, and that all necessary arrangements are made to carry out the conditions of the time table; that the men report in time; that the cars leave on time; and, as far as possible, that they return on time. He must also see that the cars are so arranged that no confusion will be caused in the depot when they are pulled in or run out. He must be familiar with the rules and regulations of the company, and must see that the men obey them while under his supervision. He must preserve order among the men, enforcing the regulations in regard to loud talking, lounging, etc. Motormen and conductors must be provided with all the appliances necessary to the safe and proper conduct of their cars and no man should be permitted to go on duty unless his appearance is up to the standard required by the rules. Any incivility, rudeness, violation of rules, or insubordination that may come under his observation must be reported to the superintendent.

53. Care of Property.—The depot master must see that all articles left on cars by passengers are turned over to him properly tagged; and that such articles are promptly forwarded to the *lost-property room*, to which all persons applying for lost articles must be directed. No transfer of cars, men, or property must be made from a depot without a written order from the proper authority, and notice of any transfer should at once be sent to the superintendent. The depot master must make the crews understand that they are responsible for the safe return of property entrusted to their care.

54. Reports and Records.—The depot master must see that all reports and blank forms used in the transaction of the company's business are properly filled out and forwarded to the proper department or filed, as the case may be. He must see that the crews' daily reports contain no inconsistencies and that the correct number of trips are accounted for. He must see that all conductors make prompt returns to the receivers, that all returns and records are made according to instructions, and that all shortages are collected or adjusted. He must see that all accident reports are complete before submitting them to the superintendent.

55. Blockades, Wrecks, Etc.—The depot master should be promptly notified in case of fires, wrecks, storms, or other casualties liable to cause delay or blockade. He will, unless otherwise instructed, repair to the scene of any blockade that may occur and take charge of the running of cars, notifying the superintendent before leaving the depot.

If the blockade is caused by a fire, or by the line being down, due to a storm or other cause, the nearest emergency crew should be called out. Should the blockade be caused by a badly derailed or a disabled car, the wrecking crew should be hurried to the scene. Every depot master should insist on having at his depot a wrecking car, properly equipped with track jumpers, ropes, drawbars, chains, jacks, blocking, chisels, crowbars, sledges, etc.

In case of snow storms, the depot master must arrange all the details for keeping the track clean. He must provide plows and sweepers and keep them in good repair, assign the crews necessary to operate them, and must designate the lines most necessary to be kept open. He must detail men to sand the rail at dangerous places on his division and must be ever ready to meet emergency demands.

The depot master is expected, through his men, to keep in touch with any defects in the line, track, or bridges, and to report them to the superintendent. Pending repair, he must, for the benefit of those men who may not have noticed the defect or who may not appreciate its gravity, post on the bulletin board a notice calling attention to it, together with any admonitions in regard to precautions to be taken when passing the affected point.

RECEIVERS

56. The main duty of the **receiver**, as far as the conductors are concerned, is to receive and check up their money and other fares; he also furnishes change on application. He is, as a rule, required to make up the money into packages of specified value, ready for the bank. To facilitate this work, he is provided with a glass tablet or other hard surface, and a drawer divided into separate compartments designed to receive money of the several denominations. He is provided with coin wrappers of such size that all coins will make up into a neat roll of the prescribed value. When a day or night receiver is relieved, he should count all his money, require his successor to check the count, and take a receipt for the amount.

Receivers and all other employes handling money or stores are, as a rule, required to give bond. Receivers are under the supervision of a superintendent, unless otherwise instructed. They, however, respect the orders of the depot master and comply with the regulations of the accounting department.

MISCELLANEOUS POINTS

DISABLED CARS

BROKEN CAR AXLE

57. If a car, while in service, breaks an axle, the conductor or the inspector on duty should at once notify the depot master, the division superintendent, or other designated authority, stating the nature of the break and the exact location of the car. The nearest wrecking crew should be despatched at once to the scene; and if a wrecking car is sent, it should go by the route that will enable it to approach the disabled car from the end most advantageous for working. Pending its arrival, the crews of the disabled car and of other cars in the vicinity should do whatever they can to forward the work of opening the line again. If the accident occurs during rush hours at a point where there is considerable traffic, it may be necessary to push the car off the track and leave it until it can be handled without delaying traffic too much.

The help of the wrecking crew will be necessary to get the car off the track, but before its arrival one or two other cars may be able to push the disabled one to the nearest curve, where it may be derailed more easily, and, by running a heavy timber from a point on the truck of the crippled car to the bumping block of the follower, push it at least partially off the track. The crippled car must be pushed along the track in the direction that puts the broken axle at the rear end. The removal of the car from the track can be completed by the wrecking crew by means of jacks, steel ways, or skids, etc. When a car has been thus thrown out of the way, it is usually advisable, before replacing the car on the track, to put in new wheels, or make repairs enough to enable the car to run to the repair shop on its own power; this is especially so if the nearest repair shop is a long distance away.

58. If the blockade will not be too serious, it is better either to repair the car at once or to push it to the repair shop, rather than to push it off the track. The motor and car journals often hold the broken ends of an axle rigidly enough to compel the wheels to follow the rail, although the binding effect may be so great that the axle cannot turn. In such a case, both wheels of the broken axle should be chained to the truck to prevent any possible turning, and the car then pushed or pulled in, the sliding wheels being on the rear end; they would not so readily follow the track if in front. Should the break be on the forward end, a single-truck car must be blocked up under the center and swung around with jacks; a double-truck car can be blocked up at one end and the defective truck swung around. If a maximum traction truck has the large axle broken, and the two trucks cannot be made to exchange ends, a new axle must be put in.

BROKEN AND LOOSE WHEELS

59. If a wheel breaks, or any other accident happens that completely disables a car, the depot master and others in authority should at once be notified and the help of the wrecking crew obtained as soon as possible. A wheel with one side broken off may be turned by means of pinch bars until the unbroken part rests on the rail, and chained in that position, so that it cannot turn; the car can then be hauled to the nearest shop, the broken wheel sliding along the track.

If a car wheel is so badly broken that there is no portion on which it can be made to slide, the car can be run in by passing a piece of rail under the axle, allowing one end to slide on the track and securing the other end to a cross-member of the truck or to a second piece of rail run across. Some street-railway companies keep a special truck with wheels smaller than the standard, ready for such breakdowns.

The disabled car is raised just enough to get out the truck with the broken axle or wheel, the special truck is run under, the car is lowered on to it, and then run in, possibly with its own motor, if it has one in working order.

A loose wheel may be chained and the car run to the shop on the others with the chained wheel sliding. A loose car wheel gives much trouble to crews not familiar with its action; if on the front end, a loose wheel will not stay on the track. If a car is continually leaving the track, it is probable that it has a loose wheel.

DERAILED CAR

60. If but one set of wheels is derailed on a paved street or where the roadway is firm and nearly level with the top of the rails, the car crew can usually replace it without summoning help. If the car is run in the direction of the wheels still on the track, the tendency of the rear wheels will be to climb back into place; and if they strike against obstructions such as stones, blocks of wood, replacers, or even sometimes a fish-plate or a rail joint, they will climb over it and slide on to the rails. A double-truck car with all the wheels of one truck off is sometimes more troublesome, for the rear truck may swing around under the car. Chain connections to the car body prevent them from turning far enough to snap the brake and cable connections. Often, the derailed wheels of either a single- or double-truck car can be run back on to the track by reversing, and in many cases this should be the first method tried. If the four wheels of one truck of a double-truck car must be raised by rolling them upon inclines or blocking, the wheels on each side must be blocked alike, otherwise the truck will turn when the car moves. If the wheels of a derailed truck slip when current is applied, their motor should be cut out of circuit and the attempt made to move the car with the other motor.

If all the wheels of a car are off, but remain close to the rails on hard road, the methods just described can be used by replacing one end at a time. With all wheels off, it will be necessary to make a connection between the truck and the rails before applying current to the motors; this can be done by hanging a switch iron to the truck so that it will drag on the rail.

61. If a car is derailed on unpaved or muddy streets, and the crew is inexperienced or without the tools necessary for replacing it, the depot master or others in authority should be advised at once and the wrecking crew summoned. Wheels down in soft soil will often become more deeply embedded when an effort is made to draw them upon blocking. In such a case, the car must be raised by means of jacks placed on slideways or skids, and then lowered on to the rails. A derailment may sometimes be so bad that the attempt to replace the car at once would result in a serious blockade, in which case the line should be cleared by pushing the car clear of the track, and replacing it during a time when traffic is less dense. A car off the track in soft soil, or one clear away from the track, may be drawn back by hitching one or two other cars to it. A derailed car that has taken a position across a double-track road is worked on to the track that seems most convenient.

BROKEN MOTOR SUSPENSION

62. Car-motor suspensions occasionally give way, one side of a motor dropping to the track and the other side remaining attached to the axle, thereby rendering further progress of the car impracticable. If possible, the wrecking crew should be summoned at once. It is a simple matter for these men to raise the motor with jacks or hoists, and secure it temporarily, or even permanently in place. But if a wrecking or shop crew is not available, it is often practicable to get the motor up off the track and secure it in a manner that will enable the car to run to the car house or to the nearest turnout. To raise the motor, apply the brake and block the wheels, so that the car cannot move when current is applied; cut out the motor that is not down, and place the reverse handle in such a position that when the current is applied the motor that is down tends to rise from the ground; alternately apply and cut off the power, and each time the motor rises, shove a piece of blocking under it. In this manner, the motor can be gradually raised even above its normal position. The drawbar or a piece of rail or timber may then be laid across the open trap in the car floor and the motor tied to it with the trolley rope, doubled as many times as its length will permit.

Another method of raising the motor, in order to temporarily secure it in the same manner, is as follows: One end of the dropped motor being hung to the axle, is considerably above the level of the track, and by placing a stone under the raised end and operating the car slowly, the motor can be dragged upon the stone; by repeating this process several times, using larger stones each time and being careful that the motor is not dragged too far, it can be raised until both ends of the motor are level. By tying up the motor at the end of each process, there will be no danger of losing all that has been gained. Unless the tied end of the motor is finally secured well above the axle end, the rope may stretch or slip and let the motor down far enough to rub the track and possibly give further trouble. Care must be taken to form a knot that is not likely to slip. To raise the motor still higher, lay a piece of wood 1½ or 2 inches thick and about 1½ feet long on each track rail, and carefully run the wheels upon them; then place a blocking so that just as the car wheels are rolling down off the pieces of wood, the bottom of the motor will strike it and be forced farther up, in which position it can be secured as already described.

ICE AND SNOW FIGHTING

63. In those sections that, during the winter, are exposed to alternate thawing and freezing, water sometimes settles in low portions of electric-railway roadbeds and freezes, so that between the rails and just outside them is a solid sheet of ice. The continual passing of cars keeps furrows cut along each rail; water fills these furrows and is thrown by the car wheels on to the bed of ice; freezing there, this gradually raises the height of the ice, until the motors, and even the journal-boxes, rub so hard on it that further running becomes impracticable until the ice is chopped away. Proper drainage will prevent such an occurrence.

64. Fig. 1 shows a **snow plow** or scraper used by the International Railway Company, of Buffalo, New York, for keeping down accumulations of ice between the rails and for removing light snow. The snow or ice is removed by mold boards *a* made of 14-inch heavy planking reenforced with steel sheathing and hung underneath a short-bodied single-truck car at an angle of about 45° with the line of the track. There are two such boards under each plow, one for each direction of travel; each plow also has movable wings *b* for

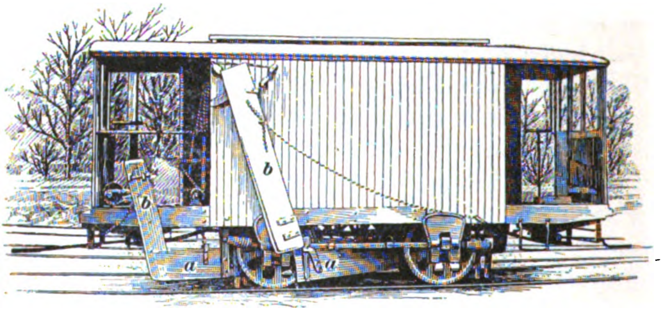


FIG. 1

pushing back the snow from beside the track. The boards run in vertical grooves and are raised and lowered from the vestibule by means of a chain wound on a drum by hand power; they can be run as close to the roadbed as is necessary to clear away all ice and snow that will interfere with running cars.

65. Fig. 2 shows another type of plow, used for removing deeper snow. This plow has a short heavy body mounted on a single truck and carrying at each end a heavy nose, or shear *a*. The position of the shears may be adjusted by hand power from inside the car body by means of chains and drums. Heavier double-truck plows similarly arranged are used for bucking snow drifts, as explained later. Snow plows for use on single-track roads are sometimes provided at each end with a V-shaped nose or shear, like the cowcatcher of a locomotive, so that the snow is shoved off both sides of the track. Snow plows must be very substantially built, as they are necessarily subjected to very hard usage and great pressure. On some of the heavier ones, the shear or scraper is raised or lowered by means of a screw and hand wheel, and is counterbalanced, so that a small force applied to the wheel will adjust a very heavy scraper. An occasional coat of grease, applied with a brush to the front of the shears, will prevent snow from sticking and thus greatly increase the effectiveness of the plow.

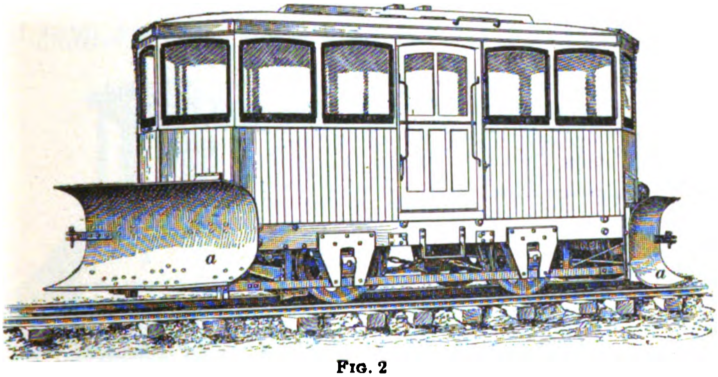


FIG. 2

66. A **snow sweeper** consists of a car body mounted on single or double trucks, according to the weight and power desired, and having the usual motors attached to the trucks for propelling the sweeper, as well as one or possibly two extra motors inside the car, used to operate two cylindrical brooms, one under each end of the body. Fig. 3 gives a general idea of the appearance of a single-truck sweeper. The angle of the brooms to the line of the track is made such as to throw the snow clear off the track, and means are provided by which the height of the brooms from the track may be adjusted; they should be low enough to clear away all snow that may cause trouble, but need not sweep the ground perfectly clean. Some companies object to sweepers because they clear away too much snow, and make it difficult for vehicles on runners to cross or travel on the bare tracks, with the result that they interfere with the running of the cars; it is therefore sometimes better to leave about 1 inch of snow on the tracks. Some sweepers have wings on the sides, as shown at *a, a*, for clearing a space each side of the track; curtains *b, b* prevent snow and dirt from being thrown on persons passing the sweeper when in operation.

The broom motors have controllers that are independent of the car motors. In operating a sweeper, care must be taken that the brooms rotate in the proper direction, that their height is properly adjusted, and that all bearings are kept well oiled.

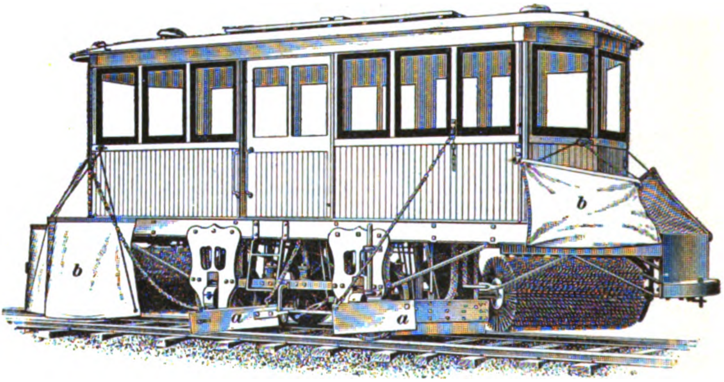


FIG. 8

67. Generally, a good sweeper well handled will keep several miles of double track open for car traffic, provided that the snow is loose; but if there are drifts over the tracks, or if, before the snow is removed from the track, a slight rain is followed by sleet and hard freezing, a plow must be used to remove the drifts or loosen the surface of the snow, so that the brooms can handle it. In hard snow storms, a plow and sweeper are sometimes sent out together, with the plow in front. If the plow encounters a large, hard drift through which it cannot cut its way, the brooms on the sweeper are raised, the plow and sweeper, coupled together, backed some distance from the drift, and then rushed into the drift at a speed of 15 or 18 miles an hour. Striking a drift under high speed in this way is known as **bucking** it, and is sometimes the only way of getting through. It is sometimes necessary to repeat the process several times before an opening can be made; the necessity for very rigidly constructed snow-fighting apparatus is thus easily seen. A heavy snow plow will force its way through very deep snow if its wheels remain on the track, so that good traction is obtained.

TRIAL EQUIPMENT

INTRODUCTION

1. By **trial equipment** is meant either an equipment placed on trial to determine, from its performance, whether it is adapted to the work in hand, or the first of a number of equipments that it has been decided to install. In either case, the trial equipment will require more careful inspection than succeeding ones, because future orders depend on its record, and data must be obtained that will save time in the subsequent work of installation. The full shipment must be inspected and tested to a certain degree to make sure that no parts or devices are missing or seriously defective. Under present conditions of competition, it is reasonably safe to accept the manufacturing company's selection of equipment to suit existing local conditions, but it devolves on the installing company to see that the apparatus goes into service in good condition; that the motors are not grounded or short-circuited; that the armature and car axles are not allowed to start unlubricated; that the gears are perfectly adjusted; and that many other details are properly attended to. In order that the equipment may have a fair trial on its merits, it is necessary that the apparatus on the car should be free from faults such as might have occurred during its journey from the factory, or from faults brought about by mistakes in installation. Most of the inspection work is done in the car barn, and the tests are made both in the car barn and on the trial runs.

INSPECTIONS AND TESTS

FLOOR INSPECTION

THE MOTORS

2. The Frame.—The joint between the motor shells must be examined to make sure that it is tight, otherwise water and dust will enter the motor and the magnetic circuit may be weakened sufficiently to cause an abnormal current and consequent roasting of the field and armature windings and throwing off solder from the armature connections. See that all field-coil or pole-piece bolts are drawn home; a loose pole piece or field coil is liable to get down far enough to rub the armature, and a loose pole piece has the effect of an open motor frame. Be assured, as far as possible, that, in drawing down the pole pieces, insulation or foreign matter has not been caught between the pole piece and its seat, thereby adding an air gap to the magnetic circuit. See that the internal field connections are properly taped and shellaced, and that the field terminals have not been interchanged with each other or with the armature terminals where they come through the frame bushings. See that no small tools are in the bottom of the shell; any tool left there will eventually be drawn up by the armature, thus ruining it. See that the commutator cover and all handhole covers are in working condition, are water-tight when closed, and that the attachments provided for the purpose of keeping them so are properly adjusted. It is well to clean the armature bearings and fill the boxes with clean waste in order to catch any grit that might get into the boxes when the lids are up; this should be done when the motors are shipped. See that the guard, or dust, plate provided on the commutator-end armature bearing is securely in place. Finally, see that a substantial motor ground connector is provided and that its screws work properly.

3. Brush Holders and Brush Adjustment.—The **brush holder** and its dependent apparatus—yoke, springs, hammers, brushes, and shunts—are the parts likely to give trouble in operation, and their inspection must be frequent and thorough. The brushes must include the proper number of bars between them, and in almost all cases must be at equal distances on opposite sides of a vertical line drawn through the center of the commutator when the motor sets level. In recent types of railway motors, the holders are not adjustable in a circular line; the correct position of the brush-holder studs, or guides, is determined and the holes for securing them are drilled through a templet, so that all holders will set alike. Notwithstanding such methods, non-adjustable brush holders occasionally lose set, especially on cars that have been in operation for some time.

It is well to count off the brushes on a motor that is to run in a trial equipment. The distance from center to center of the two brushes or sets of brushes should include one-fourth of the circumference of the commutator; as the commutator circumference changes with wear and the number of body-bar units does not, it is customary to set the brushes with so many body bars between centers. On all four-pole motors, it is sufficient if the distance between the centers of brushes of opposite polarity includes the width of one-fourth the total number of bars plus the width of two mica bodies. Thus, on a commutator having 99 bars, if the brushes are set according to this rule, a count will show the distance between centers to include $99 \div 4 = 24\frac{3}{4}$ bars plus the space occupied by 2 mica bodies. Assuming a brush (two half brushes) to span 2 bars and 1 mica body, the correct space between the inside edges of the brushes would be that taken up by $22\frac{3}{4}$ bars and 1 mica body, or approximately the space occupied by 23 bars.

The correct way to get the exact theoretical setting of the brushes, assuming all bars to be uniform in width and all mica bodies to be uniform in width, is illustrated in Fig. 1, which represents the development of a 33-bar commutator. Represent such a development on thin paper and double the paper twice. The number of bars and mica bodies between the creases will show the exact number to be included between brush centers. When applying this scheme to any particular commutator, take a piece of thin pasteboard whose ends just meet around the commutator. Cut the strip of pasteboard into four equal lengths, then cut from one of the lengths a piece as long as the width of one of the brushes to be used. The piece left can be used as a templet for setting the brushes on that commutator, the brushes being set at opposite ends of the piece bent around the commutator. After the brushes are set, turn the commutator until the inside edge of one brush lines up evenly with the edge of a bar, then count the bars, to the fraction, to the inside edge of the opposite brush. This count will be correct, not only for the commutator in question, but for any commutator, irrespective of size, provided that it has the same number of bars and brushes, because as wear reduces the circumference of the commutator, the bars become thinner.

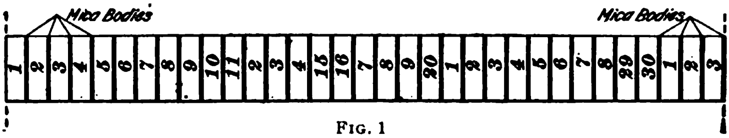


FIG. 1

4. The brush holders should set well down toward the commutator ($\frac{1}{8}$-inch clearance is good practice), but should not touch it. The greater the clearance between the holder and commutator, the greater is the liability of the brushes to chatter, the greater the likelihood of a high or a low bar breaking the brush, and the greater the tendency of the brush to wear two bevels on its commutator end, one or the other of which will make contact, according to the direction of rotation of the armature. A brush must not be too loose in the holder, for it is then liable to rattle, break, or wear a double bevel; on the other hand, it must not fit tightly, because if so fitted it will swell and stick. If a warm brush has $\frac{1}{64}$-inch clearance in a cold brush holder, good results will obtain under all conditions of operation. Brushes, like commutators, are of different degrees of hardness, and a brush that will give satisfaction on one motor may not do on another. The proper brush to use is often determined by experiment. The brush holders must be held immovable by the studs or yoke; otherwise, commutator friction will pull them out of set in the direction of rotation. Try all brush-holder bolts and nuts to see that they are firmly in place.

Be certain that the brush-holder spring is in good working order and adjust its tension until pressure of the brush on the commutator is about 4 pounds per square inch of contact surface. For stationary generators and motors, a pressure of from 2 to $2\frac{1}{2}$ pounds per square inch of brush contact surface is often used; for railway work, the pressure should be heavier, on account of the jarring to which the motor is subjected. It is well to find out by test just what is the best pressure for the type of motors used, ascertain the condition of the roadbed, and then adjust the brushes accordingly.

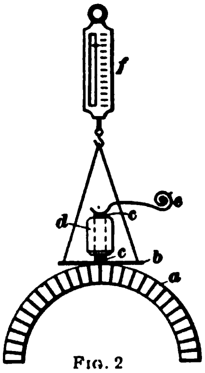


FIG. 2

The total pressure to be exerted on each brush is obtained by multiplying the area of its contact surface, expressed in square inches, by the pressure per square inch; this pressure can be measured by an ordinary house scale, as indicated in Fig. 2, where *a* is the commutator; *b*, a light strip of steel; *c*, *c*, the brush; *d*, the holder; *e*, a combination brush spring and hammer; and *f*, the scale attached to *b* by a string. The scale is lifted bodily until *b* just leaves *a*, when the scale pointer will show the pounds pressure exerted by the spring. Dividing this by the contact area will give the pound pressure per square inch.

By making this experiment with brushes of different lengths, the variation of pressure with wear can be determined. Such experiments often suggest the advisability of using a stronger or a weaker spring, or one exerting more uniform pressure between the wearing limits of the brush.

5. All **pivots** must be free in action: a little oil and a little working up and down by hand will help them. The brush hammer must be so alined that, as the brush wears down, the hammer will enter the brush-holder slot provided and not ride on the top of the holder, thereby removing all pressure from the brush—a condition certain to cause the current to flash over. See that excessive armature end play does not allow the heads of the commutator bars to come over against either brush holder; also, that the brush holders are free from interference with other motor parts. Finally, good connection of the brush-holder shunts must be insured. These shunts are used on motors of the larger powers to carry the current from the brush-holder terminals to the brush itself. If the shunt connection is in bad condition, the heavy current must pass through the contact surface between the brush and holder, with the probability that enough of it will pass through the brush-holder tension spring to heat it, draw its temper, and weaken it.

6. Bearings.—The **motor axle bearings** must fit the axle. If too small, they must be bored larger, care being taken to restore the oil feed grooves that the boring may have removed or rendered too shallow. If too large, they must be rebabbitted to fit the axle, care being taken to cut new feed grooves and to keep the hole for the axle in the center of the box, so that the axle will be thrown neither away from the pinion, thereby introducing the effect of excessive wear, nor toward the pinion, thereby decreasing the clearance between the pinion and gear and introducing a tendency to bind, thus wearing the pinion and heating the armature bearing. If the bearings have Babbitt linings, it will only be necessary to melt out the Babbitt, add sufficient new Babbitt of good quality, and rebabbitt the shell to proper size. If the shells are of solid brass or phosphor-bronze, however, they must be counterbored or have holes drilled in them before babbitting, to hold the Babbitt lining in place and prevent its getting loose and turning with the axle. The bearing seats in the motor frame are provided with dowel-pins that engage a split hole in the line of junction of the half shells. These dowel-pins act as guides to insure the proper placing of the halves of the shell in the block and prevent the shell as a whole from turning with the axle should the shell get hot and bind on the axle. These dowel-pins must be in place before starting the car.

The **motor armature bearings** are secured by caps that do not require removal when the motor is installed; and as motors are shipped with the factory bearings with which they were tested, it is not customary to remove the shells to inspect them; it is sufficient to try them by hand. After pouring a little oil in the bearings, turn the armature by taking hold of the pinion. If the armature turns stiffly, loosen the cap bolts, pour in oil, and try again. The armature should turn freely by hand and with the cap bolts screwed down. At the factory, a motor will occasionally slip through the test with the armature cap bolts loose, in which case want of alinement in the shells may not be detected. Occasionally, also, motors leave the factory without any running test at all, in which case none of the causes of hot box will develop until the roadman or operating company develop it. On lifting the armature at the pinion end, it should show no clearance in the bearing; such a condition may be equivalent to several months' wear in the shaft and linings.

An armature should have at least $\frac{3}{32}$ inch end play. The end play is limited by the thrust collars, or their equivalent, on the armature shaft. If the end play is insufficient, the armature may turn freely, by hand, when cold, but as soon as it becomes warm under operation, and the shaft expands, binding begins, followed by a hot or cut box, or by both. If it should be necessary to remove the armature to increase or decrease the end play by adding to or taking from one of the thrust collars, the armature should be run by power first to give the magnetic field a chance to centralize the armature laterally. Only in this manner can it be ascertained which collar needs correction.

7. Gears.—Some include in the term **gears** both the large gear and the small one; but it is the custom in railway work to refer to the large gear as the gear, and to the small one as the *pinion;* this distinction will be made here. The pinion and gear should be inspected to determine whether there are cracks, or big, little, or otherwise irregular teeth; whether they are of the proper bore to fit their respective seats on the shafts, and of the proper width to mesh flush with each other when in operation. The gear-halves should meet perfectly at joints. The keys of both should fit their keyways with a mild driving fit, and neither key should be driven without interposing wood or brass between the key and the hammer. Be certain that the gear-cases are not large enough to rub the paving, nor small enough to interfere with the operation of the gear, and that there are no snags or fillets against which the gear or pinion can rub. Clean out the gear-cases to make sure that no foreign object remains to get between the gear and pinion and spring the armature shaft. Slight tooth defects, not distinguishable by eye or hand, but sufficient to cause a clicking noise when the gear and pinion are in operation, can be detected only after the gear is installed or by means of a power-driven testing rack, such as is in use at gear-cutting plants. The teeth in the gear and pinion should be counted to insure that the gear-ratio is of the proper value.

8. Axles, Wheels, and Axle Collars.—Having decided on which side of the axles the motors are to be hung, see that the axle is of the proper diameter, that there is room enough between the wheel hubs for the motor and its gear-case, and that the gear-axle keyway is on the proper end of the axle. If the axle is a little large or small, the best place to make a change is in the motor axle bearing. If the axle is too small, it cannot be enlarged except at considerable expense, and the change necessary to produce a fit must be made in the bore of the bearing. If the axle is too large and measurement of the bearings shows their bore to be correct, either the bore can be enlarged or the axle turned down, according to the wish of the management. If it is desired to keep all axles and bearings at standard size, change whichever departs from standard measurement.

Assuming that there is room for the motor on the axle, it does not follow that the motor will go on without further difficulties, because the commutator-end bearing block may extend considerably beyond the axle-bearing flange on that side, and it may be a matter of selection to so hang the motor that the extension will clear the spokes of the wheels. The quickest way to determine the position for the motor is to swing it approximately into place alongside of the axle; this will show where the motor must be hung to clear all obstacles and give room for the gear-case. It may be necessary to face off one of the axle-bearing flanges or wheel hubs; this will be allowable on the first equipment, but standard changes in construction should be adopted to obviate its necessity in subsequent equipments.

In case there is too much room between the hubs, or in case of its being necessary to set the motor over to the gear-end to gain clearance on the commutator end, it may be necessary to use a split collar, called an *axle collar*, on the commutator end of the car axle. Lateral motion of the motor on the car axle is restricted at one end by the gear-hub and on the other end by the axle collar, which is clamped to and turns with the axle. The bearing flange and gear-hub on one side and the bearing flange and axle collar on the other side act as thrust bearings and are subjected to considerable pressure when the motor is forced to one side, as in rounding curves. Accordingly, the gear-hub and axle collar must have a smooth surface on the motor end to minimize friction. According to the kind of motor and the size of the wheel hub, it may be necessary to use an axle collar from ½ inch to 8 inches wide, or it may not be necessary to use any.

9. Wheels should be examined by eye to insure that there are no chipped flanges; measured by tape line and rule to see that they are of the size called for, that all wheels on the motor axles are within ½ inch of the same circumference, and that the flanges are not so deep and wide as to cause excessive friction on grooved rails or to raise the treads of the wheels from the heads of the rails. Strike the wheels with a hammer, carefully listening to the sounds produced, to make sure that there are no cracks and that the treads are not worn through the chill.

10. If the axle keyway is already cut but falls on the wrong side of the truck, the axle must be turned end for end. If necessary to cut a keyway, in the absence of better facilities, it must be cut with chisels and hammer, a task requiring the services of a man experienced in such work. Before starting to lay out the keyway, the exact position of the gear must have been determined. The gear-case, being bolted to the motor, moves with the motor, but the gear does not; therefore, excessive end play in either will eventually cause them to rub each other.

The relation of the gear, axle collar, and suspension should be such that, at rest, the motor lies neutrally between the axle collar and gear. In operation, then, there will be no stress tending to make the motor bear to one side and produce excessive wear, except when the car is in a curve or taking a switch.

SUSPENSIONS

11. Precautions.—The main point in regard to installing the **suspension** is that the motor is placed centrally between the gear and the axle collar. The suspension also should be such that when the motor is installed it will be higher at the suspension end than at the axle end. This precaution has been usually taken to provide against the motor or gear-case striking the paving between the rails, at starting, when one motor rises and the other drops, with their axles as centers. The precaution, however, is of more real use if it prevents this condition when the car, while operating at a high rate of speed, develops a short circuit or ground that causes the motors to generate. Under such conditions, the tendency of a motor to force itself down against the pavement is much greater than at starting; and this no doubt accounts for many of the cases of broken motor frames or broken gear-casings or bolts.

If the suspension bolts shipped with the equipment or provided by the operating company are too long, get shorter ones or cut them off; do not take up the excess of length by filling in with nuts and washers. It is a wise precaution, though one seldom adopted, to provide against a motor dropping to the pavement should some part of its suspension rigging break. This can be done by so disposing a hook, chain, or bar that it does not hold the motor in any way under normal conditions, but should the suspension rigging give way, the motor would be caught and held by the support provided.

FLOOR TESTS

THE MOTORS

12. Insulation Test.—Before hanging the motors, it is well to apply a few simple tests to make sure that it will not be necessary to remove any parts after the motors are installed. The insulation test is conducted with a lamp-test circuit as follows: Set the motor down on one of the track rails or run a wire to one of them from the motor frame; then connect one end of the test circuit to the trolley wire and touch the remaining end to the track rail. If the lamps glow, the test circuit is shown to be in order. Next, touch the test line to the motor frame; when this is done the lamps should glow as brightly as they did when applied to the track rail. Be certain that none of the field terminals or armature terminals touches the motor frame. Separate the terminals so that those belonging to the top fields, bottom fields, and armature can be identified at a glance. Touch the test line to the wire of every terminal; if a field coil, connector, brush holder, or armature is grounded, the test lamps will light.

13. Assume that there is a ground on the field coils. The ground may be due to a field terminal being skinned or pinched between the halves of the motor frame, or to a connector between two field coils being bent into contact with the motor frame. If a superficial inspection fails to reveal the seat of trouble, the motor frame must be opened for examination. If the ground proves to be neither on a terminal nor on a connector, it must be in one of the field coils. Next, disconnect between the two field coils and test each separately. Being certain that the ground is on the field coil itself, the coil must be removed and another put in its place. On field coils of recent construction (not wound on a shell) any ground is generally due either to the pole piece having cut through the insulation on an inside corner of the coil, caused by carelessness in assembling the motor, or to a metal chip having been caught between the coil and motor frame, and cut through the insulation when the pole pieces were drawn to their seats. Either of these faults can be seen after the field coil is removed; an extra field coil or a field coil from another motor can be installed, or the insulation of the faulty coil can be repaired.

14. Suppose that the test lamps light when the test line is touched to a certain field terminal, but fail to light when the test line is touched to the other terminal. This means that both a ground and an open circuit exist on the stretch of circuit between the two terminals. To illustrate, in Fig. 3, *1* and *2* are two field coils connected by connecting wire *a*. The test lamps will not light on touching the live test line to field terminal *x*, because field terminal *y* hangs in the air and no intermediate point touches the ground. Suppose, however, that connecting wire *a* should come loose from field coil *2* and touch the motor frame *G*, as indicated by dotted line *a'*. In such a case, the test line will show a ground when applied to terminal *x*, because the negative end of coil *1* is grounded by the loose connection; but on applying the test line to terminal *y*, the lamps will fail to respond, even when terminal *x* is touched to the ground, because of the open circuit between coils *1* and *2*. On the other hand, if connection *a* comes loose from coil *1* and drops on to the motor shell, thereby grounding coil *2*, the lamps will respond to contact with terminal *y*, but not with terminal *x*.

During the operation of a car, it makes a great deal of difference which end of connection *a* touches the motor frame when the connection works loose. The motor current enters the field at the same point as the test current. Suppose that the *x* terminal is the positive end of the field, and that connection *a* comes loose and grounds coil *1*; the consequent short circuit causes a demonstration that probably burns away all evidence of the cause of the trouble. Should connection *a* come loose in such a way as to ground coil *2*, which in this case is supposed to be grounded, there can be no demonstration immediately, because the open circuit due to *a* pulling loose from coil *1*, prevents current from reaching coil *2*.

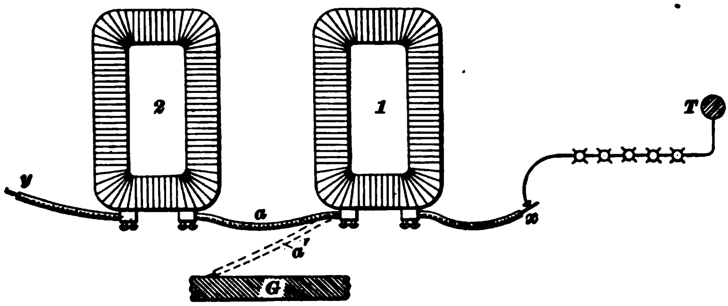


FIG. 3

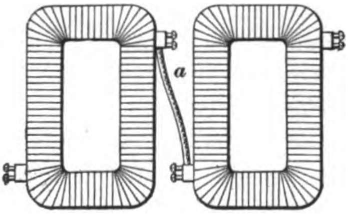


FIG. 4

On motors with connection *a* made between diagonally opposite corners of the coils, as in Fig. 4, such combination open circuits and grounds are common, because the alternate throwing on and off of the motor current causes an alternate attraction and relaxation of connection *a*, due to the interaction of the lines of force around connection *a* and the field lines, thereby producing in the connection a working movement that will eventually work the connection loose. Where such connections are used, they should be twisted and dipped in solder on both ends before insertion into the field lugs, and the lug screws should be screwed well down into the soldered ends. The connecting wire should be of minimum length, to avoid looseness, and both ends should be well taped to the lugs. It is sometimes the practice to secure long connections with metal cleats. This is poor practice, because the cleats may eventually find their way into the air gap and strip off a band or ground a coil.

15. If the lamps respond to a contact with one of the brush-holder terminals, a ground is indicated. Whether the ground is on one of the brush holders or its attached terminal, or on the armature itself, can be ascertained by drawing the brushes and touching the suspected parts separately. Before accepting failure of the lamps to light as conclusive evidence that no ground exists, however, touch the test line to the armature shaft to insure that a layer of oil in the armature bearing does not insulate the shaft from the frame. Should the shaft be insulated from its bearing lining and hence from the motor frame by a film of oil, the test lamps will not respond to contact with the shaft, showing that even if a ground existed on the armature, it would not be indicated unless the armature shaft itself were effectively grounded. If contact with the shaft fails to light the lamps, the shaft must be grounded temporarily to the track rail or motor frame before any test of the commutator can expose a ground on the commutator or armature winding. Assuming that indications point conclusively to a ground on the armature, the armature must be replaced by another, taken from a spare motor if necessary. If no extra armature is available, the defective one must be inspected to ascertain the seriousness of the ground. By disconnecting the coil leads from the commutator and testing all leads and the commutator, it can be determined whether or not a coil or the commutator is grounded, and exactly which coil or commutator bar is giving the trouble. In either case, the fault must be removed before the armature can be used, and the removal of the fault had better be entrusted to a good armature or commutator man, unless inspection shows it to be capable of being easily corrected.

16. Open-Circuit Test.—The next step is to see that the motors contain no open circuits. This test, as far as the fields are concerned, can be made with the lamp circuit. Grounding one terminal of the two top coils, apply the test line to the other end terminal; if the lamps glow, repeat the test, but with the terminals interchanged. Do the same thing with the terminals of the two bottom coils. If the lamps respond in every case, it is reasonable to conclude that the two field paths are complete from terminal to terminal, assuming that there is no accidental ground connection.

17. When testing for an open circuit in the armature, however, the indications of the test lamps cannot be made so conclusive, unless extra precautions are taken, because every direct-current armature has at least two paths from brush to brush, and both of these paths must be open in order to interrupt the test current. If, on grounding one armature terminal and applying the test line to the other, the lamps fail to light, the most probable source of the open circuit is one of the following: A break in one of the armature terminals; the brush stuck in the holder and not touching the commutator; shellac or other insulating matter between the brush and commutator; the brush missing in one holder; the tension finger up or resting on the side of the brush holder; the purposely grounded brush terminal making poor ground connection. Short-circuiting the two brush holders will show whether the open circuit lies between the two holders or not.

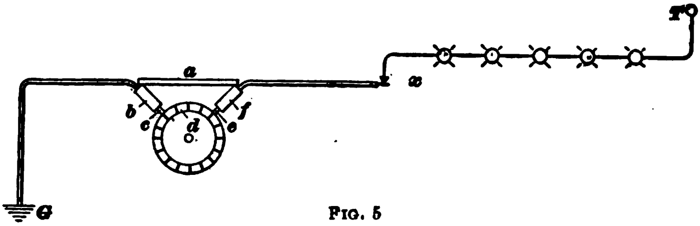


FIG. 5

In Fig. 5, if the lamps respond as soon as the holders are short-circuited by metal strip *a*, it shows that the fault must lie between the two holders. The break can be further localized by omitting strip *a* and touching the test line successively to *b*, *c*, *d*, *e*, and *f*. When touching the test point to the commutator, it should be drawn along the bars from brush to brush. If the break is due to two or more open circuits in parallel, as it must be if the whole armature shows an open circuit, the test point will be followed by a small arc when it passes over the two bars between which is the first open circuit. In testing for an open circuit between points on the commutator on which the brushes bear, the results are liable to be misleading, unless an insulation test has previously been made, because a ground between the two points will cause the lamps to light from at least one terminal point, even though an open circuit does exist in the armature winding. If the lamps fail to light from one terminal but light from the other terminal after removing the intentional ground connection, indications point to both an open circuit and a ground.

18. Having proved that the open circuit is in the armature itself, the armature should be replaced until its defects can be corrected. A single open circuit in the armature cannot prevent the test lamps from lighting. A man installing an equipment will probably not have occasion to deal with a single open circuit until he endeavors to run the armature and finds that an arc follows the commutator, unless a close examination of the commutator shows an eating-out action to have been taking place between the bars that include the open circuit. In the face of such evidence, connect the motor properly and test it further by running it. Any open circuit or combination of open circuits that will not prevent the armature from running at all will at least cause an arc to travel around the commutator in the direction of rotation.

19. Rotation Test.—In Fig. 6, *1*, *2*, *3*, and *4* are the four field coils and *A* is the armature of a motor. The two armature terminals may be called either the ***right*** and ***left*** or the *front* and *rear* armature terminals, according to whether they are viewed from the commutator end or from the front or rear end of the car. The two field terminals, as they are brought out in this case, may be called the *top* and *bottom* field terminals. As the motor is connected in Fig. 6, current enters the left-hand brush holder and leaves the armature at the right-hand holder; it enters the top field terminal and reaches the ground through the bottom field terminal. In Fig. 7, however, current enters the left-hand brush holder and leaves the armature at the right-hand holder, as before, but enters the field at the bottom terminal and reaches the ground through the top terminal. Assuming that the connections of Fig. 6 cause the armature to rotate in a clockwise direction, the connections of Fig. 7 will cause it to rotate in a counter-clockwise direction. Whatever may be the connection adopted, all armatures of the particular type of motor being installed will rotate in the same direction if the external field and armature terminals are the same, unless there is some irregularity in the bringing out of the terminals through the motor frame, or in the winding or connecting of the armature or field coils themselves. The likelihood of such irregularities makes it advisable to test all motors with the same external connections to see that all armatures rotate in the same direction. Only when this condition exists will the wiring of the cars conform to the blueprint and the necessity be avoided of crossing field or armature terminals in order to make all the armatures turn in the proper direction.

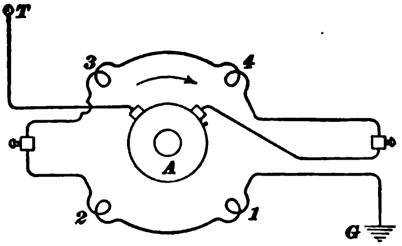


FIG. 6

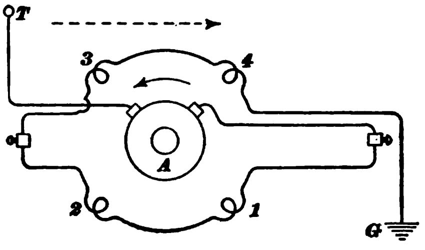


FIG. 7

If one armature rotates in the wrong direction and an inspection of the motor terminals shows them to have been brought out properly, the fault is probably in the armature itself. If the armature cannot be spared, reverse either the armature or the field terminals and obtain correct direction of rotation in that way. A record of the irregularity should be kept, in order to avoid confusion when occasion may arise for replacing the armature or for disconnecting it from the car wires. Such an armature is known as a left-handed armature; this means that the armature coils have been connected to the commutator differently from those in a regular armature, and consequently the armature rotates in the wrong direction when connected to a regularly wired car.

20. The brush at which the current enters a motor armature is the positive brush, and the brush at which it leaves is the negative brush. The field terminal at which the current enters the field winding is the positive field terminal, and the terminal at which it leaves is the negative field terminal.

As explained in *Car-Wiring Diagrams*, the motors are usually placed back to back on a two-motor equipment. In a four-motor equipment, two of the motor armatures have their commutators near one side of the truck, and the commutators on the other two motors are near the other side of the truck. In order that all the motors should drive the car in the same direction, the motors having their commutators near one side of the truck must rotate in the direction opposite to that of the motors having their commutators near the other side of the truck; the direction of rotation being observed from the commutator ends.

Assume that the connections shown in Fig. 7 are correct for the No. 1 motor, and that the car is being run forwards from the No. 1 controller. The armature rotation is counterclockwise, and the gear on the car axle is rotated in a clockwise direction, driving the car in the direction indicated by the large arrow, which is assumed to be north. The rear armature terminal of the No. 1 motor is positive; the front armature terminal is negative; the bottom field terminal is positive; the top field terminal is negative. The rear armature terminal must be connected to the A_1, or most positive, car tap, and the front armature terminal to the AA_1 tap. The bottom field terminal goes to the positive, or F_1, tap, while the top field terminal goes to the E_1 tap.

The No. 2 motor, which is near the south end of the car, is placed back to back with the No. 1 motor. In order that the No. 2 motor should drive the car in the same direction as the No. 1 motor, the rotation of its armature must be clockwise. The armature terminals must be reversed on the No. 2 motor.

As the No. 2 armature terminals are reversed and the position of the motor is the reverse of that of the No. 1 motor, the A_2 car wire from the No. 1 controller is connected to the rear brush-holder terminal of the No. 2 armature, and the AA_2 car wire is connected to the front No. 2 armature brush-holder terminal.

If the two motors intended for a series-parallel controlled car are set back to back on the floor, one being called the No. 1 motor and the other the No. 2 motor, the motor terminals can be marked as follows:

	No. 1 Motor	No. 2 Motor
Front armature	AA_1	AA_2
Rear armature	A_1	A_2
Top field	F_1	F_2
Bottom field	E_1	E_2 or G

In any case, having determined, from the rotation test, how the front-motor terminals must be connected in order to secure the proper direction of rotation, the rear-motor terminals are connected in the same order, except that the armature terminals are reversed. On a four-motor car, the two motors that hang in the same direction are considered as front motors, and the other two as rear motors, and they are connected accordingly.

21. The reversal of one armature or pair of armatures, made necessary by the motors hanging back to back, insures that all the motors aid each other in moving the car, whatever may be the position of the reverse handle. To insure that all the motors together will obey the reverse handle, the data furnished by the rotation test must be applied to the No. 1 controller connections. Connect the motor wires so that when the No. 1 reverse switch is thrown to its forward position, the car will move forwards. Correct performance of the No. 1 controller once obtained, it is only necessary to reverse all armature car wires in the rear controller to make the car obey the reverse switch at either end.

22. **Polarity Tests.**—A test for the polarity of the pole pieces may be made with nails, or by means of a small compass. A current is passed through the field coils, connected in series, as in normal operation. The compass, held in the hand, is passed around the outside of the motor frame, being brought up to the frame at the points indicated by the arrows in Fig. 8, immediately behind the internal poles of the motor. There is sufficient magnetic leakage near the outside surface of the motor to affect the compass needle in a decided manner. If, on bringing the compass up behind pole *1*, the north end of the needle should turn toward the motor, its north end should turn from the motor when it is brought up behind pole *2* or *4*. In any case, if the same end of the needle always points toward the same pole, that end of the needle should point away from the two adjacent pole pieces; in other words, the indication of the needle should alternate. Therefore, if the same end of the compass needle points either toward or from two adjacent poles, a field coil is either wrongly connected or wrongly wound. The compass should be so held as to permit as free a movement as possible to the needle.

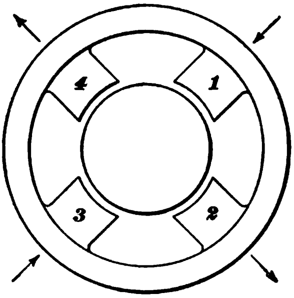


FIG. 8

23. **Spinning Test.**—The **spinning test** is made to determine whether the armature shaft is bent, or whether the commutator has a high bar or a low bar, or an extended

flat, or a swell, or both. These points can be observed when the rotation test is made. A motor set on the floor requires little current to run the armature, and when it is desired to give the armature a spin, it is the practice to ground one end of the connected motor and spin it by applying to the other end a wire run direct from the trolley wire. This is all right where there is an absolute certainty that the armature will start when the trolley connection is applied to it, because the armature works up a counter electromotive force rapidly and the current remains small. Suppose, however, that the armature fails to start; the current flow will be heavy, and the arc, caused by pulling the trolley connection away, is likely to injure the operator. Since it is little trouble to do so, it is well to put a resistance and a fuse or breaker in the wire used for spinning a motor. A quick and easy way to secure the same result is to use an equipped car. Disconnect from its starting coil the wire running to the highest-numbered end wire (the R_3, R_4, R_5, R_6, or R_7 wire, according as the coil has two, three, four, five, or six sections). Put in the place of the removed wire the wire that is to supply current for spinning the armature. By closing the breakers and putting the trolley wheel on the wire, the controller can be used for operating the motor under test, but it must not be advanced to the full series-notch, because then the car motors will take current, unless the precaution has been taken to draw one of the motor brushes. One notch will suffice to spin the test armature, and the controller must be allowed to rest on this notch for only 3 or 4 seconds; otherwise, the armature will acquire a dangerous speed.

24. Up to the negative end of the starting coil, the test-current path is the same as if the car were in operation; but when the current gets to the negative end of the starting coil (starting-coil connecting post *R 5*, Fig. 9), instead of taking the *R 5* resistance wire back to the controller, to get a ground through the car-motor circuit, it takes the test wire that has replaced the *R 5* wire (disconnected in Fig. 9) and finds a ground through the test motor.

If the armature shaft is bent or the commutator is eccentric, a characteristic pulsating noise will be emitted, and the brushes will raise and lower. If the shaft is much bent, the pinion ends will wabble. To detect a slight bend, it will be necessary to get a hand rest and hold a sharpened stick of chalk against the side of the pinion end of the shaft. If, when the chalk is held stationary, it makes a ring all around the rotating shaft, the indication points to a straight shaft; but if the ring is not continuous, the chalk touching only the higher part of the shaft, the latter must be bent. A bent shaft must be straightened before it is installed on a car. On a trial car, it is advisable to substitute another armature, because sometimes a straightened shaft will spring back into its former bent condition. If a shaft is in the least bent, the noise emitted by the gear and pinion, when the car is in operation, will differ from the noise made under normal conditions.

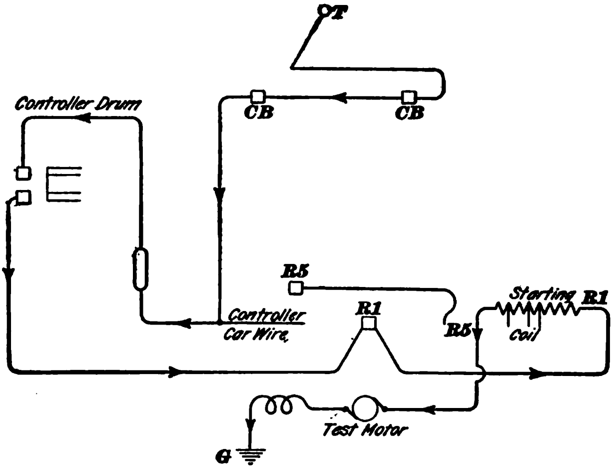


FIG. 9

A high or a low commutator bar will emit a clicking sound when the armature rotates. A high bar can sometimes be reduced with a file, but if the bar is low or the commutator eccentric, the latter must be turned down in a lathe. In any case, the armature should not be installed without trying the faulty bars with the flat part of a hammer to see if they are down solid, for nothing will have been gained if certain bars are loose and are certain to be forced outwards when the car is operating at high speed. If the hammer test indicates want of solidity, the commutator must be drawn off, heated, put under pressure, and tightened, while under pressure. It will probably then be solid, and after being installed on the shaft and connected, it must be turned in a lathe.

25. The best time to test the armature for end play is while it is rotating with the current on; the field then exercises a centralizing force that will divide the end play if the armature sets level. See that it does set level. Start the armature and, while the current is on, push, by hand, first one end of the shaft and then the other. In each case, the armature should move over a little, but should return to central position as soon as the hand is removed.

26. Short-Circuit Test.—Short circuits in the field winding cannot be readily detected without applying instrument tests, but a short circuit in the armature will be indicated by holding a nail to the head of the armature while it is turning with the current on: a short circuit will cause the nail to vibrate as the short-circuited coil passes near it.

THE CONTROLLERS

27. Electric Tests.—All **electric tests** to be made on the controller can be made with the lamp-test circuit. To test the insulation of the controller, lay it on its back across one of the track rails or run a wire from the rail to the controller frame. Touch the test line to the rail to see that the test current is in order and then touch it to the frame to insure that the frame is properly grounded. The test consists in touching the live test line to every binding post, finger, and drum connection in the controller. As soon as the live test line touches any grounded part the lamps will light. They should not light except when the test line touches a part that the controller wiring diagram shows to be a ground connection.

The test for open circuits is conducted by using the live test line and a short test line run from a grounded part; when the two test lines are touched together, the test circuit is directly grounded and the lamps light. The test consists in touching one test line to one end and the other test line to the other end of the stretch of circuit to be tested; if it is intact, the lamps will light. Thus, in Fig. 10, wire *A*, *D*, *B* is supposed to connect posts *A* and *B*. If there is no open circuit in it, the lamps will glow when the two test lines are applied as shown in the figure. To make the open-circuit test, one must either have a plan of the controller connections or must be familiar with them.

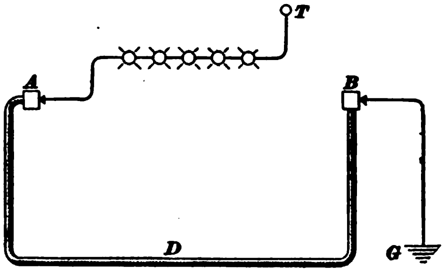


FIG. 10

Two lines are also required to conduct the test for short circuits. The test consists in holding a test line on any given connection and touching every other connection with the other test line. The lamps will light only when the two test lines touch parts that are connected; they should light only on touching parts that the controller diagram shows ought to be connected.

28. Mechanical Test and Inspection.—Both the power and the reverse handle should go on without trouble, but neither should fit loosely. It should not be possible to move the power drum with the reverse handle at off-position, nor the reverse handle with the power handle on an operating position. The reverse handle should be installable and removable only when the reverse drum is at the off-position. The action of both drums should be springy and decisive. When either drum is on an operating notch, the fingers and tips in action on that notch should have full contact. All fingers should be in alinement at the off-position, and, as far as possible, should have the same amount of motion in riding up on a drum tip on operating positions. The amount of motion, hence tension, is adjusted with screws provided for that purpose. After adjusting the finger tension, see that the adjusting screw locknuts are run down as far as they will go, so as to hold that adjustment. Be certain that the controller-drum shaft is not bent, and that neither finger board is buckled. With a light screwdriver, test all screws, except the adjusting screws, to see that they are down firmly. Be certain that all connecting-board screws will turn the full depth of the hole that is to take the connecting wire. It is well, for future convenience, to remove these screws, grease them, and put them back.

The cut-out switches should be movable in either direction without being pried, but should not be free enough to run any chance of shaking out of position. See that the controller door works freely on its hinges and that the door can be closed and fastened without undue force being applied. Finally, blow out the controller with air, put a little vaseline on the drum tips and index, close the door, and keep it closed, except when necessary to open it for repair or adjustment.

THE STARTING COIL

29. Inspection and Test.—The **starting coil** must be inspected to see that all bolts, screws, and grids or panels are tight, and that, as far as can be seen, there are no short circuits. The coil can then be tested for open circuit and insulation. To test it for open circuit, use two test lines, securing the ground test line in one of the end binding posts and touching the live test line to the other post. If the lamps light, the indication points to the absence of open circuits; but the indications are not absolutely conclusive if the coil has parallel connections. For example, in Fig. 11 branches *c* and *d* are in parallel between posts *3* and *4*. An open circuit, such as at *x*, in either *c* or *d* would not prevent the test lamps from showing a closed circuit, because the circuit is closed through the other branch; but such an open circuit would affect the starting and acceleration of the car and might burn out the coil. To make the lamp test fully reliable, one of the branches should be disconnected from post *4* long enough to test each branch separately; if the lamps light on touching post *4* with the live test line, and also on touching the wire temporarily removed from post *4*, the continuity of the coil is shown and the disconnected wire can be replaced. If the lamps indicate the presence of an open circuit in a starting coil, the test line must be moved from post to post to determine between which posts the open circuit lies. If the resistance metal is exposed, so that the test point can be run along it, the open circuit can be located exactly, and inspection may show that it can be remedied without taking the coil apart.

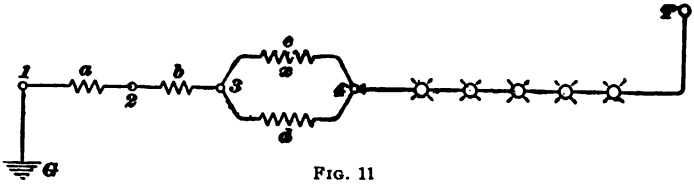


FIG. 11

The insulation test consists in grounding the starting-coil frame to the track rail and touching the live test line to any of its binding posts, being certain that the live test line makes good contact. If the test lamps light under these conditions, the resistance metal must be touching the frame—a very bad contingency, because the frame and all supports will be alive whenever the starting coil is. Any such contact should be removed before installing the coil on the car.

30. Danger in Grounded Coil.—In Fig. 12, *A* is a bolt that has been allowed to extend through the car floor; *A* supports iron strap *a* on which the starting coil hangs. A through bolt *B* secures the strap *b* that supports some part of the grounded air-brake equipment.

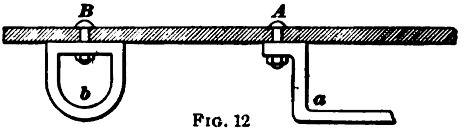


FIG. 12

If the resistance metal of the starting coil touches its frame, bolt *A* will be alive when the starting coil is, and any one stepping on bolts *A* and *B* simultaneously, is liable to shock.

THE TROLLEY

31. Inspection and Adjustment.—The **trolley base** should be inspected to see that it has not been impaired. If the foot has no roof-wire terminal, it should be drilled, tapped, and provided with one. The foot should then be set up level on the floor and the base set on it, after the pivot has been greased; the base should turn freely on the foot, but on taking hold of the socket and shaking the base there should be no knocking; the clearance that permits such knocking causes a binding action when the device is in operation. The pole is then clamped in the socket. The pole must be straight and must be installed with the flanges of the wheel parallel to the trolley wire and in a vertical plane. The tension adjustment may be made as explained in *Current-Collectors*. If a spring scale is not available, use weights.

THE LIGHTNING ARRESTER

32. Lightning arresters should be inspected for open circuits and closed circuits and to see that the air-gap adjustment is correct. On an arrester like the Wurts, the only thing to do is to apply the test lines to see that the air gap is not short-circuited. This test should be made on all arresters. On arresters having three terminals, see that the terminals are correctly marked, and that the circuit is continuous from line to motor, but open from both of these to ground. Where an arrester has actual spark points, see that they are not chipped, blistered, or broken, and that the air gap, as tested with a gauge, is of the thickness recommended. Where an arrester has movable parts, as the Garton, for example, with its gravity-solenoid plunger, try the moving parts by hand to see that they are not stuck.

THE CABLES

33. The main points to be taken into account in making up the **car-wiring cables** have already been considered. As a rule, the cables to be used on a trial equipment are made up at the factory and tagged, the necessary information in regard to the car body and truck, and the method of hanging the motors, having been previously acquired. If this duty devolves on the shop or road man, however, the first points for him to ascertain are: the path of the cables in or under the car; how many car wires there must be; the positions of all splices. The positions of the splices cannot be decided until the positions of the devices to which they connect have been determined. Whether the car wires shall be run in one cable or two is a matter of choice. The present tendency is to run them in one cable, but its desirability is questionable. The main advantage of using two cables is that each motor has its own cable near it and that cross-over wires are not necessary. On four-motor equipments, where the total number of wires cannot well be included in a single cable, the wires of the two motors that have their commutators pointing to the same side of the car may conveniently be included in one cable. The resistance wires are preferably included in the cable that contains the trolley wire and most positive motor or motors, while the ground wire, as a rule, is run outside of the cables.

INSTALLATION

MOUNTING DEVICES

THE MOTORS

34. Preparation.—The motors are now ready to be swung on to the truck. The gears have been installed. The axles, at the places where the motor bearings are to be placed, have been sandpapered, wiped off, and greased. The motor terminals are twisted into pigtails and secured on the top of the motors. All lids are closed and secured, so that no tools may be dropped into the motors. The lids are kept down when it is not actually necessary to have them up. The axle caps and brasses are removed and laid aside in pairs in the order in which they will be required.

35. Swinging the Motors.—The motors can now be picked up by a crane or other hoisting device, raised above the level of the truck, and the truck run under, the motor being lowered on to blocking that brings the bearings on a level with the axle. In the absence of overhead hoisting devices, the truck must be jacked up on one end and the motor slid under the axle on greased sheet-iron skids, or on two pieces of rail. Whatever the manner of getting the motors in position between the axles, they must be blocked up to the proper level. The brasses are then put on the axle, flanges outwards, the grease previously smeared on preventing the brasses from dropping, though, if necessary, a piece of wire may be twisted around the flanges.

The truck can now be pushed toward the motor and the bearings sighted to see if it is necessary to raise or lower the motor a little in order that the brasses and blocks may register. If the motor block and cap split in a vertical plane, as in Fig. 13 (*a*), the axle and brasses can be pushed right in, care being taken to show due regard for the dowel-pins. If the axle cap goes on the bottom, as in Fig. 13 (*b*), the block must be raised above the axle, the axle run in, and the motor lowered. But if the cap goes on top, as in Fig. 13 (*c*), the underhanging block must be lower than the axle, requiring the motor to be raised after the axle and brasses are in line. Once the bearings are in place, the caps are put on and the cap bolts run in up to their heads, but not tightened. Should a cap resist being mildly forced to its seat, do not exert more force, for the probabilities are that the brasses have slipped around, throwing the dowel-pin out of the hole. If inspection shows the dowel-pin hole to have slipped out of line with the dowel-pin in the block, the brass and block must be realined before trying to force the cap to its seat.

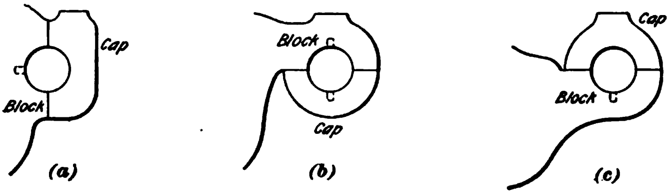


FIG. 13

After putting a little grease on the side of the gear-hub, the motor is moved over until the flange on that side bears against the gear-hub. The axle collar is then fitted into the clearance between the opposite flange and wheel hub, and the hanging of that motor is complete, so far as the axle side is concerned. Where the clearance to be taken up by the axle collar is excessive, it is sometimes the practice to use a short collar to hold the motor in position, and rely on a setscrew that passes through the collar and engages a shallow hole in the axle to hold the collar. This is bad practice, because an axle should never have unnecessary holes drilled into it, and a construction of this kind will fail to hold the motor over under severe conditions. If one axle collar is not long enough, use part of another, or

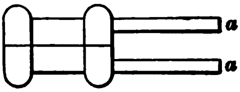


FIG. 14

two axle collars, or put legs in one collar, as indicated at *a*, *a*, Fig. 14. These legs bear against the hub of the wheel and act as a positive resistance to end play, in addition to the frictional resistance of the axle collar.

36. Lining Up the Gears.—If none of the dimensions are wrong (in motor or gear), the gear and pinion will line up in such a manner that the end play in the pinion, due to the end play in the armature, will be equally distributed on both sides of the gear. The errors in dimensions most likely to prevent such desirable alinement are errors that can be easily overcome: the hub of the gear may be too long or too short or the flange of the axle-bearing shell too thick or too thin. If the hub is too long, it can be turned shorter or the bearing flange made thinner; if the hub is too short or the flange too thin, the flange can be made thicker by babbitting on to the end, as indicated at *a*, Fig. 15.

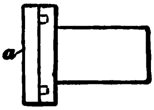


FIG. 15

After the motor has been properly centralized and secured on the axle, the next step is to secure it on the suspension side. On most equipments recently installed, the nose suspension is used, as it is simple and efficient. Whatever the method of suspension used, it should be so installed as not to subject the motor to side stresses due to forcing the suspension over to get a fit. When the suspension is ready, it should only be necessary to move the motor vertically in order to secure the registering of corresponding connections. Deflection of the suspension links from the vertical should be avoided.

37. Testing the Gears.—Having secured the motors on the axle and suspension sides, before running the truck under the car, spin the motors to see if the gears emit any irregular noises. Pour oil into the armature and axle boxes, pack them with oil-soaked woolen waste, and pour more oil on top; also inspect the truck axle boxes to see that they have lubrication. Jack the truck up on one end until the wheels on that end clear the rail; also jack up and block the motor on that end so as to take its weight off the axle, because with the truck jacked up without the motor the axle drops to the bottom of the truck journal-box, where there is no journal brass and where the axle will be cut unless all weight, including its own, is taken off it. The motor on that end is then connected and spun as in the rotation test, except that additional resistance is inserted to hold the wheels down to 100 or 150 revolutions per minute.

While the motor is running, watch all boxes to see that none of them get hot. If the gear emits a grinding noise once per revolution, indications point to a sprung axle or to a lopsided or eccentric gear. If the axle is sprung, the motor frame will work back and forth and up and down once each revolution, and in the case of a very marked bend, one or both car wheels will wabble. A sprung axle will cause a movement of the car body. An eccentric gear can be detected by measurement. Another method is to put stiff grease on the gear and note its distribution on the teeth and in the troughs between the teeth. On the high side of the gear, the grease will be pushed farther down into the troughs than on the low side. If a gear is on one-sided enough to cause grinding, its wabble will be easily discerned.

38. If a slight grind occurs several times per revolution of the gear, indications point to an eccentric pinion or to a bent armature shaft. A bent armature shaft will wabble on the pinion end and the motor brushes will chatter. A clicking noise once per revolution of the gear may mean that the gear has an odd-sized tooth or an open joint. A big tooth will show rubbing. An experienced man can reduce the tooth to standard size with a chisel and file, but in most cases the best thing to do is to replace the gear. In case of a small tooth, the gear must be thrown out. Inspection will show whether or not the gear is open at the joint. If open, the outside gear-bolts must be slacked off, the inside ones tightened, and then the outside ones tightened again.

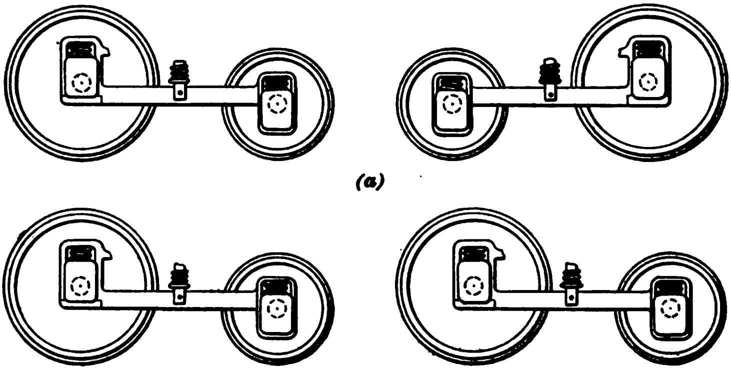
Clicking of either gear or pinion can be caused by a tooth being burred on the end. Such a burr can be removed with a file; wear will remove it, but excessive burr is liable to bend the armature shaft. It is on account of the possibility of burring the teeth that striking them with a hammer is so vigorously prohibited. For the same reason, the motor must be carefully handled when it is swung into place, to keep the pinion end from swinging around and striking the car wheel or gear. The pinion should never be borne against by the crowbar used for moving the motor along the floor, nor should a car or newly equipped truck be forced along by running a pinch bar down between the pinion and gear. Aside from the liability of injury to a gear or pinion tooth, such a practice is liable to bend the armature shaft.

Where a decided, heavy knocking noise is emitted once each revolution of the gear, probably a gear is loose; possibly a key is loose. Where the keyways in the gear and axle differ in size, necessitating different dimensions at the top and bottom of the key, it is difficult to set the gear perfectly. If the gear is loose on the axle, the only advisable thing to do is to reset it.

39. Assuming that the gears act satisfactorily with the gear-cases off, install the gear-cases and give the motors a spin to see that there is no rubbing between the gear and the case. The gear-case must be cleaned and, if necessary, all rough, raised places chipped off with hammer and chisel. To minimize the chances of rubbing, the fillet must be smoothed down at both inside edges of both halves of the case.

Gear-cases are likely to be found misfits. The gear-case must be installed symmetrically; that is, the gear and pinion must have the same end-play clearance on both sides; otherwise, the pinion may play over against the case and wear a hole in it. The case clearance must be central, even if it is necessary to chip the case or file out bolt holes to let it over. When the case is installed, it must be firm, and all bolt shanks must have a split pin through their ends to keep the nut from working off. If trial shows that the gear or pinion is rubbing on the gear-case, the case must be opened and the fault corrected.

40. Running Trucks Under the Car.—If the gears run smoothly with the cases on, the truck is ready to go under the car, so far as the electrical equipment is concerned. It is sometimes the practice to test the car wires for grounds and short circuits before the car body is connected to the truck. The truck or trucks can be moved under by applying power in the same manner as when spinning the motors, or they can be moved under by hand. In the case of a single truck that is intended for a car that operates on a belt line or loop, if one of the wheels has a slightly chipped flange, and it is necessary to use this wheel, run the truck under with the chipped wheel toward the rear end, where it is least likely to give trouble on curves and switches. If the flange is badly chipped, remove that pair of wheels. In the case of maximum traction trucks, run them under in the relation indicated in Fig. 16 (*a*) unless there are instructions to the contrary. In Cleveland, Ohio, all cars that turn in a belt or loop have their maximum traction trucks installed as indicated in Fig. 16 (*b*), the advantage being that the small wheels are always followers, thus causing less trouble from the wheels jumping the rail.


(a)

(b)

Fig. 16

Before running the truck under, see that the truck axle boxes will clear the horses or bands on which the car rests, and that there are no hanging obstructions to engage the truck. It is well to spin the truck up and down the barn a few times before installing it, to limber up the parts and give the bearings a chance to adjust themselves. See that the gears are supplied with grease. In many cases no grease is put in the gears until the car is about ready for use, and then it is crowded in through the grease hole over the gear and pinion, with the result that the resistance to turning offered by the grease, added to the general stiffness of the bearings and the weight of the car, make it necessary to move the controller around to a parallel notch, in bad cases, before the car will start. Stiff grease crowded between the pinion and gear and forced through by the application of excessive power has been known to spring an armature shaft.

If the car has double trucks, be certain that the side bearings and rollers are lubricated. If the car has a single truck, be certain that the truck holes and the holes in the car body, through which pass the bolts that fasten the body and truck together, register; else the body will have to be raised again.

THE CONTROLLERS

41. The top of the controller should come at least to the top of the dash rail. To secure this condition it is generally necessary to set the controller on blocks. Bolts passing through the controller feet, blocks, and platform secure the controller at the bottom. It is steadied at the top by angle irons secured to the dash rail. All fastenings should be substantial; otherwise, the working of the controller will loosen the car-wire connections inside and cause trouble. The first consideration in placing the hole through which the car-wire cable comes up to the connecting board is to avoid cutting a platform sill; the next consideration is its convenience to the motorman, who must be able easily to hold the controller and brake handles simultaneously.

When a car is vestibuled, or likely to be vestibuled later, the controller and brake must be set back far enough for a heavily gloved hand to clear the vestibule front. Where controllers are to be installed on a car whose platforms have dropped or sagged, the platforms should be raised and reenforced, because if they sagged without controllers, they will certainly sag farther with them. If the controllers show abrasions or scratches, they should be given a coat of thin asphaltum when the angle irons and blocks are painted. Finally, see that both cut-out switches are cut in, oil the controller hinges, close and fasten the doors, and remove the handles until needed for operation.

THE STARTING COIL

42. The starting coil must be installed where it will not be rubbed by a brake rod under any condition of operation. It must not be installed under a platform of the drop-step type, as the controller is as much as such a platform should support. In the absence of a fuse box, which generally marks the front end of the car, regard as the front end the end at which the roof wire comes down. If the car has two roof wires, coming down at opposite ends, call the front end the end at which the controller car-armature wires are not reversed in the controller, and install the coil on that end. Place the coil with its R_1 connecting post toward the front end of the car. The resistance taps in the car-wire hose should be brought out in the same relation. If brought out in some other relation, however, the starting coil must be so disposed as to avoid crossing the wires, and to simplify connecting the leads to the coil should occasion arise for disconnecting them after all marks or tags have become unreadable. The bolts that support the starting coil must under no circumstances extend through the car floor. The coil should be supported in stirrups fastened to the car sill sides. Too much stress cannot be laid on the advisability of keeping all possibly live parts below the car floor. Brass screws should be used in the connecting posts, as they are less likely to stick.

THE TROLLEY

43. From a paper pattern of the trolley foot, or from the foot itself, the holes for the stand are laid off on the trolley board and the foot installed. If the car is to have but one trolley, the foot is installed in the center. If the car is so long that two trolleys must be used, a foot must be installed toward each end. The distance from the end is determined by the length of pole that can be used. The wheel should be within easy control of the conductor, who must replace it when it flies off. Where two trolleys are installed, but one is in use at one time, and hooks must be provided at both ends of the roof to hold down the idle pole. The foot may be secured by bolts or by lagscrews; each is recommended by good authorities. The lagscrews will pull out, in case of entanglement, and save the car roof. The foot being installed, the base is put on, care being taken not to cave in the car roof or side while handling it, the base being a very awkward device to handle, especially if the pole is in the socket.

THE LIGHTNING ARRESTER

44. The wire to and from the lightning arrester should be as straight as possible. It should be located where it can be reached for inspection without crawling under the car. It should be protected from water thrown by the car wheels. If it has parts depending on gravity for action, it must be installed in a vertical position. If it has a lid secured by thumbscrews or wing nuts, see that these can be turned without the aid of a wrench.

BREAKERS AND SWITCHES

45. If circuit-breakers are to be installed under the side of the car, they are installed in a vertical position; if under the bonnet, they are placed in a horizontal position. In either case, they must be tried before instalment to see that they stay closed when closed by hand, and that they open when the hand button is pressed. Where overhead switches are used, they are installed in the car bonnet, above and a little forwards of the motorman's head, and with the handle pointing in the forward direction. Switches should open and close with a snap. They should not work hard, nor should they work so easily as to be likely to come open while carrying current. Switches require no test except an insulation test, to see that the front plate is not alive when the switch carries current. In addition to the insulation test, breakers are tested with the current for which they are to act, to insure their acting at the proper current value.

CONNECTING DEVICES

46. It is assumed that work on the car has kept step with work on the motors, so that when the truck is ready to be run under, the car is ready to receive it. The trolley, the breakers or switches, the controllers, starting coil, and arrester, are in place, and the cable installed and secured and its ends brought up through the platform holes into the controllers and bent back out of the way.

BREAKERS AND SWITCHES

47. In connecting the hood breakers or switches, the connecting post nearest to the motorman should preferably be made negative, so that when the device is open, the post that the motorman is most likey to touch, in slapping at the handle to close it, is dead. So far as the operation of the device is concerned, it is immaterial which post is made positive. The positive wire on the No. *1* end, Fig. 17, comes directly from the trolley stand, and the positive wire on the No. *2* end is the roof wire from the No. *1* switch or breaker. The roof-wire ends coming through the bonnet are skinned, twisted, dipped in solder, and then trimmed to fit the connecting post hole. If a longer

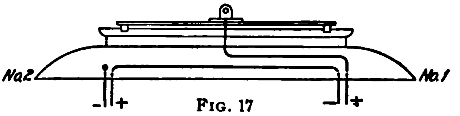


FIG. 17

length of wire is used than necessary to make the connection, the excess of wire is twisted into a neat pigtail and the end run into the connecting post clear up to the insulation. The two binding screws are then screwed home and the joint taped, the end of the tape being turned back, so that it can be found when wanted. A coat of thick shellac is applied to the taped joint. When the work is done, see that both breakers are left at the off-position.

RINGING THE CAR OUT

48. If the cable taps, car-wire ends, starting coil, motor, and arrester terminals, have been tagged or otherwise plainly marked (the controller terminals are marked at the factory), all that remains to be done to complete the car for operation is to join together neatly and safely all connections of the same name. For the purpose of acquiring information, however, it will be assumed that none of the connections, save the controller connecting posts, is marked, and that in order to get devices properly connected, it will be necessary to **ring the car out**; ringing the car out is an expression that originated from the practice of using a magneto-bell circuit for locating or identifying the far end or intermediate taps of any given car wire. Now, as a rule, a lamp circuit is used for this purpose, but the same name still applies to the operation. Take up any wire projecting out of the hose that sticks up in the No. 1 controller; before that wire can be connected to the controller, it is necessary to make sure that the wire is clear of faults and to ascertain to what device it connects. This must be done for the several car wires, which are generally rung out in the following manner and order.

49. Insulation Tests.—Run a small flexible wire to ground to be used as one test line; the live terminal of the test-lamp circuit will be the other test line. Be certain that none of the cable taps touch any grounded part. On this account, it is well to make the insulation tests before letting the car down on to the truck. Touch the live test line to each of the car wires coming up through the controller. If all wires and the taps from them are free from grounds, the test lamps will not respond to contact with any of them. If the lamps do light, however, on making contact with any wire, that wire or one of its taps is grounded, probably in consequence of the other end of the wire touching the controller frame or door, or of one of its taps hanging down on a motor or truck. In any event, the ground must be removed before proceeding farther.

Assuming that the hose proves to be free from grounds, the next step is to insure, by test, that no wire in the hose touches any other wire, thereby constituting a short circuit certain to give trouble later. To conduct this test, hold the ground test line on any given car wire and touch the live test line to every other car wire in the hose; then hold the ground test line to another car wire and repeat the test. As each series of tests is made, the wire to which the ground test line was held can be bent back out of the way to avoid unnecessary repetition. Should the lamps light when the ground test line is held to one wire and the live test line to another, a short circuit between those two wires is indicated; otherwise, the live test line could get no ground through which the lamps could be lighted. Investigation may show the short circuit to be due to some parts of the two wires resting on a grounded part, in which case, however, the lamps would light on touching either wire. Should the short circuit be due to parts of both wires touching each other or a conductor that is not grounded, the lamps will not light when the test line is touched to either wire while the test ground wire is disconnected.

50. Connection Tests.—Being assured that no wire touches the ground or any other wire, the next step is to ring out for connections. Before doing this, the car is let down on to the truck. To ring out for connections, begin with the trolley and ground wires, because these, being larger than the others, are readily identified. Find, among the wires entering the bottom of the No. 1 controller, the wire that is supposed to be the trolley wire; it will be one of the two larger wires and will probably come out of the hose; skin the end of it and ground the skinned end, either to the ground test line or to the controller frame direct. If the live test line is now touched to the other end of the trolley wire or to any of its taps under the car, the lamps will light. Accordingly, get under the car and find out which taps ring up with the controller trolley wire. If the overhead switches or breakers are in parallel and have independent wall wires, there will be a trolley tap coming out near where each of these wall wires comes through the car floor. If the overhead switches or breakers are in series, however, there will be but one trolley tap coming out of the hose where the fuse box (where such is used) is located, or where the single wall wire comes through the car floor on the front end. In either case, the lamps will light on touching any tap coming from the hose trolley wire, because that wire is purposely grounded by the ground test wire or by the controller frame. Tag or mark all such taps *T*.

Proceed to the No. 2 controller and, by means of the live test line, find the end of the car trolley wire sticking out of that controller; the lamps will light as soon as the live test line touches it. Mark or tag this wire *T*; disconnect the other end of it from the ground test line or frame and also tag that end *T*. Both ends of the controller trolley wire and its intermediate tap or taps are now identified and marked. The two ends marked *T* will go into the controller terminals marked *T*, and the intermediate tap or taps will go into the device to which they are opposite.

The remaining large wire in the controller is the ground wire. Skin the end and ground it as in the last case, for the so-called ground wire is not grounded until the ground connections to the motor frames are established. Next, take the live test line under the car and ring out the ground taps. There should be three ground taps coming out of the hose —one for each motor frame and one for the lightning arrester. Having identified the ground taps, mark them *G* and proceed to identify and mark the other end of the ground wire in the No. 2 controller.

51. In ringing out the remaining connections begin at the cable taps. For example, take the cable tap opposite the No. 1 end of the starting coil, mark it R_1, and attach the live test line to it; then go to both controllers and successively ground to the frame as many of the wires as may be necessary until the test lamps light; the two ends, one in each controller, that cause the lamps to light must be marked R_1. The same is done with all the cable resistance taps, the taps and the controller wires with which they ring up being marked R_2, R_3, R_4, etc., in the order in which they come out of the hose, on up to the last resistance tap, which may be R_3, R_4, R_5, R_6, or R_7, according as the starting coil has two, three, four, five, or six sections.

52. The motor wires may be rung out next. Take the No. 1 motor armature terminal taps first and ring out to the No. 1 controller, to which the armature car wires will run straight. For example, the rotation test has shown that for the car to start according to the indication of the No. 1 controller reverse handle, the rear armature terminal must connect to the A_1 post in that controller; accordingly, mark the cable tap nearest to the rear armature terminal A_1; connect the live test line to that tap and by successively grounding the remaining wires in the No. 1 controller, either to the frame or through the ground test line, find the wire to which the A_1 tap belongs and mark that also A_1; find the other end of the A_1 wire in the No. 2 controller, in the same manner, and mark it AA_1. Next, mark the cable tap nearest to the front armature terminal AA_1; find the corresponding wire in the No. 1 controller and mark it also AA_1; the other end of that same wire, in the No. 2 controller, will be marked A_1. Assuming that the rotation test has shown that the current must enter the bottom field for the armature to rotate in the desired direction, mark the cable tap nearest to the bottom field terminal F_1 and also mark the two ends of the car wire with which it rings up F_1. Mark the remaining motor cable tap E_1, and also the two ends of the car wire with which it rings up.

The taps opposite the terminals of the No. 2 motor are rung out and marked in the same order and manner. The rear armature terminal is marked A_2; the cable tap opposite is marked A_2; the wire end with which it rings out in controller No. 1 is marked A_2, but the wire end with which it rings out in controller No. 2 is marked AA_2. The front armature terminal and the cable tap opposite are marked AA_2, the corresponding car wire is marked AA_2 in the No. 1 controller but A_2 in the No. 2 controller. The bottom field terminal is F_2; the cable tap opposite and the two ends of the car wire with which it rings up are marked F_2. The remaining or top field terminal of the No. 2 motor connects either directly to the No. 2 motor frame or taps on to the hose ground wire, in which latter case the hose ground wire will have four taps instead of three. If, on connecting up the motors, it is found that the taps come out of the hose in such a manner that much neater work can be done if the armature terminals are run to just the opposite cable taps to those called for by the rotation test, there is no objection to doing so, provided the field terminals also are run to just the opposite taps, in order to keep all the motors rotating in the same direction.

53. Under the given conditions of designating the armature terminals as front and rear terminals, the terminals connect to the car wires in the same order on both motors; that is, No. 1 front goes to AA_1 and No. 2 front to AA_2; but a little thought will show that since the motors present different sides to the front of the car, being turned end for end, current enters the No. 1 armature at the opposite absolute terminal from that by which it enters the No. 2 armature, but it enters the fields at the same absolute terminals. The average barn man, in connecting up a single equipment with whose connections he is not familiar (suppose, for example, he takes off a pair of old motors and puts on a pair of new ones), connects the field and armature terminals hit or miss, so far as rotation is concerned, relying on his experience to get the rotation requirements straightened out afterwards. Much time can be saved, even when hit-or-miss methods are followed, if the operator will take the trouble to mark the corresponding terminals on the two motors *1*, *2*, *3*, *4* before the motors are installed. Assuming that *1–2* are the corresponding armature terminals (that is, the same absolute terminals) on the two motors, and *3–4*, the field terminals; call one *1*, A_1; the other *1*, A_2; one *2*, AA_1; the other *2*, AA_2; call one *3*, F_1; the other *3*, F_2; one *4*, E_1; the other *4*, E_2 or G. Connect them to the cable taps accordingly, and the two motors will either obey the reverse handle entirely, or disobey it entirely; in the latter case it will only be necessary to reverse the field or armature terminals on both motors.

THE CONTROLLERS

54. The controller connecting posts are now marked and the wires that are to go into them are also marked. Wire T will go into post T; wire E_1 into post E_1; wire R_2 into post R_2, and so on, each wire going into the post that is similarly marked. The first thing to do is to work the wires around in the mouth of the hose so that they will come out of the hose approximately in the direction they must take in order to reach their respective connecting posts. To illustrate, the manner of bringing out the wires in Fig. 18 is much better than that of Fig. 19, because in the latter figure wires that come out on the right-hand side of the hose are crossed over to posts on the left-hand side of the board, and those on the left-hand side of the hose are crossed over to posts on the right-hand side of the board; whereas in Fig. 18 there is some approach to order. The wires cannot be brought out in exact correspondence with the directions in which they must spread, but this can be done very nearly. They can be worked into position in the end of the hose and bound in that position with tape.

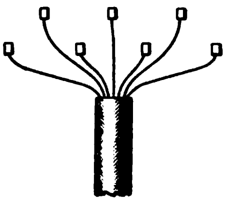


Fig. 18

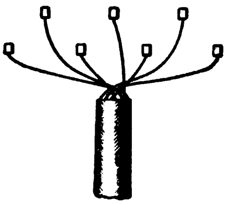


Fig. 19

The hose and wires are pulled well up into the controller and wedged there from below. Beginning with the lowest connecting post, the wires are cut off to proper length. Where the distance from the mouth of the hose to the connecting posts affords plenty of working room for the hand, should some future occasion require the wires to be disconnected, the wires can be run straight up to their respective posts, as indicated at *a*, Fig. 20; but where the distance is very limited, the wires must be bent as shown at *b*. They can afterwards be pressed to one side. In cutting the wires off, due regard must be had for these two conditions. Also, in cutting the armature wires off, both should be left long enough to reach either controller connecting post, in case a mistake makes it necessary to change the connections.

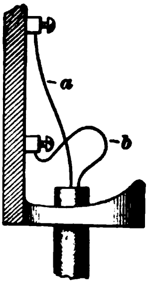


FIG. 20

After the correct direction of motion under all conditions is assured by trial, the armature wires can be cut the proper length for the connecting posts.

55. The controller wires having been cut to proper length, their ends are skinned and twisted with pliers. They are then dipped into melted solder, the solder allowed to set, and the end trimmed and rounded off with a file until it fits the hole in the connecting post. As each wire is cut off, the tag is slid to the position that it will keep after the completed ends are in place. Should occasion arise in the future for disconnecting or replacing the controller, the wires can be identified without ringing them out.

THE MOTORS

56. The motor terminals and the cable taps opposite them having been properly tagged, it only remains to connect terminals of the same mark. Assuming that the truck is a single truck and therefore will not swing independently of the car body at curves, the cable taps are run to points near where the motor terminals come out of the motor frame, so that the part of the connection that must hang in the air will hang as nearly vertical as possible. These hanging connections must be kept clear of the motor frame and suspension bars. If local conditions are such that a motor terminal must rub an iron part when a heavy load compresses the car springs, the iron part must be protected with wood, so that if the insulation wears through, the terminal will not ground. Where the cable tap is more than long enough, take up the excess length in the form of a pigtail cleated at both ends.

Connection between the motor terminals and cable taps is made by means of ordinary two-way sleeve connectors. The ends of the terminal and tap are skinned, twisted, dipped, and trimmed to fit the hole in the two-way connector. The trimmed ends of the tap and terminal are run into the connector clear up to the insulation. The screws, which should be not more than long enough to strike the bottom of the hole when there is no wire in it, are screwed down as far as a 6-inch screwdriver will force them, and the connector and both wires for 2 inches on either side of the connector should be tightly wrapped with friction tape and coated with shellac. As a rule, wiremen defer wrapping the joints until a trial of the car shows that no mistake has been made. Where practicable, it is desirable to avoid having the two-way connector included in the swinging part of the connection, or having the connector so disposed that the motor terminal tends to work loose from it.

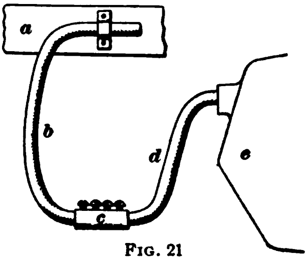


FIG. 21

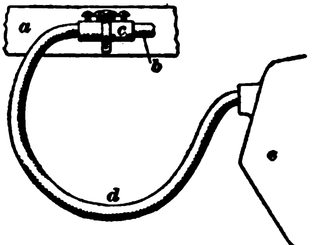


FIG. 22

In Figs. 21 and 22 *a* is the sill or cross-piece along which the cable tap *b* runs. The two-way connector *c*, which is well taped when the connections are completed, joins tap *b* to motor terminal *d*, coming through the rubber bushing in motor frame *e*. In either case the wires in the connectors are subjected to considerable motion.

The best manner of disposing the connector is shown in Fig. 23. In this figure, the two-way connector is secured to the car body in the same way as in Fig. 22, but the motor terminal is cleated to the body between the motor and the connector, thereby doing away with the working action caused by the motion of the motor. In many cases, the motor terminals are not long enough to permit of such a precaution. In such cases, it is worth while to make them long enough by splicing. Use either a soldered wire splice or a thin sleeve splice.

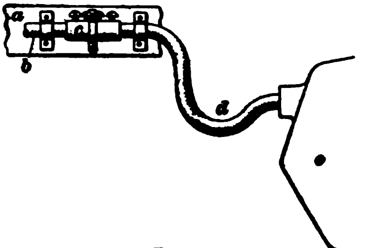


FIG. 23

57. Splicing Terminals.—Motor terminals may be safely and neatly spliced as follows: Skin the end of the terminal and the end of the piece to be spliced to it for about 1½ inches; untwist and sandpaper the composing strands of wire, and straighten each one, as shown in Fig. 24 (*a*); dip the ends in soldering salts, and close them in as symmetrically as possible, until the two insulation heads are 1¾ inches apart or less, as indicated in (*b*). Work the strands down to as small a diameter as possible and secure them with a single turn of small, tinned copper wire at both ends, as shown at *x*, *x*. Clean the surface with soldering solution and solder by pouring the metal over the joint from ladle to pot. When the solder has thoroughly permeated the joint, allow it to harden before moving the joint. Next, smooth the surface with a file, shellac it, and wind friction tape on the joint so

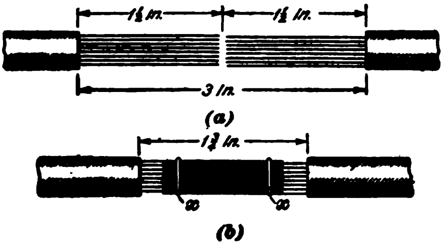


FIG. 24

that the tape is almost flush with the top of the insulation of the two wires. A coat of thick shellac will complete the process. The main object is to get a good electrical contact joint that will not be too large to pull through the bushing in the motor frame. This joint will be fairly water-tight, and will be further protected by the rubber tubing in which it is customary to enclose the motor leads.

58. Where the motors are mounted on double trucks, special precautions must be taken to insure that the motor connections to the cable taps will not be pulled apart at curves where the trucks, to which the motors are hung, turn independently of the car body, to which the cable is hung. If the terminal tap connections are too short to allow for the truck's turns, they will certainly be pulled apart; on the other hand, if they are excessively long, besides the likelihood of their insulation being impaired by rubbing, they are also liable to be pulled apart as a result of sagging on a straight track and catching under some motor suspension, or truck projection, thereby being without sufficient play when the truck rounds a curve.

The problem of properly disposing the motor connections on double trucks is a serious one, and that it has never been generally solved to suit all conditions is evidenced by the motor reports on many roads operating double-truck equipments. Such reports will show many delays due to open-circuited and grounded armature and field terminals. Most of these troubles are experienced where the clearance between the tops of the motors and the bottom of the car is small, and where no regard has been had for existing conditions in the manner of arranging the motor terminals.

59. The point of least movement between the four wheels of a double truck is in the vertical line passing through the king pin around which the truck rotates; and to obtain minimum movement of the motor connections the motor terminals should come out of the motor as near the king pin as practicable and pass vertically upwards to the cable taps immediately above. Where the clearance between the top of the motor and the under side of the car permits it, a connecting board may be installed on top of the motor. The motor terminals are then connected to posts on this board and the cable taps drop vertically to the same posts. Where the motor is hung outside the axle, leaving the space between the motor and the center of the truck comparatively clear, the terminals are brought out of the motor on the side near the center of the truck and ascend to the hose on a slant. When the motors are hung outside the axle and the terminals are brought out from the motors on the sides near the ends of the car, the longest leads are required. Whatever the manner of running the terminals to the hose, they should be protected against abrasion by wire-mounted hose, and the terminals should be supported from the car body. All iron parts that the terminals are liable to rub should be covered with wood. The terminals should be carefully watched on the trial run to ascertain if they require lengthening or shifting, or will permit of shortening.

THE TROLLEY

60. The trolley cable tap runs to a fuse box or breaker, to the motor terminal of a three-terminal lightning arrester (or to its choke coil), or directly to the wall wire, where no fuse box or breaker is used on the under side of the car and the arrester is of the two terminal type and is without a choke coil. In any case, the trolley tap is enclosed in shellac-coated or wire-armored rubber tubing, or in circular loom, throughout its length. It must be clear of grounded parts, allowance being made for changes in position of those parts when in action. To whatever device the trolley tap may connect, the connection must be substantial. If spliced to a choke coil or wall wire, the splice must be soldered. If connected to a fuse, breaker, arrester, or choke coil, the end of the tap must be skinned, twisted, soldered, and trimmed, and must be held in the device by at least two screws. If the hole in the connecting post is too small to take the full size of wire, do not pull off strands to make the trolley tap smaller, but ream out the hole.

THE GROUND TAPS

61. The motor ground taps are run to a point just over the motor-frame ground terminals and cleated to the car body. The taps then run to the ground terminals in the form of vertical pigtails. The cable taps are preferably sweated into the ground terminals, to reduce the chances of their shaking loose. Instead of sweating the ends into the terminals, they may be held in the terminals by at least two screws. The ground tap to the lightning arrester must be free from twists and kinks and without any pigtail. The liability of the arrester ground wire to be shaken loose is preferably minimized by cleating the tap on a level with the arrester connector into which it must connect. Where the No. 2 motor terminal that is permanently grounded (usually a field terminal) runs into the regular car ground wire, that wire must have an extra ground tap, which is then connected to the motor ground terminal in the usual manner. Where the field terminal is grounded to the motor frame itself, it is customary to provide a ground connector like that shown in Fig. 25. The field terminal goes into one end and the regular motor-frame ground-wire tap goes into the other.

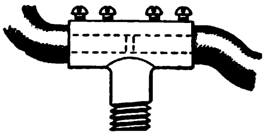


FIG. 25

THE STARTING COIL

62. The starting-coil taps should come out of the hose in the order in which the connecting posts lie. On account of the heat emitted by the coil when in operation, it is better that the insulated taps should be brought up to the connecting posts from below, so that their insulation may not be burned off. To do this, cleat the taps to one side of the coil, bring them down, and then bring them up. It is hardly advisable to solder the ends of taps on many types of starting coils, because the excessive heat will cause the solder to run, leaving the connection insecure. A good plan of insuring proper contact is to twist the wires together compactly and slip them into a soft-copper sleeve; wires and sleeve are inserted in the connecting-post hole and the screws tightened. The sleeve prevents the screws from cutting through the unsoldered strands of wire and insures liberal contact surface between the wires and the connector. As the starting-coil connections are never taped and are therefore easy to disconnect, they can be permanently made at once.

TRYING THE CAR

STARTING

ADJUSTMENT OF BREAKERS

63. Approximate Adjustment.—As the car now stands, all devices are installed. The trolley stand, breakers, trolley and ground taps, and starting coil are connected. The motors are temporarily connected, and the controller wires are permanently in place, except the armature wires, which it may be necessary to reverse and which have been left long in anticipation of such a possibility. Before **trying the car,** set the breakers so that they may be promptly operated in the event of a short circuit existing. Where overhead switches are used in conjunction with a fuse box, see that the box contains a fuse of the proper size.

To approximately set the breakers, one at a time, proceed as follows: Disconnect the wire that goes into the R_1 controller connecting post and in its place put a wire leading to a switch in series with a variable resistance; also, draw the No. 1 motor brushes. As a fuse, put in series with the wire that grounds the variable resistance a piece of copper wire one size smaller than the equipment would require. The piece of fuse wire should be at least 1 foot long, and should touch nothing except at the points of support. On placing the controller on the first notch, assuming the trolley wheel to be on the wire and both switches or breakers to be closed, if connected in series, the current path will be normal as far as the R_1 controller connecting post; from there the current, instead of passing to and through the starting coil and thence to the motors, will reach the ground by way of the variable resistance and fuse wire. The value of the current can be regulated by the variable resistance.

The current is increased gradually until the fuse wire blows. Leaving the variable resistance undisturbed, open the circuit by means of the switch that is in series with the variable resistance, and short-circuit the gap created by the fuse blowing. When the circuit is again completed, practically the same value of current will flow as that required to blow the fuse. First, adjust the breaker so that it will blow when it and the switch are closed. Then close first the breaker and next the switch. When the breaker has blown, open the switch, readjust the breaker so that it will take more current to operate it, and then close it and the switch. Repeat this operation until the breaker stays in when the switch is closed. Then, while the current is flowing, let out on the breaker adjusting screw until the breaker operates. The current that operates the breaker is approximately the same in value as that which blew the fuse.

64. Exact Adjustment.—To adjust the breaker to the exact current value for which it is intended to act, an ammeter must be connected into the test circuit. Suppose, for example, that a breaker is to be set at 200 amperes to protect an equipment consisting of two 40-horsepower motors. The adjusting screw is turned until the pointer is opposite 200 on the scale. The circuit is then closed and the current run up until the ammeter indicates 200 amperes, at which value the breaker should operate. Should the breaker operate either below or beyond 200 amperes, its adjusting screw must be turned a little in the required direction and the breaker again subjected to a current of 200 amperes. By repeated trials and adjustments, the breaker can be made to operate at 200 amperes. Where the two breakers to be adjusted are in parallel, the idle one can be left open and the live one adjusted. Where the two breakers are in series, the operation of one can be prevented, during the test, by taking up on its adjusting screw, so that it will not blow for the same value of current that causes the other breaker to operate.

FINAL INSPECTION

65. After the breakers are adjusted, the test circuit is disconnected and the R_1 wire restored to its connecting post. See that all brushes are in and the brush hammers down, and that all drums are at the off-position. See that there is nothing to derail the car when it starts; that there are no obstructions on the side to scratch the varnish off the body; that there are no test lines nor lamp wires to be run over, and that there are no workmen on top of the car or in a dangerous position underneath it. Try the hand-brake on both ends and see that it is not set on the end opposite to that from which the car is to be first tried. Inspect the shoes to see that they do not hug the wheels when the brake is released.

TRYING ROTATION OF ARMATURES

66. With the wheel on the wire, and one or both circuit-breakers, according as they are in parallel or series, closed, the reverse handle is installed on the No. 1 controller and moved to forward position, and the power handle advanced to the first notch. If the truck has been given a spin to limber it up, the car will probably start on the first notch, but not necessarily so. If it fails to start, throw the drum to off-position and note if the controller flashes. Assuming that it does, advance the controller handle several notches.

A car should never be tried for the first time without having at least 20 feet of clear track ahead and behind; even then all slack must be taken out of the hand-brake chain, and the hand kept in readiness to apply the brake should occasion require it. If the car fails to start, throw the reverse handle and, if necessary, advance the power handle several notches. If there is nothing but excessive stiffness to prevent the car from starting, this treatment will either start it or blow the breaker.

Assuming that the car will not start in either direction, stand inside the car and watch the motors through the traps while an assistant moves the power handle on and off several times. If the motors are properly connected, so that they do not oppose or buck each other, one motor will lift when the current is applied, but the other will drop, that is, provided that the motors are hung back to back or front to front; but if the motors are hung with their commutators pointing in the same direction, both will lift or both drop when the current is applied. Therefore, if the motors are hung back to back, as they are usually, and both motors move their suspensions in the same direction when the current is applied, the two motors are trying to start the car in opposite directions. If motors that are similarly hung move their suspensions in opposite directions, they also are trying to start the car in opposite directions. In either case, one of the motors is so connected as to turn in the wrong direction, and it must be rectified before the car can start. Before trying to ascertain which motor needs changing, try operation from the No. 2 controller. If the motors act in the same way when operated from this controller, whatever changes in connection are to be made must be made at the motor itself, because the irregularity affects both controllers; but if the car starts normally from the No. 2 controller, the change must be made in the No. 1 controller, because only that controller is affected.

67. Correcting Rotation.—Next, determine which motor is turning in the wrong direction: this can be done in either of two ways: (1) Cut the motors out, one at a time, and find, by trial, which motor starts the car in the direction indicated by the reverse handle. The motor that starts the car in the direction opposite to that indicated by the reverse handle is the motor whose connections must be changed. After trying one motor, before cutting it out preparatory to trying the other, see that the other is cut in before the power is applied. In other words, do not apply the power with both motors cut out, because such an oversight may burn out the starting coil. Also, see that both cut-out switches are cut in when the test is over. (2) Even when the two motors on a car are opposed in effort, so that the car cannot start, there is sufficient clearance between the pinions and gears to allow the armatures to turn a little when the current is applied. This is evidenced by the single click emitted by the gears when current is applied to two motors opposed in rotation. If the click does not occur with the reverse handle forwards, move the reverse handle to reverse and apply the current; the click will be heard under any condition where the power applied is sufficient to move the armatures.

By having an assistant operate the controller and noting which commutator top moves forwards when the reverse handle is forwards, or back when the reverse handle is in the reverse position, the faulty motor, which operates in this manner, is at once identified. The armature pinion rotates in the opposite direction to the gear. If the commutator top moves forwards, the top of the gear moves backwards and the car moves backwards.

There are several conditions of error in rotation. Both motors may act wrongly from both ends: reverse the armature connections of both motors at the motors themselves. Both motors may act wrongly from one end: reverse both pairs of armature wires in the controller on that end. One motor may act wrongly from both ends: reverse its armature connections at the motor itself. One motor may act wrongly from one end: reverse its armature wires in the controller on that end. One motor may be wrongly on one end and the other motor wrongly on the other end: reverse the armature wires of each motor in the controller from which its operation is irregular. In any case, where the rotation of a motor is wrong at both ends, the reversal of connections must be made at the motor itself; but where the wrong rotation is at but one end, the reversal in connections must be made in the controller at the affected end.

OPEN CIRCUITS

68. Car Dead at Both Ends.—Any single open circuit that affects both motors from both ends and on all notches must be between the trolley wire overhead and the point where the trunk trolley wire taps the controller trolley wire or in the common ground connection: the line may be dead as the result of a section switch, fuse, or breaker being open; the trolley wheel may rest on an insulator; the base of the pole may have thick japan on it; a car fuse, switch, or breaker may be open; the roof-wire connection to the trolley stand may have been forgotten; or the car may have paper wheels, or the rails on which it stands may be dead. In any of these cases, no flash can be obtained in either controller by throwing it on and off, or by throwing it from series to parallel or from parallel to series; the car will stay dead until the open circuit is located and the fault corrected.

69. Operation Irregular From One End.—Any single open circuit that affects both motors on but one end must be either in the controller on that end or in some car wire local to that end. If the car is dead on all notches on the affected end, the break is probably in the trolley or ground circuit; the trolley car wire may be loose in the connecting post; there may be an open-circuited blow-out coil or connection; a trolley finger may be making no contact; or the ground wire may be loose in its connecting post. If the open circuit affects operation on one series-notch and one parallel notch, it is likely to be in one of the resistance fingers, or in some wire running to it, or in one of the resistance car wires. If the open circuit affects operation on series-notches but not on parallel notches, it is in some wire, finger, or connection that is used in series but not in parallel operation. If it is such as to affect operation on parallel but not on series-notches, it is in some wire or connection that is in circuit on the parallel notches, but is not used on series-notches.

70. Operation Irregular From Both Ends.—Any single open circuit that affects operation on certain notches on both controllers is in some cable tap or operating device other than the controllers. For example, leave out a brush on one motor or leave a field or armature terminal disconnected; the car cannot start on the series-notches of either controller, but will start on one motor as soon as either controller is advanced a certain distance beyond the last series-notch.

Suppose that the R_1 resistance cable tap comes loose or that there is an open circuit in the R_1–R_2 starting-coil section. The car will not start on the first notch of either controller, but will start on the second notch of either controller with a slight jerk; operation in parallel will not be affected, because neither the R_1 tap nor the R_1–R_2 starting-coil section is used on any of the parallel notches, unless the starting coil is connected and operated on the multiple addition plan, which is not probable on ordinary surface cars.

GROUNDS

71. There is little probability of a **ground** on a new equipment that has been tested in the manner described. The general effects of grounds on different parts of the motor circuit have been considered at length elsewhere. Should the ground develop at the time of starting, however, the first place to look for it is in the lightning arrester. The lightning-arrester spark points may have shaken together, or the arrester (if of the three-terminal type) may have been connected wrongly. In either case, a breaker or fuse will operate when the trolley wheel touches the wire, and until the ground is removed it will be useless attempting to operate from a controller.

A ground similar in effect to the above is due to the confusion of the controller trolley and ground wires in a controller having its frame connected to the ground post of the controller. If the trolley wire is put into the ground post, a breaker or fuse will operate the instant the wheel touches the wire, because an abnormal current flows from the controller trolley wire to the ground post, thence through the grounded controller-frame dash rail, brake staff, etc., direct to the ground.

72. A ground may obtain as the result of both reverse switches being thrown to an on-position, as explained in *Car-Wiring Diagrams.* A ground that affects operation from only one controller must necessarily be in either the power or reverse drum of the affected controller, for only these devices have an off-position, in which position the ground does not cause a demonstration. If the fuse or breaker operates on putting the power drum on the first notch, indications point to a ground on the power drum top casting. Should the fuse or breaker operate only on reaching a parallel notch, the ground must be on one of the two castings used only in parallel, or in the upper half of the reverse drum. Should the car fail to start and blow a fuse or breaker on an advanced series-notch, showing that the current must be passing through the starting coil, a ground either on the power-drum series-castings or on the lower half of the reverse drum may be looked for. A grounded drum cannot affect operation as long as it is at off-position.

ACCELERATION

CONDITIONS NECESSARY FOR SMOOTH ACCELERATION

73. **Acceleration** refers to the gradual increase of the car speed from zero to maximum, following the gradual advance of the power drum from the first notch to the last. Where the starting coil has from four to seven sections to be gradually cut out by advancement of the power drum, smooth and continuous acceleration can be effected under nearly all conditions by proper distribution of the resistance among the several notches. Where the starting coil has any less than four sections of resistance, there is bound to be some jumping, and the nearest approach to smooth acceleration is secured by so distributing the resistance that the jumping tendency will be equally divided among the several notches.

ADJUSTMENTS FOR OBTAINING SMOOTH ACCELERATION

74. The quicker the start allowed, the easier it is to make the rest of the acceleration smooth, because the less difference is there between the maximum speed and the speed that the car will acquire on the first notch. The allowable starting impulse is best adjusted after the starting coil is well heated by regular operation. If a car starts smoothly when the coil is cold, it may not start at all on the first notch after the coil has been in operation part of a trip. Accordingly, it is customary to make the maximum resistance of the starting coil such that the car starts a little too freely on the first notch when the coil is cold; the heating due to operation will increase the resistance to a value that will give an easy start.

The maximum value and distribution of resistance of a starting coil is generally decided by the manufacturing company on certain assumptions that may subsequently prove to be in error. In such a case, the resistance must be changed to suit local conditions. If the car starts too freely, resistance must be added. If it starts too slowly, the over-all resistance of the coil must be decreased. If the car shows a pronounced tendency to jump on a certain notch, the section of resistance cut out by that notch must be decreased, and without decreasing the over-all resistance of the coil.

Suppose, for example, that the car jumps on the fourth notch, the notch on which the R_4 finger goes into action; the R_4 resistance car wire operates to cut out the starting-coil section that lies between the R_3 and R_4 starting-coil posts, and in this case the resistance of this section is too great. To decrease it without decreasing the over-all resistance, either the R_4 starting-coil post must be moved nearer to the R_3 post, or the R_3 post must be moved nearer to the R_4 post. In the first case, the resistance of the R_4–R_5 section will be increased, thereby tending to increase the jump that takes place on the fifth notch. In the second case, the resistance of the R_2–R_3 starting-coil section is increased, thereby tending to increase the tendency of the car to jump on the third notch, the notch on which the R_3 finger and car wire operate to cut out the R_2–R_3 starting-coil section.

75. These conditions are illustrated in Fig. 26, where (*a*) represents the original distribution of resistance in a four-section starting coil. In (*b*), the R_4 post has been moved toward the R_3 post, thereby decreasing the resistance of the R_3–R_4 section, as desired, but increasing the resistance of the R_4–R_5 section. In (*c*), the R_3 post has been moved toward the R_4 post, thereby decreasing the resistance of the R_3–R_4 section, as desired, but increasing the resistance of the R_2–R_3 section. If trial proves that the jump on the fourth notch cannot be sufficiently reduced by moving R_4 toward R_3 or R_3 toward R_4 without introducing an excessive jump elsewhere, R_3 may be moved a little toward R_4 and R_4 a little toward R_5, thereby distributing the jump among the third, fourth, and fifth notches.

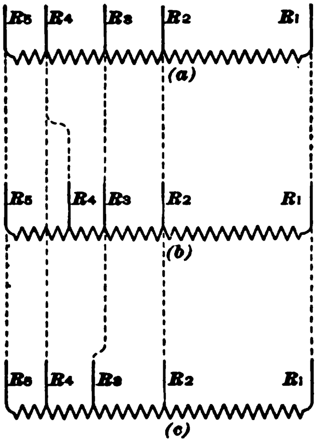


FIG. 26

In order to secure, by trial, the best distribution of resistance, it is not necessary to actually move the starting-coil posts for each trial. If the starting coil is of the grid type, the ends of the resistance-cable taps can be bent into a hook to be hung over the grids at different points. If the starting coil is of the band-iron type, the resistance-cable taps can be connected to flat and sharp-ended iron terminals that can be driven into the coil at any desired points. By repeated shifting of these temporary terminals and trial of the car, the correct changes are determined and made.

If a car jumps forwards too much on the controller being thrown from series to parallel position, there is too large a portion of the total resistance in the first section of the starting coil, because that is the section usually omitted on the first parallel notch. Such a car would also show a decided tendency to jump on the second series-notch, because the first section also is cut out in passing to that notch. All loaded cars ascending a heavy grade tend to halt, more or less, when the controller is thrown from series to parallel. Should this tendency assert itself strongly when the car is light and on a level, there is not enough resistance in the first section of the starting coil; or, to express the conditions more directly, too much resistance remains in the starting coil when the first section is dropped preparatory to throwing the motors to parallel.

RUNNING TEST

FINAL PREPARATIONS

76. Assuming that the car starts and accelerates normally and that therefore no further changes will be made in its connections, the controller armature wires can be cut off and the ends prepared and installed permanently. See that all cut-out switches are properly cut in, and then close and fasten the doors. Next, tape up the motor connections and shellac them. See that the armature and the motor-axle and car-axle boxes are properly lubricated and packed. Even though oil is not to be regularly used as a lubricant in the motor bearings, it is well to use it on the trial trip, because it feeds more promptly. If the boxes are not constructed to feed oil (oil tends to run through such boxes very rapidly) pack them with oil-soaked woolen waste and then pour more oil on top. The waste will prevent the oil from feeding through rapidly enough for a box to run dry and cut the axle before its condition can be detected. Take at least a gallon of oil on the car ready for cooling off any box that may run hot. See that all motor-cap bolts are drawn down until their heads compress the lock washers sufficiently to prevent the bolts from working loose and dropping out; it is not well to tighten the bearing bolts until the car has had a run and the bearings have been given a chance to find a seat.

See that the hand-brake and any other brake to be used in conjunction with it are in working order. See that the sand boxes are full of sand and that sand flows on the rail when the levers or foot-buttons are operated. If the car has a fuse box, see that extra fuses are provided; if it has breakers, see that they will operate when the hand push buttons are pressed. If the breakers are connected in parallel, see that the breaker on the end opposite that from which the car is to be operated is open. Be certain that the car has a drawbar and switch iron. See that everything is in order about the trolley rigging. If the trap doors are not already up, see that they can be pulled up without first being forced loose from the under side of the car. Be certain that the bell-rope rigging is in good order and that the car has platform gongs and foot-buttons for operating them. Where a fender should be used, see that one is provided; if practicable, put fenders on both ends to avoid the trouble of changing the fender from one end of the car to the other whenever the running end of the car is changed.

TRIAL RUNS

77. Before running a trial car on to the main line, the formal approval of the official in charge of the division must be secured. Where the car is being installed by a manufacturing company, it is customary to entrust its handling either to a regular crew or to depot shopmen well acquainted with the running times and meeting points of regular cars and with local conditions. The car should be run back and forth in the house on the series notches for 10 or 15 minutes to give the worst of the bearings a chance to get hot. After such a trial, feel all the bearings above and below to find if any of them show a tendency to heat; this will at least indicate which boxes are to be most closely watched. If any box gets so hot that the hand cannot be kept on it, the bearing cap must be removed, the shells opened, and an inspection made to see if the shaft is rough or nicked. If the heating is due to a tight bearing or stopped-up oil groove, the fact is apt to be evident. In the first case, the shaft bearing will be brass colored if brass shells are used; in the other case, part of the bearing will be dry, showing that the oil is not reaching it. If the bearings are tight, the places that show rubbing must be thoroughly scraped. If a shaft is cut, it must be removed and filed smooth; in either case, bearing and box must be flooded with light oil to remove dust and scrapings or filings.

MAIN-LINE TRIP OUT

78. Being assured, as far as possible, that the boxes are not inclined to heat, the car, if it must be tried on the main line, is run over the road a short distance behind a regular car. The brushes must be watched to see that they do not spark excessively. If one brush shows a tendency to spark more than the other or others, press down on the brush hammer with a stick; if the increased pressure improves its action, the tension in the brush spring should be increased. The brush may be a little tight, or the brush holder may have a burr on it or be too far from the commutator. On reaching a curve, if the car has double trucks, watch the motor terminals carefully, to see that none of them is subjected to a pull in consequence of being too short, and that none of them is unnecessarily long and liable to catch on any projection from the truck or motor. At the sharpest curve, look carefully to see that no motor part is bearing over against the car-wiring hose, and that no brake rod or lever is in danger of rubbing the starting coil or any other device.

Feel all bearings at frequent intervals. Should any motor bearing show a decided tendency to heat, keep pouring oil through it; in all probability this will prevent the bearing sticking until a switch, depot, or siding is reached, where the box can be opened without delaying traffic. If an armature bearing gets unbearably hot to the touch, loosen the cap and cut out that motor, relieving it of all work. If a car-axle box begins to whistle, the axle bearing is probably running dry. It will take only a few minutes to jack up the box, draw the packing, take out the check-plate and brass, and cool the axle bearing with oil sufficiently to admit of running at least until the whistling begins again.

TERMINAL INSPECTION

79. Assuming that the car has made the half trip without any serious irregularity developing, apply the hand-brake and trip the breaker. Inspect the starting coil to see if any part of it is red hot or if any plates are warped or buckled. If the coil is red hot, but the starting and acceleration are satisfactory, a coil of greater current-carrying capacity, but of the same over-all resistance and of the same sectional resistance, is needed. If any part of a coil gets red hot, the coil will, in time, deteriorate. If the coil is of the grid type, excessive expansion and contraction will cause the grids to get loose and shaky. If of the band-iron type, the insulation will be disintegrated and will cease to insulate.

Feel the motors to see that one has not heated more than the other. If the trip out has included many steep grades, the rear motor will naturally be somewhat warmer than the forward one, owing to its doing more work on grades, where, some of the weight being removed from the forward wheels, the friction between the forward wheels and rails is less and the wheels tend to slip.

Open the controllers and see that none of the power-drum tips or rings shows scoring or blistering, and that none of the reverse fingers has changed color; any one of these conditions indicates poor contact. A poor controller contact sometimes causes very irregular action of the car; the motors may fail to respond to some notches and jump on others; or the car may run along smoothly for a time and then seem suddenly to lose part of its power. If such action is accompanied by a sizzling noise in the controller or by an odor of burnt metal, the trouble is probably due to a poor contact. A poor contact must be improved at once, or it will cause a flash over, either in the controller or at one of the motors, causing damage that will be costly to repair.

MAIN-LINE TRIP BACK

80. As the half trip has been run behind a regular car, its running conditions approached those of regular operation; and if bearings and all other devices have acted satisfactorily on the trip out, it will be safe to run the car home ahead of a regular car in order to try it at maximum speed for a long stretch of track. The car is not nearly so likely to give trouble on its return as it was on its run out, because all parts have been limbered up by jolting over switches and crossings and the bearings have taken up stable alinement, so that no unnatural stresses are exerted on them. Before starting back, see that the bearings have plenty of oil in them and tighten the armature and axle caps. Run the car back and forth for 10 or 15 minutes, at full speed, but within a limited distance, to see that the tightening of the bearing caps does not in any way tend to make the bearings run hot.

Before starting on the home trip see that the rear brake is released and that the circuit-breaker on the rear end is cut out and the forward circuit-breaker cut in, if the breakers are in parallel connection. Men have been known to run a car through a round trip with the rear brake partly set and then turn the car in for being "slow." If the hood breakers are in series, or are in parallel and one of them is open, the rear brake need be but very lightly set to cause the breaker to blow at some stage of the advancement of the controller handle to full parallel. If both parallel-connected breakers are left closed, however, the current must be twice as great in order to operate either of them.

81. When the car is started homewards, as much as possible of the trip is run at maximum speed. The bearings and brushes are carefully watched. Just before getting to the car barn, the brake is applied several times, with full power on, and the action of the brushes noted. Assuming that the breaker is in good order and that the adjustment is approximately correct, the brake may be applied until the breaker operates. The object of this test (its conditions are really no more severe than some of the conditions to be encounted in actual operation) is to note the action of the brushes under severe conditions and to burn out any weak parts or connections on the trial run, instead of leaving them to burn out on a regular run and delay traffic.

Any motor will spark to some extent when subjected to such treatment, but one motor in the given equipment should spark no worse than another, and none should spark destructively. If the action of the brushes is satisfactory in one direction of rotation, the test should be repeated with the car running in the opposite direction. Assuming that correct setting of the brushes has been insured by previous inspection, if they spark much worse in one direction than in the other, it is probably due to looseness of the brushes in the holders, or to excessive clearance between the holders and commutators, allowing the brush contact surfaces to wear in a double bevel. Conditions that will permit a double bevel to develop will not only permit the setting of the brushes to change with the direction of rotation; but the probabilities are that the two bevels on any given brush will acquire different areas, increasing the sparking when the direction of rotation is such that the smaller areas must carry the current.

ARMATURE REPAIR WORK

(PART 1)

INTRODUCTION

1. Armature repair work, except repairs to the shaft, core, and commutator, is practically new work; for when a modern railway armature is sent to the repair shop on account of a grounded or short-circuited winding, the prevailing practice is to replace all coils with new ones. Theoretically, in case of a faulty coil, it would be necessary to remove only the coils that lie on top of the faulty one and then replace them after that has been renewed; but practically, after an armature has run any length of time, very few of the coils that are lifted or removed are fit to go back on the core. Even if an armature has just been newly wound, it will in many cases be impracticable to remove the new coils without injuring many of them, unless the coils were originally mechanically formed in a steam-heated and water-cooled press—perhaps the only method by which coils of absolutely uniform dimensions can be produced. If the coils were formed in any other manner, some of them, doubtless, required driving into the slots, even if the core was new, and cannot be removed without being twisted out of shape. On an old core, conditions are even more unfavorable for removing coils from the slots without injury, because, on account of the various mechanical abuses to which armatures are subjected, the teeth of the laminations get bent out into the slots, thereby effectively decreasing the slot width.

PREPARATIONS FOR WINDING

ARMATURE SHAFT

TEST FOR A BENT SHAFT

2. Single Bend.—If an armature shaft is bent, the armature will not run true; and if installed in a motor, the gears will emit a characteristic noise, there will be sparking at the brushes, and if the bend is great enough, the core will strike the pole pieces, burst the band wires, and injure the winding. To test for a bend, the core and shaft are swung in a lathe and spun around; if the bend is bad, the core can be seen to wabble. The most accurate test is made by resting the hand on some fixed part of the lathe, preferably on the butt end of a tool in the tool post, and gradually moving the point of a piece of chalk toward the rotating shaft until it touches. If the shaft is straight, the chalk will make a continuous ring around it; but if it is bent, the chalk will touch only the higher part. By applying this test along the shaft at several places, the point of greatest bend, where the straightening device must be applied, will be located; it can also be ascertained whether the shaft is bent in more than one place.

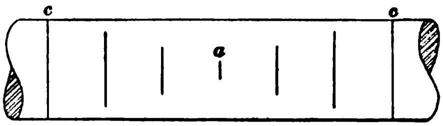


FIG. 1

Fig. 1 represents the tested and marked part of a bent shaft. The bend is turned toward the observer, hence it does not show in the illustration; but the series of marks made by the chalk at several points along the rotating shaft plainly indicates that the higher point, or the point of greatest bend, must be immediately under the shortest mark *a*, and that on each side of the mark *a* the shaft becomes straighter, until at *c*, where the chalk mark extends entirely around the shaft, there is no bend.

3. Double Bend.—If, in applying the chalk test along the shaft on both sides of the core, two points are found that give a short chalk mark between longer ones, the shaft is bent in two places. A shaft should be carefully tested, whether the core appears to run true or not, for two bends may occur in such a way as to so neutralize each other, as far as the core is concerned, that the core may apparently run true, thereby indicating that the shaft is true, but the bearings may heat excessively when the armature is put in service. In Fig. 2, two exaggerated bends *a*, *b* are shown on opposite sides of the core. If the bends are diametrically opposite each other, the core may not appear to wabble, but the chalk test will show the two bends, either of which, alone, might cause considerable wabbling and both of which are bad enough to cause the bearings to heat.

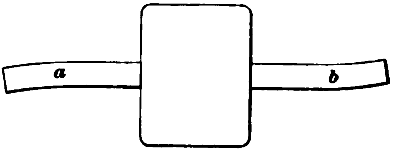


FIG. 2

STRAIGHTENING A BENT SHAFT

4. Not all bent armature shafts can be straightened with the core on, for sometimes the bend is right at the end plate. On the other hand, some bends are so located that they can be straightened even when the armature is completely wound, connected, and banded. In a factory, because of the liability of the shafts to bend under the stresses due to pressing the laminations of the core together, preparatory to clamping them between the end plates, all shafts with the cores on are tested for bends before being sent to the winding department. Bent shafts are straightened by *bending* or *turning*.

5. Bending Method.—The **bending method** consists in applying a device to straighten the bend by springing it in the opposite direction. In a crude way, this may be done by means of a lever and a lathe. The armature or the core and shaft, as the case may be, is swung between extra heavy lathe centers; by the chalk test, the high side of the bend is determined, and the shaft *a*, Fig. 3, is turned until the bend lies on the under side; by means of suitable blocking *b* on the lathe bed, a lever *c* is placed against the high side of the bend and the shaft is sprung upwards by forcing down the end of the lever, as indicated by the arrow. In some cases, simultaneously with the springing of the shaft upwards, sharp blows are struck on the shaft above the area of contact of the lever, an operation known as *peening*. In any case, the pressure of the lever must be exerted against the high point of the bend and at right angles to the axis of the shaft; and, after each series of straightening efforts, the shaft must be spun and the chalk test applied to determine progress. If the high point of the bend gives a longer chalk line than it did at first, and on the same side as at first, the shaft has been made more nearly straight; but if the chalk mark is on the opposite side of the shaft, the straightening process has been carried too far and the shaft is sprung in the opposite direction. The shaft should be bent until the chalk test shows continuous rings.

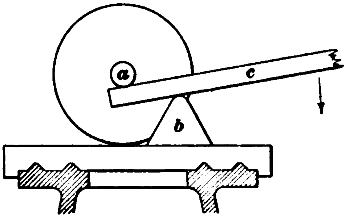


FIG. 3

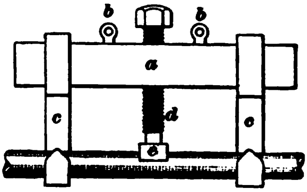


FIG. 4

6. Fig. 4 shows a device for straightening heavy armature shafts without causing stresses on the lathe centers. A heavy bar of steel *a*, provided with eyebolts *b* for lifting purposes, carries heavy steel hooks *c*, that may be moved lengthwise of the bar; the lower ends of the hooks are formed to receive the shaft to be straightened. A heavy bolt *d* threading through bar *a* has a V-shaped block or saddle *e* that sets on the high point of the bend to be straightened. The bent shaft is first swung in a lathe and the chalk test applied to determine the high point. The straightening device, usually hung on a chain hoist, is then swung into place, hook bars *c*, *c* are adjusted on each side of the bend, block *e* is set on the high point, and screw *d* is run down until the block is clamped in place. The lathe centers are then slackened and pressure is brought to bear on the bend by turning screw *d* with a wrench. When the bend is forced down as far as experience suggests that it should be, the lathe centers are run in again, the straightening device loosened, and the chalk test applied to ascertain results. In straightening a bend in metal, it is necessary to apply force until there is a slight bend in the opposite direction, because when the straightening device is loosened the metal will spring back.

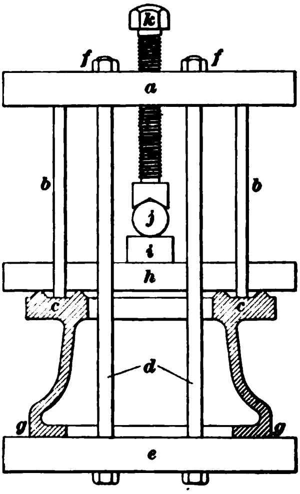


FIG. 5

7. Fig. 5 illustrates a still better shaft-straightening device, one that exerts no stress on the delicate lathe parts during operation, and that does not need to be swung out of the way for spinning the armature for the chalk test. Cross-bar *a* is supported on four legs *b*, *b* that stand on lathe guides *c*, *c*; bolts *d* passing through cross-bar *a* and between the lathe guides *c*, *c* support cross-bar *e*, which, by tightening nuts *f*, *f*, can be drawn up against the bottom of the lathe bed *g*, *g*. Two cross-pieces, one of which is shown at *h*, lie on the lathe guides and support the blocking *i* on which the bent shaft lies when the lathe centers are eased off. The bend, having first been located by the chalk test, is brought directly under the V-shaped block under the end of the screw *k*, which is run down hard enough to hold the block and the shaft in place, and the lathe centers are withdrawn from the ends of the shaft. By means of a long wrench, screw *k* can be forced down on the shaft *j* with great pressure, the resisting pressure being that of the bar *e* against the bottom *gg* of the lathe bed. A large shaft that presents great resistance to being straightened can be made to yield by training a blow torch on the bend to soften it, and applying pressure at the same time.

8. Turning Method.—If a shaft has several bends or kinks, it is sometimes impracticable to straighten it by bending, any effort to entirely straighten one bend resulting in making others worse or in creating new ones. In such cases, it is customary to get the core to run practically true by equalizing the error among the several bends, somewhat as indicated in Art. **3**, and turning the journals down to a smaller size to keep the bearings from heating. Certain parts of the shaft may then wabble slightly, but as long as the core, bearings, and pinion seat run true, or nearly so, slight eccentricities elsewhere can do no harm.

SHAFT RENEWAL

9. Entire Renewal.—When an armature shaft is so badly or so peculiarly bent that a new one must be used, which is generally the case when the bend is close to one of the core end plates, care should be taken to test the new shaft before and after installing it, to make sure that it is straight. A press suitable for forcing shafts out of and into cores should be installed at a convenient location in each repair shop.

The core end plates generally back against a shoulder turned on the shaft at one end, and are secured on the other end by means of a nut threaded on the shaft and suitably locked to prevent backing off. To force out the shaft, this nut is removed, the shaft being pressed toward the end having the shoulder. If the core laminations are confined on an independent shell or spider that is keyed to the shaft, no precautions need be taken to hold the core laminations rigidly together when removing the shaft; but if, as is generally the case, the core laminations are assembled on the shaft itself, a special device must be used to hold them in place until a new shaft is forced in.

Fig. 6 shows a simple device for this purpose; *a*, *a* are bolts or studs of a diameter slightly less than the width of the slots in the core. Steel or iron rings *b*, *b* go on opposite ends of the core and have holes through which bolts *a*, *a* can pass. The outside diameters of the rings are about the same as that of the core, and their inside diameters are such as to bring the rings below the bottoms of the slots. If studs are used, they can be wedged down into the slots first, the rings put on, and nuts put on the ends of the studs and tightened. There should be at least eight bolts used, and the holes in the rings must be drilled so that they will come opposite the slots in the core.

It is sometimes the practice to make the core seat, that is, the part of the shaft on which the core is placed, slightly larger in diameter on the new shaft than it is on the old one, to allow for the slight enlargement of the hole in the core due to forcing the first shaft in and out. In turning a new shaft, care must be taken to turn the shoulder so that the core, when pressed against it, will have the correct location with reference to the journals. The end nut is screwed on and locked while the core is still under compression against the shoulder.

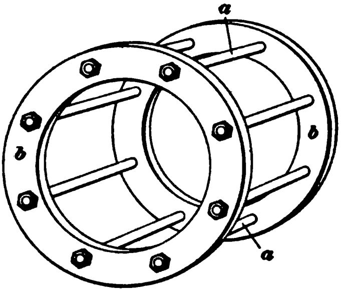


FIG. 6

10. Partial Renewal.—A **partial renewal,** or a renewal of a part of a shaft, may be advisable under any of the following conditions: Sometimes, when the shaft is broken; when the pinion seat needs a new keyway, for which there is no room; when the thread on the pinion end of the shaft is destroyed; when the journals are worn down below standard; when it is desirable to increase the length or the diameter of the journals; or when the pinion seat is excessively worn. The method to be followed, in any case, will be suggested by the following processes.

11. Either end of a straight shaft, or the straight part of a shaft that has tapered portions, may be renewed by the **plug method.** Fig. 7 shows the renewing of a pinion thread on the end of a straight shaft by this method; *a* is the pinion seat and *b* is the thread cut on the reduced portion at the end. If this thread has become destroyed in some way, and there is insufficient stock to permit chasing a new thread of smaller diameter over it and then using a pinion nut with a special thread, as is ordinarily done in such cases, the threaded portion is cut off, a hole is bored in the end of the shaft, and a new steel plug *b*, Fig. 7 (*b*), is driven in and secured by transverse pins driven through holes *c*; or, better, threaded in as shown in Fig. 8, and secured by a single transverse pin *c*. The pinion thread is then cut on plug *b*. Threading in the plug *b*, as shown in Fig. 8, has the advantage that tightening the pinion nut does not so much tend to strain transverse pin *c* and withdraw the plug, since such stresses are resisted by the opposing surfaces of the inside and outside threads.

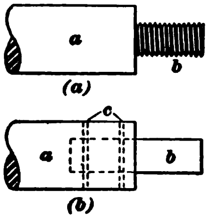


FIG. 7

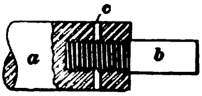


FIG. 8

12. The plug method is not applicable where the pinion seat is tapered, because the small end of the taper will not admit a plug that is large enough in diameter to be safe. For example, if a hole were bored into the pinion seat *a*, Fig. 9 (*a*), to admit a plug large enough to be safe, there would be very little stock left on the small end of the taper and the pinion keyway *b* would be undermined.

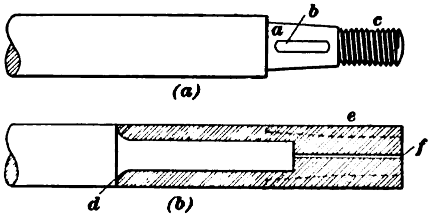


FIG. 9

Accordingly, to piece such a shaft, and obtain sufficient stock for the threaded portion *c*, the shaft is first turned for a considerable distance beyond the impaired part, the shoulder being curved, or filleted, as at *d*, Fig. 9 (*b*), to give it strength. A thimble *e* is then bored out enough smaller than the turned-down portion of the shaft to require a pressure of from 20 to 30 tons to force it on. A small hole *f* must be drilled through the blind end of thimble *e* to allow the air to escape; otherwise it will be impossible to force the two parts together. After the thimble is in place, it is turned down and cut off to dimensions, and the pinion seat, keyway, and thread cut as on a new shaft.

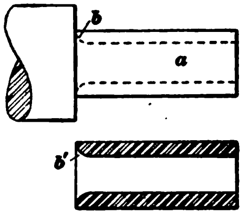


FIG. 10

13. Fig. 10 shows a method of standardizing a journal badly worn on the commutator end of the shaft. The journal *a* is turned still smaller with a fillet at the shoulder *b*. A steel sleeve with a corresponding filleted shoulder *b'* is bored out enough smaller than the turned-down bearing to produce a *shrink fit;* that is, the sleeve must be expanded by heating in order to get it over the bearing. When it is put in place, it cools, contracts, and grips the shaft so tightly that slipping is not likely to occur.

The bushing of a journal on the pinion end of a shaft is a little more difficult; for example, if it were necessary to reduce the bearing below the size indicated by the dotted line, Fig. 11, part of the taper and keyway would be cut away, and in such a case it would be better to go well back on the shaft and splice on a new end, as shown in Fig. 9. Such a procedure would be rarely required, however, as in most cases it is only necessary to turn the bearings down to the bottom of the shoulder at *d* and to shrink on a sleeve in the same manner as on the commutator end. The end of the sleeve then acts as a shoulder, and it must be faced off, so that the pinion will bear against it only when fully seated.

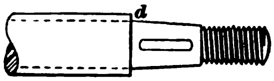


FIG. 11

ARMATURE END PLAY

14. By **end play** is meant the side motion of the armature and shaft in the bearings. The end play is limited by collars or shoulders on the shaft bearing against the ends of the Babbitt-metal bearing linings; as the Babbitt metal is much softer than the steel or iron shaft collar that is thrust against it by the end play, the rate of wear of the collar will be very low compared to that of the Babbitt. Some end play is necessary; but if the Babbitt metal becomes worn through, the rubbing of the iron or steel shaft collars against the iron bearings will soon heat the bearings and wear the collars. Excessive end play will allow the pinion to rub the side of the gear-case, or let the commutator or armature head over against the brush holder, besides increasing the violence of the blow that the collars give to the bearings when the car suddenly strikes a curve.

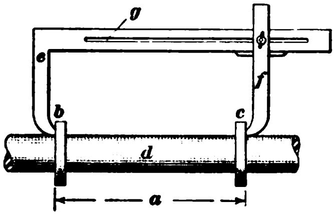


FIG. 12

15. Gauging End Play. Before an armature is put into a machine, its end play may be ascertained by gauging or measuring the distance between the faces of the bearings and the distance between the outside faces of the thrust collars or rings that limit the end play, or by gauging or measuring the distance from the outside face of each collar to the end of the shaft, or to some designated mark on the shaft. In Fig. 12, the distance *a* between the outside surfaces of two thrust collars *b* and *c* on shaft *d* can be gauged by means of large calipers, or by a gauge *e* on which movable arm *f* can be adjusted and clamped in any position by a small bolt through slot *g*.

16. When collars *b* and *c* are cup-shaped, as in Fig. 13, either special calipers with bent arms *e*, *f* must be used to measure the distance *a*, or the measurement of that distance may be discarded and end measurements taken instead.

Thus, b' is the distance from the bearing surface of collar *c* to the pinion seat shoulder *h*, and c' is the distance from the bearing surface of collar *b* to the commutator end of the shaft. In case of excessive end play due to wear in the thrust collars, the distance *a* between the outside or bearing surfaces of the two collars will be less than it should be, but end measurements b', c' will be greater than they should be.

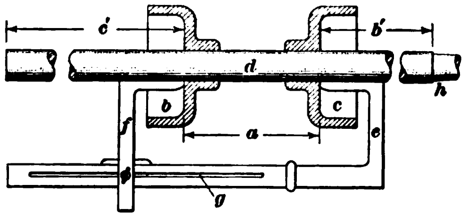


FIG. 13

17. Use of End Play.—If, when an armature is first put into a machine, the distance *a*, Figs. 12 and 13, between the bearing surfaces of the thrust collars is so great that there is no end play whatever, as soon as the machine begins to warm up in service the heat will expand the shaft so that the collars will bind against the ends of the bearing linings; and the excessive heat caused by the friction of the two surfaces on each other will melt the Babbitt bearing linings and possibly let the armature down on to the pole pieces. Somewhat more clearance than expansion would call for is allowed in order that the pinion may play sidewise on the face of the gear and thereby insure more satisfactory wear of both gear and pinion, and also in order that the wear of the commutator surface by the brushes may be more even.

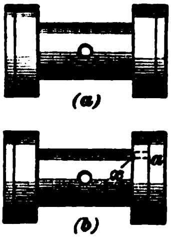


FIG. 14

18. Taking Up End Play.—Ordinarily, end play is taken up by making the Babbitt lining on the end of the bearings extra thick, as indicated in Fig. 14, where (*a*) shows the bearing as ordinarily babbitted, and (*b*) shows it with the extra Babbitt extension *a*. To secure the Babbitt lining on the ends, it is sometimes the practice to drill a series of holes *x* in the iron flange of the bearing shell, and permit the molten Babbitt metal, when putting on the extension, to run into these holes. Extending the babbitting in this way is good practice until through long wear the thrust collars have become thin; they should then be renewed or repaired. If the collars are cup-shaped, as shown in Fig. 13, it is best to draw them off and put on new ones; but it is practicable to face off the bearing side of a straight collar or shoulder, and shrink on a new ring and machine it to standard size. In Fig. 15, ring *a* shows the faced part of the old collar; and ring *b*, the new one.

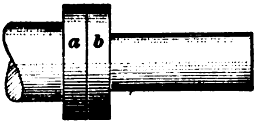


FIG. 15

WORN KEYWAYS

19. Pinion Keyway.—It is very important that the pinion keyway be in first-class condition, otherwise the key cannot hold the pinion rigidly—a most necessary condition. The pinion keyways of shafts that have been in service for some time often show the sides badly worn as a result of loose pinions. Fig. 16 (*a*) shows a cross-section of a shaft with a keyway rectangular and unworn; (*b*) shows a keyway that has been hammered, or worn out of shape by a loose pinion. It is impracticable to utilize a badly worn keyway without milling it out to take a larger key, in which case either the key must have different top and bottom widths or the keyway in the pinion must be recut to take the larger key. The best plan is to cut another standard keyway opposite the worn one, thereby keeping all parts standard. It is always advisable to stick as closely as possible to a standard practice; special work is hard to keep in mind, and may result in vexatious delays sometimes when repairs are urgently needed.

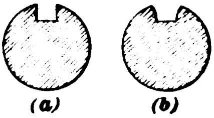


FIG. 16

20. Commutator Keyway.—It is equally important that the commutator keyway should be in perfect condition, for if the key fails to hold, the commutator will wabble, and it will be but a short time before constant bending will break the coil leads to the commutator and thus open the armature circuit. If the commutator keyway is so impaired that it is not safe, and if it is desired to keep all parts standard, a new keyway must be cut; but care must be taken that the new one is located in the same relation to the core teeth and slots as the old one, otherwise the coil leads will come down to the commutator at a different angle than before, and the motor into which the armature is put may spark. To illustrate, if the old keyway is directly opposite the center of a tooth or slot, as in Fig. 17, the new one must also be cut directly opposite the center of a tooth or slot, as the case may be. Here, again, it is advisable to use a standard keyway rather than to enlarge an old one. It is not well in any case to enlarge an old keyway, except when there is not sufficient room to cut a new one.

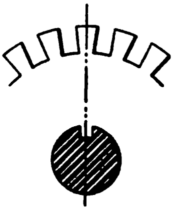


FIG. 17

TAPERED SEATS AND SHOULDERS

21. Testing.—It is important that the tapered seats on the shaft for the pinion and commutator should be of standard dimensions and that the pinions and commutator shells should be taper bored to suit these dimensions. The seats are tested by means of a standard gauge kept for that purpose. It is not sufficient that the engaging parts be of the same taper; their extreme diameters must conform in order to secure a good fit at the proper point. For example, if the plug *a*, Fig. 18, is to be machined to fit the tapered sleeve *b*, so that the fit is tight when the end of the sleeve strikes the shoulder *c*, not only must the taper of *a* be accurate, but the diameter at each end must exactly conform to the corresponding inside diameters of the sleeve. The dotted lines across the sleeve indicate the position a plug

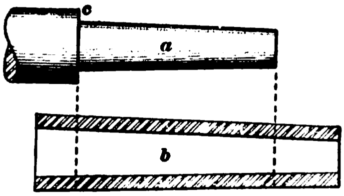


FIG. 18

turned too small might have to take before a tight fit would occur. Likewise, if either wear or careless machining results in a loose fit of a tapered pinion or a commutator shell, the pinion or shell will touch a shoulder on the shaft before it fits the tapered seat. If the hole is too small or the seat too large, the commutator or pinion will not go on far enough. In any case, application of the proper gauges will show which member is at fault, and the faulty member is the one to be corrected, so that all parts may be kept to standard size.

22. Correcting the Fit.—If either the pinion or the commutator shell cannot be forced home to its seat on the shaft, one or both of the engaging surfaces must be machined to a fit. In either case, if the fit is not firm and close when the shoulder is reached, either a special sleeve or a special cone on the shaft is necessary. If the pinion is loose, either a pinion with a special bore can be used, or the shaft can be spliced, as shown in Fig. 9, and a new cone turned. If the commutator shell is loose when shoved home against the shoulder, it is best to use a commutator with a special bore. Numerous methods are adopted to avoid using a special commutator bore, all of which are questionable. One is to prick-punch the tapered commutator seat, as shown in Fig. 19. This raises a series of slight projections on the shaft, and on these the commutator shell rests. These projections do not afford a secure seat, and they are likely soon to be worn off or depressed, leaving the commutator loose. Another method is to face off the shoulder against which the commutator bears, thereby allowing the commutator to go on far enough for the tapered surfaces to engage sufficiently to produce a fit. The objection to this method, if carried too far, is that the brushes will not rest wholly on the commutator; the outer brushes will play over the ends of the bars, thus wearing a shoulder on the brush, and when the armature plays endwise this shoulder will lift the brush from the commutator and cause serious

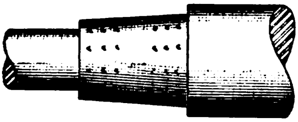
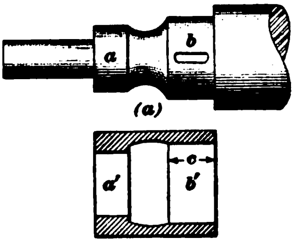


FIG. 19

sparking. The third method, a very bad one, is to flatten the commutator key until it is a little too wide for the keyway in the commutator shell, and then force the commutator on over it.

23. In testing a pinion or commutator seat with a gauge, especially in the case of a tapered fit, great care must be taken that all surfaces involved in the fit are perfectly clean and free from oil, grit, lint, and other substances that would influence the fit in any way.

24. Stepped Commutator Seats.—Fig. 20 (*a*) shows a style of commutator seat made in two parts, *a* and *b*, turned to diameters differing about $\frac{1}{16}$ inch, both parts being straight, and the space between them being of less diameter than either. The commutator shell, Fig. 20 (*b*), is so bored that hole *a'* fits seat *a* and hole *b'* fits seat *b*. In installing the commutator, no force is required until hole *b'* begins to go on seat *b*; then force must be exerted only through distance *c*, which also represents the distance through which force must be exerted in removing the commutator. This construction affords most of the advantages of a tapered seat without its disadvantages, and does not require the maintenance of expensive test gauges.



(*a*)

(*b*)

FIG. 20

ARMATURE CORE

LOOSE CORE

25. A loose core is a condition that seldom obtains on modern armatures, and for that reason is apt to cause considerable trouble before the defect is discovered. A loose core in operation will cause open circuits, the result of broken leads caused by the relative motion between the armature core and the commutator, exactly the same as previously described for a loose commutator. A sure test for a loose core, when it cannot be discovered otherwise, is to swing the armature in a lathe and turn the shaft by pulling the belt back and forth by hand, the core being so braced that it cannot turn. If there is any relative motion between the shaft and core, the core must be loose.

ALINING AND CLEANING THE SLOTS

26. Causes of Poor Alinement.—Rough handling of an armature core is almost sure to force some of the laminations out into the slots, so that they will prevent the insertion of the armature coils. A toothed armature core is easily injured, and great care should be taken that it does not receive severe blows or bruises in handling. Rolling cores over a rough or uneven floor, piling them together, dropping them, allowing them to strike against or be struck by any hard object—any of these things may throw the teeth out of alinement. In service, the core may have rubbed against a pole piece, or some hard substance may have become wedged in the air gap, thus forcing the teeth out of alinement.

27. Methods of Alinement.—If the core teeth project into the slots, they must be pushed back into place before attempting to install armature coils; otherwise they may cut into a coil unknown to the winder, possibly not far enough to produce an immediate ground, but far enough to greatly impair the insulation at that place.

28. The **drifting method of alinement** consists in forcing the teeth back into line with a light hammer and an ordinary drifting tool. Fig. 21 shows the shape of a drifting tool, or a drift, and Fig. 22 shows the manner of applying it to straighten core teeth. In Fig. 22, *a* represents the general line of a row of teeth that are straight, *b* the outline of a tooth bent out into the slot, and *c* the drift. The tooth must be straightened gradually to

FIG. 21

avoid breaking it off. Breaking out teeth should be avoided, if possible, though armatures with a total of several inches of teeth broken out will still operate. A tooth that breaks off during straightening generally breaks off straight at the root, leaving no ragged projecting stub to cut into the insulation of a coil.

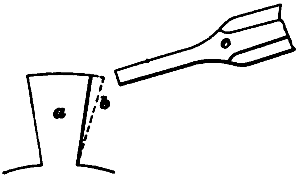


FIG. 22

29. **The parallel-bar method of alinement**, generally employed on new cores, may be used to supplement the drift method where the distortion of the teeth is very general. As indicated in Fig. 23, it consists in driving into the slots steel bars with parallel sides and of a thickness that will give the proper width of slot. A dozen or more bars are driven in successively, then the first is withdrawn and driven in the slot next to the last bar, and so on until a bar has been driven into every slot on the core. Where there are bars enough, it is still better to fill all slots before drawing out any bars. The bars are slightly tapered at the bottom, so that they may enter the slots without binding.

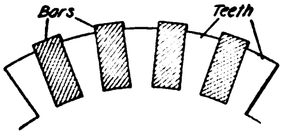


FIG. 23

30. **Smoothing the Slots.**—After alining, the slots are generally smoothed by passing a new flat file back and forth in each slot several times. The file may have a smooth flat steel spring *s* attached to one side, as shown in Fig. 24, so that the spring will press against one side of the slot and hold the file firmly and evenly against the other. If an armature has had a ground from the winding to the core, the location of the ground in the slot will be blistered or beaded, and there may even be a hole burned in the core. In such cases, every trace of roughness must be removed with hammer, chisel, and file. The roughness found around the seat of a ground

FIG. 24

is sometimes quite difficult to remove, as the projecting fins and bumps consist of a hard alloy of copper and iron, and a hard tool is required to cut them out.

31. Cleaning the Core and Slots.—The core is generally thoroughly blown out with compressed air or a hand bellows by the man who *strips it*, that is, the man who cuts the old coils loose from the commutator and pulls them from the slots. The winder, however, should again thoroughly air-clean the core inside and out, including the ventilating ducts. This cleaning should be done where the dust cannot go into neighboring armatures in process of winding. The slots are then further cleaned by drawing a piece of muslin back and forth in them. The muslin will also locate rough places by catching in them.

COMMUTATORS

32. While one department is inspecting and preparing the shaft and core, another may be preparing a commutator, either the one removed from the shaft or another. The commutator used should, in any case, be as nearly standard as practicable. In hand winding, the core is generally insulated and wound before the commutator is put on the shaft, because the commutator would be in the way of the winder. In winding an armature with coils previously made of round wire wound on formers, the commutator is sometimes put on the shaft before winding, but this is not absolutely necessary; if the coils are formed from copper bar, the coil leads are generally continuous and very stiff, and point rigidly very nearly to the commutator bars to which they will connect, and it is the practice to force on the commutator before installing the coils. Each coil is then put on the core and its bottom lead is connected at once to the proper commutator bar, so that practically the armature is wound and connected simultaneously. Hand winding will not be considered in the discussions to follow, because railway-motor armatures always have formed coils.

PREPARATION, TEST, AND INSPECTION OF OLD COMMUTATORS

33. Removing Commutator.—When it is decided that a core must be stripped and rewound, the first step is to remove the commutator. To do this, the leads must first be loosened. If it is not desired to save any of the old coils, the leads are cut loose with a cold chisel; but if some of the coils are to be saved, or if the coil leads are composed of heavy bar copper, the severing of which in such manner would be likely to injure the commutator ears, or lugs, the leads must be loosened by melting the solder that holds them in the ears, and then lifting the leads while the solder is soft. The flame of a blow torch directed against the ears will furnish the necessary heat.

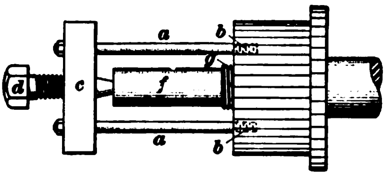


FIG. 25

There are different methods of forcing a commutator from a shaft. In some cases, the commutator shell has in it two threaded holes, *b*, *b*, Fig. 25, provided for the insertion of bolts or studs. Long bolts or rods *a*, *a* screwed into holes *b*, *b* pass through crosshead *c*. The crosshead is threaded to receive a large screw *d*, the point of which enters the counter-sink in the end of shaft *f*. After removing the holding nut from the threaded shoulder *g*, the large screw *d* is turned in, thus forcing the commutator loose. If, instead of the holding nut on *g*, a ring is shrunk on, or if the commutator has no threaded holes for receiving rods *a*, *a*, these rods must be bent as shown in Fig. 26, so that they will hook behind the commutator shell. If the part to be removed offers great resistance, the work can be made much easier by heating the shell or ring with the flame from a blow torch. Pinion

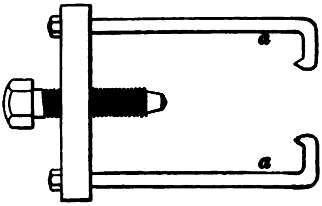


FIG. 26

pullers are sometimes made on the principle shown in Fig. 26.

34. Cleaning the Commutator Ears.—If the coil leads are cut loose from the commutator, short pieces will still remain soldered in the commutator ears. These must be removed and the ear slots restored to standard dimensions. If the ears are short and stocky, as indicated at *a*, Fig. 27 (*a*), and the solder is not excessively hard, the slots can be cleared by driving the pieces out with a blunt chisel point, as indicated at *c*; or sometimes the slot is cleared by driving a drifting tool against the front end, as at *d*. It will not do to drive hard either way, for the ears will be bent or the insulation under or between the bars will be injured. If the solder is very hard, or the ears are long, as in Fig. 27 (*b*), the solder must be melted; this is preferably done before cutting off the leads, as the coils then afford a means of pulling the leads out when the solder softens. If a drift or chisel is used for clearing the slot of such an ear as that shown in Fig. 27 (*b*), the probabilities are that the ear will be bent or broken, making it necessary either to replace a bar or to splice a piece to the broken ear. Probably, the best way to thoroughly clean the solder from the slots in commutator ears after the leads have been lifted is to train the blow torch on the ears and, while the solder is in a molten condition, draw a piece of canvas through the slot. Some winders wet the canvas to keep it from taking fire, but the more skilful workers do not.

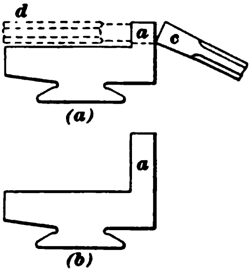


FIG. 27

35. Standardizing Ear Slots.—If the coil leads are to be soldered into the ears, as they are in almost all cases, or if they are to be fastened in with screws, the operation of driving a drift through the slot is sufficient; or the slots may be cleaned out with a piece of hack-saw blade inserted in a wooden handle, as indicated in Fig. 28, the teeth being set to clean out the slots to a width sufficient to readily admit the ends of the coils. In some cases, however, solder has not been considered necessary to a good connection; the width of the slot is made somewhat less than the diameter of the wire that it is to receive, and the wire is well tinned and forced into the slot with a drift, all being held down by winding a band over the leads close to the commutator. In such cases, the width of the slots must be exact, and such accuracy can best be insured by cleaning out the slots on a milling machine. Where no solder is used in the connections, it is customary, in order to give greater rigidity to the ears, to form them by cutting a circular groove in the commutator, as indicated in Fig. 29, where *a* is the ear.

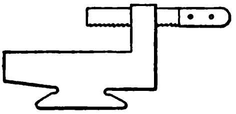


FIG. 28

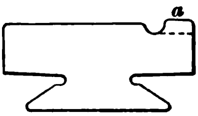


FIG. 29

36. Counting and Testing the Bars.—The commutator bars must be counted and the completed commutator must be mechanically tested for solidity and parallelism, or direction of bars with reference to the shaft. It is not very likely that a commutator removed from a machine that has been in operation will have the wrong number of bars in it, although this has happened. Such a mistake, however, is more likely to occur on a new commutator; and unless the precaution is taken to count the bars before using the commutator, the error may not be detected until the commutator leads are nearly all connected. Counting the bars first may save much labor and material.

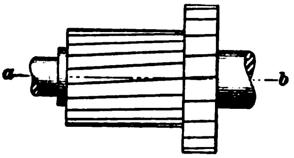
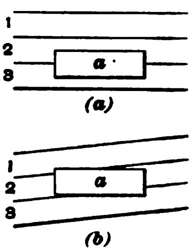


FIG. 30

37. The test for **parallelism** is made to determine not only whether the bars are parallel to one another, but also whether they are parallel to the shaft. To illustrate: in Fig. 30, the bars are parallel to one another, but in tightening the commutator they have been skewed around to an oblique angle to the direction *a b* of the shaft. The obliqueness is exaggerated in the figure to bring out the idea clearly, but some commutators are twisted enough to cause sparking, or excessive heating of the commutator, because the brushes make contact simultaneously with too many bars. For example, in Fig. 31 (*a*), the bars *1*, *2*, *3* are straight, and brush *a* can touch but two bars simultaneously; but in (*b*) the bars are so skewed that brush *a* makes contact with three bars simultaneously. In such a case, the commutator should be loosened, the bars straightened until they are parallel with the shaft, warmed, put under hydraulic pressure, and again tightened.



(*a*)
(*b*)
FIG. 31

38. The test for **solidity** is to determine whether any of the bars are loose. The test is made by striking the surface of the commutator with a hammer. Any bar that is not down solid will sink below the level of the others. If the commutator is perfectly tight, the hammer will rebound from the blow, as it would from solid metal. A commutator that has loose bars must not be used until it has been reheated and again tightened, to make all bars solid. Driving a bar down to a seat will do no good, as it will be thrown out again from centrifugal force during operation. In making this test the blows of the hammer should not be heavy enough to badly bruise the bars or to crush the insulating mica between them or under them.

39. **Grounds** between the commutator bars and the shell are usually located by means of a lamp-test circuit, as shown in Fig. 32, where *T* is a trolley wire; *L*, a group of five lamps in series; *G*, a ground connection; *c*, the commutator; and *s*, the shaft. If the live test line *1* is touched to the commutator and the ground test line *2* to the shaft, the lamps cannot light if the insulation is good, because no current can flow from the bars to the shaft. Instead of testing between the bars and the shaft, the test may, if preferred, be made between the bars

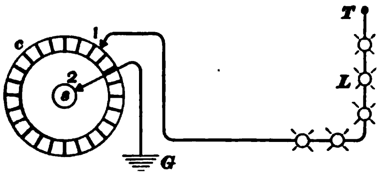


FIG. 32

and the commutator shell by touching one point to each bar in succession while the other is held against the shell. The same rule then applies as before; namely, if the lamps light when any bar is touched, a ground is thereby indicated, and the commutator must be loosened and the cause of the defect found and removed. The cause will often prove to be an iron or brass chip embedded in the mica ring, probably pressed in at the time the commutator was made. In some shops such a defect is called a *nigger*, in others a *bug*.

In some cases, no source of trouble can be found, and on retightening the commutator it will test clear, indicating that the short-circuiting particle has been shifted or forced out during work on the commutator. The test is usually conducted by holding one test point on the shaft or shell and passing the other around the commutator; any bars that show a ground to the shell are marked, so that they may be readily identified when the commutator is taken apart. To avoid having the bars and bodies, or mica separators between the bars, fall away from the shell when the end ring is removed, a piece of wire or a clamp is passed around the commutator to hold them together; after taking off the end ring, the commutator shell is set upright on an arbor, so that the defective bars can be lifted out and inspected, one or two at a time, without disturbing the others.

40. Short circuits are located by touching one test point to any given commutator bar and the other to the bar next to it; if the insulation is good, the lamps will not light. The two test points are then *walked* around the commutator until the insulation between every adjacent pair of bars has been tested. If the lamps light during these tests, or when one point is held on one bar and the other point on any other bar in the commutator, there must be one or more defective mica bodies. It is very often the case that a piece of metal becomes embedded in a body at the time of making the commutator; such a defect may not have shown up under the ordinary tests at the time the commutator was made; or, if it did show up, it may have been apparently burned out by running a test current through it for some time. This method of burning out grounds or short circuits, while sometimes apparently effective, is not reliable. If a short circuit occurs between two bars, as at *a*, Fig. 33, and inspection shows that it is not due to a burr, or projection that can be removed by scratching between the bars with a sharp-pointed tool called a *scriber*, the commutator should be loosened and the defective mica body removed, and either made good or replaced by a perfect one. This is the only reliable way of removing such defects from a commutator, though sometimes pounding the bars between which the trouble occurs seems to jar the foreign substance away, so that the short circuit disappears, temporarily at least; but it will be likely to reappear and cause trouble after the armature is put in service.

Occasionally, when holding the two test points on adjacent commutator bars, a light can be seen on looking down through the intervening mica body, showing a partial short circuit of some kind to exist where it cannot be safely removed without taking the commutator apart. If the commutator shows evidence of blistering between the bars on the surface and at the ends, it is probable that the same condition exists on the inside, and the commutator should be opened for examination.

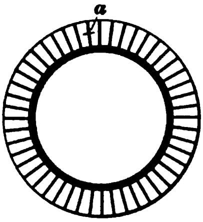


FIG. 33

When a machine tool has been used in turning a commutator, the machined surface must be gone over carefully with a scriber and all fins and burrs removed from between the bars. Machined parts behind the ears, after all fins and burrs have been removed and after a thorough cleaning, should be given a coat of thick shellac that will dry with a glaze.

41. Open Circuits.—If two or more mica bodies are burned or cut out between bars, as at *a*, Fig. 34, it is probable that the armature on which the commutator was last used had an open circuit in its winding or connections. If the mica bodies are nearly all burned below the surface of the commutator, there must have been serious sparking, the cause of which should be found and removed: the core or commutator may be loose and some of the leads broken; the solder may have been melted from the connections and thrown out, leaving partially open circuits; excessive overloads may have been the direct cause of the sparking or may have caused the solder to melt, thus becoming the indirect cause. After finding the cause and before using the commutator again, the burned places in the mica bodies must be thoroughly scratched out and cleaned; and if the cavity is not more than $\frac{1}{8}$ inch to $\frac{3}{16}$ inch deep, it is customary to turn down the commutator in a lathe until the surface of the copper and that of the sound mica are even or flush with each other. If the commutator is needed at once, or if the bars are also eaten out, turning down must be the remedy; otherwise, it is preferable to take the commutator apart and insert new bodies, thus saving the copper that would practically be wasted by turning down.

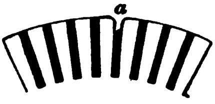


FIG. 34

42. Partial Renewal of a Mica Body.—In the case of large commutators, involving great labor in removal from the shaft and great waste of copper in turning down, burned mica bodies can be partially renewed if most of the burned portions are near the end of the bars, as is usually the case. A hand saw of the proper width is worked down into the affected body as shown in Fig. 35, until all burned portions are removed. The saw must be handled in such a way that the bottom of the cut is a perfectly straight line, as at *a b*. The slot is thoroughly cleaned out and inspected to insure that the sides of the saw teeth have not forced bits of the adjacent bars into

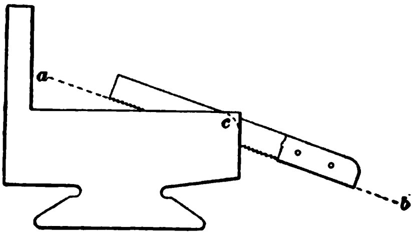


FIG. 35

positions to form short circuits. If the commutator is connected to the winding, a short circuit between the two bars cannot be readily detected without removing the coil leads from the ear slots; but if the commutator is disconnected, the lamp test can be used. If no short circuit exists, a piece of stiff mica is driven into the slot, as indicated at *a*, Fig. 36. It is a good idea to apply thick shellac to the bottom edge of the inserted piece to insure a perfect joint at the bottom. When the inserted piece is down against the bottom, the two adjacent bars are slightly prick-punched on the top and at the ends, so as to expand them into the inserted piece, which is thus bound and prevented from moving. The inserted piece is cut off flush with the commutator surface with a knife, and is further reduced to more exact size when the commutator is finally turned in the lathe. As many as twenty of these pieces have been inserted in a commutator without afterwards giving trouble. Many mica bodies show a tendency to crumble on the end; this tendency can be decreased by beveling off, or rounding, the end of the commutator, as shown by the dotted line at *c*, Fig. 35; but the face of the commutator must not be cut away under the bearing surface of the brush.

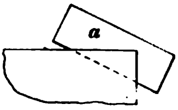


FIG. 36

43. Carbonized Mica Bodies.—Commutators in operation are liable to be subjected to more or less oil or grease. This oil or grease gradually works its way into the mica bodies, and in course of time, owing to the heat and arcing to which it is exposed, the mica becomes carbonized, the carbonization extending to a depth depending on the length of time these causes have been active. If a bar-to-bar test indicates general short-circuiting of bars, and a thorough scratching and cleaning between bars does not eliminate the trouble, the mica is probably damaged in this way. If the action has been going on but a short time, a light cut taken off the surface of the commutator may remove the carbonized portion of the bodies and clear the short circuits; otherwise the commutator must be rebuilt with new mica bodies. There have been cases of carbonization so bad that the test lamps would light to full power on applying the test points to bars located on opposite sides of the commutator.

PREPARATION, TEST, AND INSPECTION OF NEW COMMUTATORS

44. Modern methods of making commutators have greatly simplified and cheapened the processes, and at the same time have produced results more satisfactory than those secured by the old methods, which required numerous split rings and other devices for holding the bars and bodies in adjustment during construction. The introduction of hydraulic pressure for compressing the binding parts during the tightening of the end nut has made it an easy matter to get the bars parallel with one another and with the direction of the shaft, and to get them firmly secured in place. Bars and bodies are now punched to exact size in the same punch press, thus considerably lessening both the manual and the machine work previously connected with them, doing away with much of the waste of metal incidental to machine work, and making it possible to assemble them directly in the commutator.

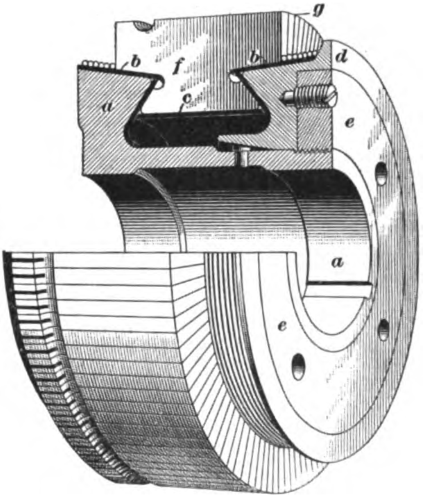


Fig. 37

45. Construction of a Commutator. Fig. 37 shows a perspective and half-section view of the commutator of a railway motor. The parts are as follows: *a* is the shell; *b*, *b* is the micanite insulation made up in the form of rings, or cones, by sticking sheets of mica together with insulating varnish and pressing the mass by means of suitable forms or molds into the desired shape; *c* is a micanite ring underneath the bars; *d* is an iron or steel ring that is forced against the bars and held in place by annular nut *e*, the nut being turned by means of a spanner inserted in the holes shown; the nut is held from loosening by a setscrew; *f* is a commutator bar and *g* is one of the mica insulating bodies that separate the bars from one another.

46. Selection of Bars and Bodies.—The commutator bars are press-punched from long bars of hard-drawn copper of the correct thickness and bevel for the particular commutator under construction. The shape of the stock to be used differs for commutators of different diameters, or for commutators of the same diameter but different numbers of bars; hence, care must be taken to select suitable stock in each case. It is important that the mica bodies should be punched with the same dies as the commutator bars; otherwise they may not be of the same outline, and it may be necessary to do additional machine work after the commutator is assembled. The commutator bars are beveled, but the sides of the mica bodies are parallel, and every mica body should be gauged for thickness in order to make sure that the completed commutator will have the correct diameter. The bars and bodies should be the same in number. A man long experienced in the assembling of certain sizes of commutators may be tempted to judge by the filling of his assembly ring whether he has the correct number of bars or not; but it is better always to count them, as a slight difference in thickness might make a difference of one or two bars in the total number required.

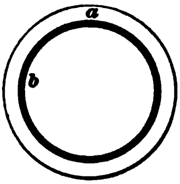


FIG. 38

47. Assembly of Bars and Bodies. Fig. 38 shows an assembling ring, which consists of a steel ring *a* bored true inside and lined with a fiber ring *b*. Both faces of the ring are machined to lie true on a plane surface. To assemble a commutator, a surfacing plate *c*, Fig. 39, is wiped off clean and laid on the bench, and assembling ring *a* is laid on top of it. The bars and the mica bodies, which have been previously brushed off and kept protected from flying particles and bench filings, are assembled around the inside of the ring, as indicated at *d* and *e*. If the bars are of the proper dimensions, the bodies of the proper thickness, the ring of the proper inside diameter, and if the correct number of bars and bodies are employed, the last bar inserted will go in with sufficient snugness to bind the rest, just as a keystone binds an arch, and the ring and bars can be lifted without impairing the alinement.

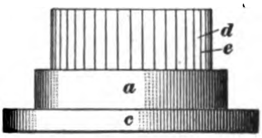


FIG. 39

The shell *a*, Figs. 37 and 40, previously insulated by micanite rings, as indicated at *b*, is set up on the surface plate beside the assembly, on parallels *k* if necessary to protect the projecting end of cone ring *b*. The insulating rings and the inside of the commutator are thoroughly brushed or cleaned with an air jet, and the assembly is then bodily lifted and set down on the shell flange, as indicated in Figs. 40 and 41. In Fig. 41, *c* is the surface plate; *k*, *k*, the parallels; *l*, *l*, the projecting cone ring; *a*, the assembly ring; and *d*, the bars and bodies above which shows the threaded portion of the shell.

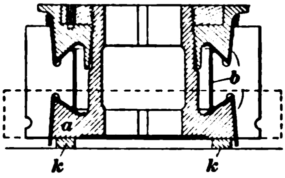


FIG. 40

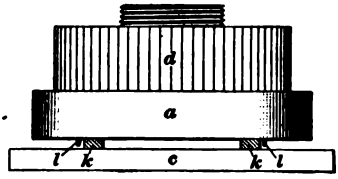


FIG. 41

48. Tightening the Commutator.—After being thoroughly brushed out and fitted with its cone insulation ring, which also must be thoroughly brushed, the ring *d*, Fig. 37, is dropped into its place over the shank of shell *a*; nut *e* is then screwed by hand on the thread at the end of the shell *a*, as far as it will go, special care being taken that the bars are not twisted out of parallel during this process. The construction of the spanner used for turning nut *e* is indicated in Fig. 42, where pins *a* are placed at the proper distance apart in disk *b* to engage the holes of nut *e*, Fig. 37. The commutator is then set in a vertical press in such a manner that pressure can be exerted on ring *d* without any being put on nut *e* and without interfering with the turning of the nut with the wrench. On account of the tapered shape of the surfaces that receive the pressure, and the bevel of the commutator bars, the bars are not only compressed firmly between ring *d* and the head of shell *a*, but are forced in toward the shank of shell *a*, thereby pulling radially inwards on the bars and bodies and wedging them into a solid compact mass. While shell *a* is under pressure, nut *e* is tightened. The commutator is then baked to soften the insulating rings and thereby render them more pliable; while it is hot, pressure is again applied and nut *e* further tightened.

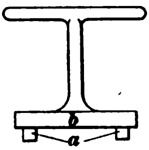


FIG. 42

49. Formation of Ears and Slots.—Assuming that trial with the hammer shows the bars to be down solid, a lamp circuit is used to test the insulation from bar to bar and from each bar to the shell. If the insulation proves to be good, the commutator is placed on a suitable arbor, swung in a lathe, and a circular groove cut around it, as indicated in Fig. 29, so as to form the ears. A light surface cut is also taken along the whole face of the commutator to make sure that it is true and that all uneven places are cut down. Great care must be taken that the arbor used is an exact counterpart of the shaft, that the commutator shell is accurately placed and rigidly clamped on it, and that the arbor is accurately centered in the lathe; if these precautions are not taken, the commutator, when placed on the shaft, will very likely not run true. If the commutator shell is bored to fit a tapered seat on the shaft, the turning must be done on a tapered arbor, else the groove will not be true. Likewise, when a stepped seat is to be used, precautions must be taken to have the work turn true.

50. The ear slots are cut on a milling machine, the width of the cutter employed depending on the diameter of the wire to go in the slot. Before running the cutter through an ear, it is well to inspect the bars at the ends to see that they point toward the center of the shaft. If a bar is truly radial, the slot, when cut, will appear as in Fig. 43 (*a*); if not truly radial, the slot will run down toward one side of the ear, as indicated at *x*, Fig. 43 (*b*), greatly weakening that tong of the fork and rendering it likely to break when old connections are subsequently drifted out of the slot. The error of a non-radial bar may be magnified by starting the tool a trifle to one side of the center of the bar, so that a careless operator may practically cut off one corner of the ear. If the bars are generally non-radial, the commutator should be taken apart, all measurements, including the gauging of the bars and bodies, carefully verified, and the commutator reassembled. The most likely cause of the bars not being radial is the use of too thin bars or bodies, so that they tilt over to one side when the nut is drawn down preparatory to putting the commutator in the press.

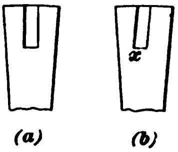


FIG. 43

51. Testing and Cleaning.—Too much stress cannot be put on the importance of thoroughly brushing each part before assembling; and the dust should not be brushed off one part on to another. If a chip or filing no larger than a pin point gets between two surfaces that are to be subjected to pressure, when the commutator is tightened, the chip or filing will be forced into the insulation of one surface or the other. This may not form a complete path through the insulation, so that the lamp test will not show a short circuit or ground; but the insulation will be weakened at that point and may break down soon after the motor is put in service. It must be remembered that a breakdown in the insulation between the bars and the shell or clamping ring of the commutator of a motor operating on a grounded railway circuit constitutes a short circuit from the trolley to the rails, The shell, the shank, and the cone rings should be very carefully brushed before setting the assembly in place, and likewise the top ring and the tops of the bars before the top ring is put on. On screwing down the nut to hold the parts together, preparatory to using the press, the bar-to-bar and the bar-to-shell tests should be applied, and the same tests applied after tightening the nut, both before and after heating the commutator. The bar-to-bar test must be applied after forming the ears, or after subjecting the commutator to any other machine operation, besides carefully inspecting between bars and scratching out any burrs that may wholly or partially reach over from one bar to the next one. By testing after each operation, a weak spot in the insulation may often be detected and removed. After the commutator is complete, the exposed parts, except the face where the brushes are to bear, are given a coat of thick shellac that will dry with a glazed surface.

52. String, Cloth, and Mica Bands.—Where the mica insulating rings extend well beyond the ends of the commutator bars, as indicated at *b*, Fig. 37, there is less danger of the current flashing over from the end of the bars to the iron commutator shell. It is customary to mechanically protect the mica ring by winding string or cloth around it. A coating of thick shellac is finally applied to the band.

ARMATURE COILS

WINDING COILS

53. While an armature core is being stripped, note should be made of the size of copper used in the coils, the insulation of the individual conductors as well as of the complete coils, and the number of turns per coil. Other data, such as the slots in which a coil lies, the bars to which the leads of a coil are connected, etc., should also be noted. This data will be useful in rewinding.

The coils used on modern railway-motor armatures are usually wound on metal or wooden formers that are revolved on machines similar to the headstock of a lathe. The formers are cast, carved, or otherwise shaped to form a coil that will so fit the armature core that the completed winding is symmetrical. An end view of a simple form of coil-winding machine is shown in Fig. 44; *a* is one of two wooden legs, each being steadied by two iron braces *b*, *b*. Legs *a* are provided at the top with suitable bearings that support a horizontal shaft *c*, to one end of which is keyed a driving pulley *d*; to the other end a coil former *f* is clamped. The pulley *d* is driven by a belt *e* in a counter-clockwise direction. The belt tension is adjusted by an idler pulley *g* on the end of the arm *h* of a crank that is connected by a vertical rod *i* and a crank-arm *j* to a shaft extending lengthwise of the machine and carrying at the end near which the operator stands a foot-lever *k*. A downward pressure on *k* pulls downwards on rod *i* and causes idler *g* to move to the left around *c* as a center, as indicated by the curved arrow *l*, thus coming into engagement with the belt, which it tightens. When the pressure is removed from lever *k*, idler *g* moves back to the right and releases the belt tension, so that the machine stops. When the coil former *f* is rotated counter-clockwise, wire is wound off the reel *m* and on to the coil former.

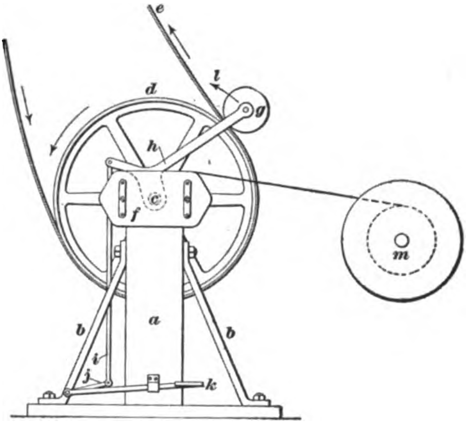


FIG. 44

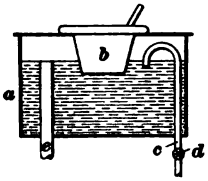


FIG. 45

54. Convenient to the coil winder is a glue pot constructed as shown in Fig. 45; *a* is a tin box with a circular hole in the top to receive glue pot *b*; *c* is a steam pipe provided with a valve *d*; and *e* is a waste pipe. Water is poured into the box to the level of the waste pipe and the steam turned on. The water soon reaches a temperature sufficient to melt the glue, and the admission of steam can be regulated to keep the glue liquid. It is necessary to fill the box with water only at starting, as the condensation of the steam keeps it full thereafter. Glue or its equivalent must be applied to the coil to preserve its shape after removing the temporary clips applied while the coil is on the former.

55. Instead of using a round wire larger than a No. 7 B. & S. gauge, it is customary to use two smaller wires equivalent in cross-section to the larger one; that is, the coil winder, instead of handling one wire, handles two, but winds them on to the former together as if they were one. Instead of drawing wire from one reel, as in Fig. 44, he must draw two wires simultaneously from two reels set up one behind the other. The advantages of two small wires over one equivalent wire are that they are easier to handle and shape to the former, and that the local or eddy currents generated in them when the armature is in operation are less. The double ends of a coil wound with two strands in parallel must be treated exactly the same as would be the single end of a similar coil wound with but one strand.

56. In all cases, the wire must be put on the former under sufficient tension to draw the turns firmly into place, especially where the coil is wound with two or three wires in multiple. If the reels were not restrained in any way, the jerking incident to stopping and starting the winding machine during the process of winding a coil would cause the reels to run too fast at times, and the wire would become tangled. The tension necessary to keep the wires taut is generally obtained by braking the reels, either with a weight or with a spring. The periphery of one of the circular ends of most reels is

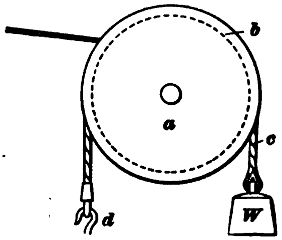


FIG. 46

grooved out to take the rope used for this purpose. Thus, in Fig. 46, *a* is one end of a reel grooved at *b*; a rope *c* is fastened to a hook *d* in the floor on one side; it passes over the reel and supports on the other side an adjustable weight *W*, by means of which the tension, due to the resistance offered by the friction between the rope and the groove, can be varied at will.

57. Types of Armature Coils.—Fig. 47 shows a Westinghouse No. 3 armature coil wound on a coil former quite similar to the one indicated in Fig. 44. The coil consists of four turns of No. 11 B. & S. cotton-covered wire, and as only one strand of wire is used, but one reel is necessary, and only one lead is brought out from each side of the coil. One side is more nearly radial to the armature core or more nearly perpendicular to the plane of the coil than the other side; this difference in the slope of the sides makes the coil easier to install on the core. For the same reason, the side *a*, which is the first side installed when placing the coil on the core, is made a little longer than the side *b*. The Westinghouse No. 3 coil is not strictly a formed coil, because it must be shaped on the armature ends when installing.

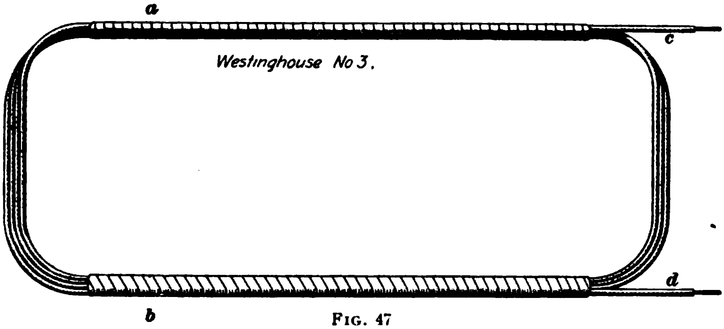


FIG. 47

The coil leads *c*, *d* are insulated by drawing cotton sleeving, or *stockings*, over them. The colors of the two sleeves on one coil are not the same; for instance, one may be black and the other white; this affords a ready means of distinguishing the starting and finishing ends of a coil when connecting. The sleeves are usually drawn on before the coil is taped and are of proper length to extend back to the taped portion of the coil.

58. The Westinghouse No. 3 armature is wound with two lengths of coils, known respectively as bottom coils and top coils. The bottom coils are put on the core first and the sides are pressed into the bottoms of slots, so that the end connections not only lie close to the core, but also cross a shorter space *y*, Fig. 48, than that crossed by the top coils represented by *x*. Not only do the sides of the top coils lie farther apart, being in the tops of the slots, but the end connections must pass outside those of the bottom coils, which have piled up to some extent on the core ends; hence, the top coils are longer and wider than the bottom ones.

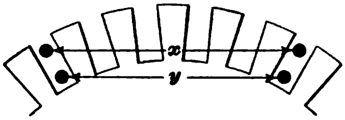


FIG. 48

When the winding of the armature is complete, each slot contains a side of two coils; that is, there are two half-coils, each containing four wires, or a total of eight wires in each slot. The coils are so wound and laid on the armature that the leads from each coil come out at the top, or on the side nearest the top of the slots. This is accomplished by shaping the former so that the wires twist around each other at the rear end of the coil, as shown in Fig. 47; the wire that is on top of side *b* becomes the bottom wire of side *a*, and the bottom wire of side *b* becomes the top wire of side *a*, and so on.

59. Fig. 49 is a sketch of the Westinghouse No. 68 form-wound armature coil. The general appearance of the complete former on which this coil is wound is similar to that shown in Fig. 44, the main difference in any two coils of different types being due to the difference in the shape of the grooves and shoulders of the former on which the coils are wound. The No. 68 is typical of coils wound from two reels, two wires or strands forming one conductor.

Each coil contains three turns of two strands of No. 12 B. & S. wire, or the equivalent of one strand of No. 9 B. & S.

wire. This makes the coil show six wires across the rear end and four wires across the front end, the remaining two coming out as leads. The coil shown may be called an *individual coil;* but as the No. 68 motor armature contains twice as many coils as there are slots, there must be two coils, or four half-coils, per slot; that is, two half-coils must lie in the bottom of each slot and two in the top. This is done by placing two individual coils side by side and binding them together by wrappings of tape or other insulating material, so that the two individual coils form one *cell* or *cell coil*, which is handled as a unit. A side of a cell is of just the proper width to slip into a slot; and when the armature is completely wound, each slot contains a side of two cells.

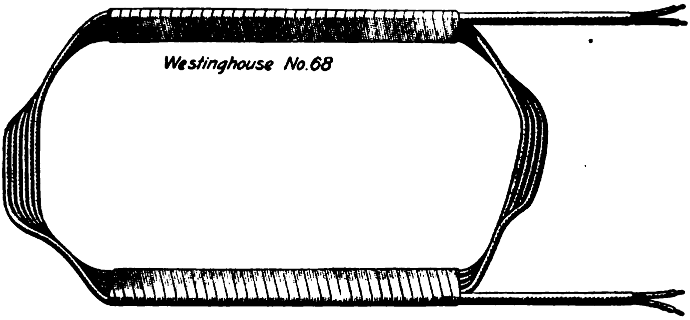


FIG. 49

As each cell contains two individual coils, and as each individual coil contains three turns or six wires, each cell must contain twelve wires per side; hence, each slot contains twenty-four wires. From the end of each slot will protrude four stocking-covered leads, each lead including two No. 12 wires, which constitute one conductor.

60. The use of wide slots with correspondingly thick coils or cell coils has several advantages. For example, it makes commutation better, within certain limits; these limits are determined from experience in designing and manufacturing, and are important only to designing engineers. The use of wide slots also makes fewer teeth, which may then be thicker and stronger. Moreover, if coils are tied together in cells, less total thickness of insulation is required; hence, less iron need be punched out for slots than would be necessary if each coil were insulated singly from iron. For example, if the ninety-five coils of a No. 3 armature were grouped in cells of two coils each and laid in forty-eight slots, there would be but forty-eight wrappings or insulations instead of ninety-five; and as the insulation on the side of a cell having two or more coils need be no thicker than if it consisted of but one coil, the total thickness of the forty-eight cell insulations would be much less than is that of the ninety-five individual coils laid singly.

Finally, grouping the individual coils into cells reduces the cost of an armature by reducing the number of core slots to be punched and cleaned, and the number of coils to be handled by a comparatively highly paid armature winder. The individual coils may be wound, assembled into cells or groups, insulated and shaped, and in some cases even put on the core, by boys or girls.

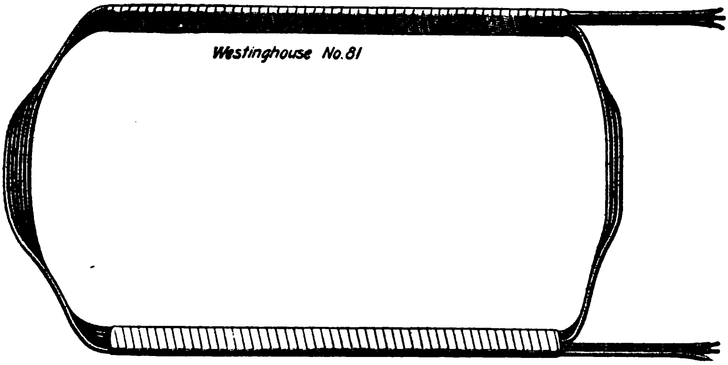


Fig. 50

61. Fig. 50 shows an armature coil for a Westinghouse No. 56 or No. 81 railway motor. Its general appearance is very much the same as that of a No. 68 coil. It is wound on the same kind of former and is assembled and insulated similarly. One side is longer and a little more nearly perpendicular to the plane of the coil than the other. The coil has three leads coming out of each side; in fact, it is wound with three strands of No. 10 B. & S. wire drawn simultaneously from three reels. This coil is similar to an individual coil, but really contains halves of three individual coils. Two coils such as are shown in the figure are placed side by side and bound together by insulating them as one cell. The six wires then protruding for leads from each side of the cell (three from each individual coil) are separated into pairs, each pair containing one wire from each coil; and over each pair is drawn a piece of colored sleeving. The cell then really contains three coils of two turns each, the conductor being two strands of No. 10 B. & S. wire in parallel. The construction of the coil is peculiar and the object of it is not evident.

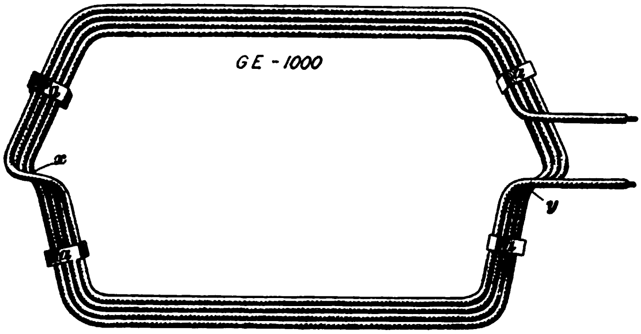


FIG. 51

The side of each individual coil contains six wires; the side of each cell coil, twelve wires; and, as one side of each of two cells is placed in a slot, there are twenty-four wires to a slot. A cell coil will have three leads protruding from each side, making a total of six leads per slot. On some railway armatures, four individual coils are grouped into one cell coil, in which case there are eight leads per slot.

62. Fig. 51 shows the style of armature coil used on G. E. 800, G. E. 1000, G. E. 1200, etc. railway motors. The coil shown is an individual coil and the coils are not grouped into cell coils, because the core has as many slots as there are coils; that is, each slot contains a side of two coils. The coil consists of four turns of No. 9 B. & S. gauge cotton-covered wire, so that each slot will contain eight conductors and will have but two leads protruding from the end. In the figure, the slot insulation has been omitted, so that the turns of the wire can be more easily followed. At *a* are shown the four metal clips placed on the coil before removing it from the former. These clips or their equivalent are used on all form-wound coils, so that the coils will not be distorted by handling before being insulated.

63. The manner of forming this coil is peculiar, and is best done on the style of former originated and recommended by the company that makes the motor. The sharp turns in the coil at *x* and *y* make it very difficult to wind by any other than the standard method. The former is constructed to wind the coil closed; it is shown in Fig. 52, together with a side view of a completed coil ready to be removed from the former. Cast-iron pieces *a*, *b* are grooved out as shown at *a′* on the side view of *a*, and are each fitted with stepped cone circles *1*, *2*, *3*, *4*. Two other cast-iron pieces *c*, *d*, shaped as shown in the side view of *c*, are fitted with tops *e*, removable by pulling out the spring knobs *f*, *f*. When tops *e* are in place, a groove *c′* remains between *c* and *e*.

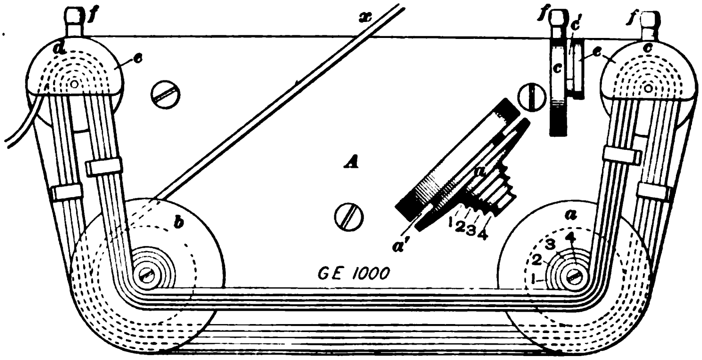


Fig. 52

These four formed pieces *a*, *b*, *c*, *d*, around the curved outlines of which the coil is wound as indicated, are mounted on a baseboard *A*, which is screwed to a bench or board. The coil is started by fastening the end of the reel wire *x* at some outside point, and then passing the wire by hand successively around the groove in *b*, the groove in *a*, the groove in *c*, the largest circle *1* of the stepped cones on *a* and *b*, then to the left around the groove in *d*, and back to the groove in *b*; thus completing the first turn. The second, third, and fourth turns are put on in the same manner, except that the turns are wound successively on circles *2*, *3*, and *4* of the stepped cones on *a* and *b*. After making the last turn around groove *d*, the metal clips shown at *a*, Fig. 51, are put on and the wire is cut off. Spring knobs *f*, Fig. 52, are then pulled out, caps *e* taken off, and the coil removed. Fig. 53 shows a side and an end view of the coil when removed from the former. To give it the shape indicated in Fig. 51, it is only necessary to pull the sides apart to the required distance.

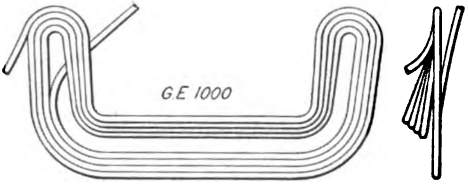


FIG. 53

64. Fig. 54 shows the Westinghouse 50L type of individual armature coil, three bound together, constituting a complete cell coil ready for the armature core. The coil is formed from .078″ × $\frac{5}{8}$″ copper strip, and has several favorable peculiarities. As it consists of but a single turn, it remains open on the commutator end and can easily be pulled apart to the required distance to install on the core; owing to the coil being open, the two sides are both radial; whereas, on a coil of more than one turn, one side must be more nearly perpendicular than the other to make the coil easier to put in place; in removing such a coil as that shown in Fig. 54 from the core for repair purposes, there is less likelihood of destroying its shape, because the coil is especially rigid in the direction in which the removing force must be applied, that is, in the direction of the width of the copper strip. Finally, if the individual coils are accurately shaped, the complete coil will have the correct shape without *pressing*, a process to be described later.

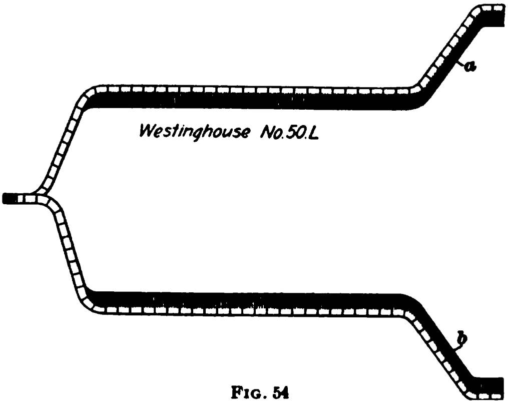


FIG. 54

As each cell has three individual coils, and as each slot takes one side of two cell coils, each slot will contain six conductors and will have six leads protruding from it. The ends of the coils *a*, *b* themselves serve as leads, being bent to fall over the three commutator bars to which they should connect.

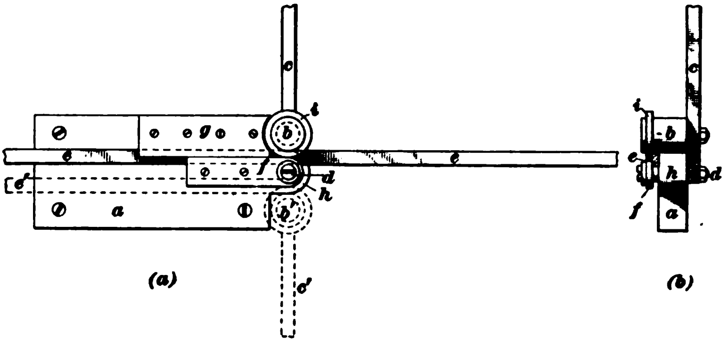
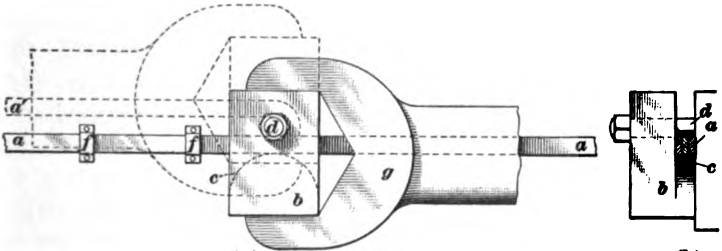


FIG. 55

65. The Westinghouse 50L coil is typical of coils formed of copper bar, and as such stock cannot be conveniently machine wound, special forming tools must be used. In forming an individual coil, a piece of copper strip of proper size and length is first cut off and run into the bending tool, plan and end views of which are shown in Fig. 55 (*a*) and (*b*). The tool consists of a bedplate *a* screwed to the bench, a steel roller *b*, provided with a handle *c* that can be moved around *d* as a center, to the dotted position *c'* bringing the roller *b* in position *b'*. Bar *e*, in its straight position, is held snugly between the undercuts of steel form plates *f* and *g*, and is held down against the curved extension *h* of bedplate *a* by a flange or overhang *i* on the roller *b*, as shown in the end view (*b*). When the copper strip is in place and handle *c* is moved around to the right to position *c'*, view (*a*), the strip is bent around the pin *d* by the roller *b* to the position *e*, *e'*. The tool shown is intended for bending the strips one at a time; but with a heavier form of bending tool, the three strips that are to form a complete cell coil are bent simultaneously, thereby saving time and making individual coils fit into each other better.



(*a*) (*b*)

Fig. 56

66. Fig. 56 (*a*) and (*b*) is a plan and end view of the tool employed at the Westinghouse factory for bending three individual coils at once; *a*, *a* is the position of the three strips before bending and *a a'* the position after bending. A metal block *b*, with a circular shoulder *c* is pivoted by a bolt *d* to a true surface screwed to the bench. The three strips *a* are run under the block, just filling the space between the shoulder *c* and the bolt *d*, and the free ends are secured vertically and horizontally by clamps *f*, *f*. A heavy wrench *g* is then applied and the block is forced around to the left; the shoulder *c* forces the strips to wrap snugly

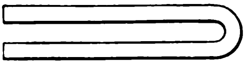


Fig. 57

around the bolt, which has the exact radius of the desired bend. The block is moved around until an interference lug stops it, the lug being so situated that when the strips are removed their two sides will be parallel to each other, as shown in Fig. 57. Whether the strips are bent singly or three together, their shape is the same.

67. The **U**-shaped strips are next clamped in a vice and the two sides bent away from each other, as indicated in Fig. 58 (*a*), the operation being similar to that of opening the G. E. 1000 coil. They are laid on a former, the general shape of which is indicated in Fig. 58 (*b*). The strip is hammered around the former, and as each stretch is forced into place it is secured from springing by pins and latches. Leads *a*, *b*, Fig. 58 (*a*), are bent to the proper arc for connecting to the commutator by passing them through a bending tool similar in construction to that shown in Fig. 55.

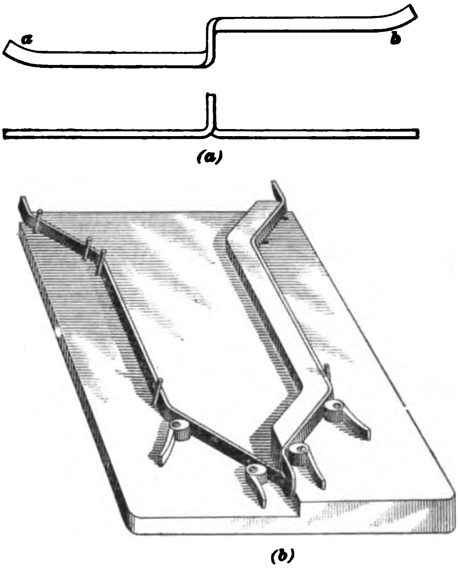


FIG. 58

INSULATING COILS

68. The insulation of the different types of armature coils varies in details according to the construction of the coil, the kind of conductor (square, rectangular, or round), and the circumferential slot space available for insulation.

69. **Machine-Wound Coils.**—By machine-wound coils is meant coils wound on a former turned by a power-driven machine, such as that shown in Fig. 44. All such coils are wound with double cotton-covered wire, and the cotton covering insulates the several turns of the individual coil from each other. The wire is wound on the former over strips of Manila paper continuous along each side; and just before removing the coil from the former and while the wire is yet under tension from the reel, the wires and paper are given a coat of glue and the paper is folded over and glued shut, as indicated in Fig. 59 (*a*). Each side of the coil is then supported between sheet-iron slats *a*, Fig. 59 (*b*), held in place by metal spring clips *b*. The object of this protection is to hold the wires rigidly in place until the glue dries. The paper is glued to the coil all around, and if held compactly until the glue dries, the holding of the wires to each other and to the folder will make the coil rigid enough to be handled without danger of distortion. As soon as the glue is dry the spring clips and iron slats are removed and the individual coils are ready for the real operations of insulating to begin.

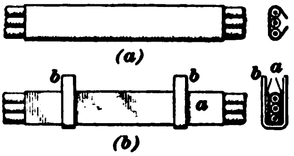


FIG. 59

70. The method of insulating an armature coil for a Westinghouse No. 81 railway motor is a good one, and will be described as typical of all. The description of the process will not apply to all shops, because details vary, according to the experiences of different armature-department foremen. Two of the original coils, Fig. 50, as they come from the coil winder are put together, as indicated in section in Fig. 60, with a strip of insulating paper *a* between them. The paper is the full length and width of the sides of the coil and is held in place by a drop of glue at each end. The full length of each side of the cell coil is next wrapped firmly with oiled linen ribbon, the ribbon being lapped sufficiently to virtually give two layers of oiled linen. Each side of the coil is then encased in a leatheroid covering or slot

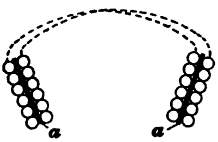


FIG. 60

cell, which is held closed and in position by a binding of white linen tape, which is also wrapped around the ends of the coil. On the leatheroid itself, the tape is wound with sufficient pitch or lead to leave a little clearance between turns, the object being only to bind the leatheroid case; but on the ends, especially at the bends, the tape is lapped to give two or more layers, its object there being not only to bind the individual coils together, but also to insulate them.

In order to drive all moisture out of the insulation, the coil is next baked for about 2 hours in an oven in which the temperature is maintained at from 180° to 190° F., after which it is dipped in armature insulating varnish, armalac, or some equivalent mixture, allowed to drain, and again baked for 8 or 10 hours, to dry the varnish or armalac. After the coil is removed from the oven the second time, the leads are tinned and, in some cases, the sides are pressed. The insulation is then complete and the coil appears as shown in Fig. 61.

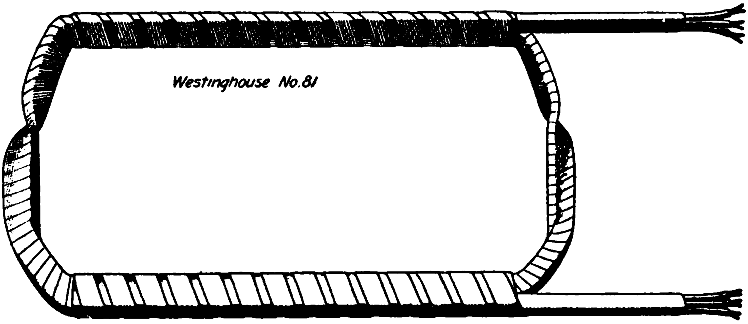


FIG. 61

71. Formed Coils.— Fig. 62 (*a*) shows the general appearance of a Westinghouse 50L coil complete, the method of insulating being as follows: The three individual coils, bent and formed together for one cell coil, are separated, all fins and burrs caused by fitting them to the former are carefully removed from each; each coil is thoroughly cleaned by brushing or by means of a jet of air, and then each is wrapped full length, up to the short bend for the commutator connection, with linen tape, which is glued at the finishing end to prevent unwrapping. The three insulated individual coils are then assembled, as indicated in the end view (*b*), care being taken to group them in the order in which they were originally bent, and a strip of oiled linen, the width and length of a side of the coil, is inserted along each side of the middle coil, the strips being held in place by glue. Between the individual coils on the curved ends that serve as the leads, strips of clear mica are inserted.

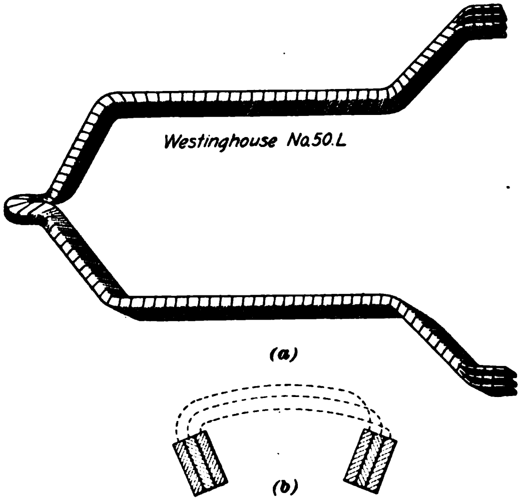


FIG. 62

The three individual coils are then bound together full length by wrapping on a layer of linen tape, which serves also to hold the oiled linen and mica separating strips in place. The sides of the cell coil are next tightly bound with oiled linen ribbon, one-half lapped, making two thicknesses, after which a leatheroid slot, cell, or armor, is placed on each side. The leatheroid is held in place and bound to shape by winding the coil throughout its length with a tightly drawn wrapping of linen tape, the finishing end being secured with glue. The coil is then baked 2 hours, dipped in armature varnish, or its equivalent, allowed to drain, and again baked—this time for about 10 hours. After the lead ends have been tinned, the coil is ready for use.

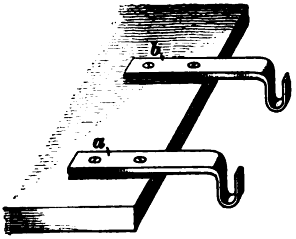


FIG. 63

72. As the various insulations wound on the coil must be applied under considerable tension, some means must be provided for holding the coil if the winding is done by hand. Fig. 63 shows a simple form of holder. Spring copper strips *a* and *b*, screwed to the bench, extend out as shown; they are hook-shaped at the ends to receive one side of the coil to be insulated. The stock is thinned out so as to give the hook some spring, and all corners against which the coil may rest are rounded off.

PRESSING COILS

73. Hand Press.—About the simplest form of **hand press** in use is shown in Fig. 64 (*a*) and (*b*), plan and end views, respectively; *a* is a bedplate screwed to the bench; *b* is a straight bar of iron resting against a shoulder on the bedplate and used as a spacing block; *c* is one side of the coil to be pressed; *d* is a bar, thicker in the middle than at the ends, to minimize its tendency to spring when subjected to pressure; *e* is an eccentric roller, which may be rotated by handle *f* around a pin secured in the bedplate. When handle *f* is moved in a clockwise direction, as indicated by the arrow, the eccentricity of the roller *e* causes it to force bar *d* against coil *c*, compelling it to take the lateral dimension of the space in which it is confined. The less the

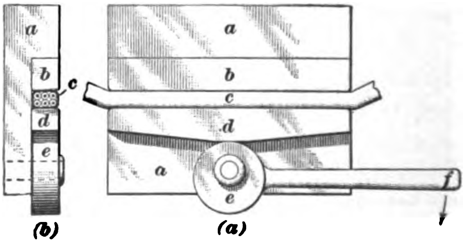
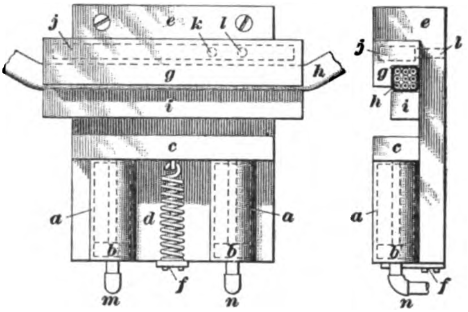


FIG. 64

eccentricity of the cam *e*, the greater is the force exerted on the coil under compression, but the less the distance through which bar *d* will move. Therefore, if the press is designed for considerable power, the movement of bar *d* will be comparatively small, and several widths of spacing bar *b* will be required when using the press on coils of several thicknesses. Before subjecting a coil to pressure, it should be warmed to loosen the insulation and render the coil more pliable; it will then be more readily pressed to the desired form and will be less likely to spring back to its original shape and dimensions after removal from the press.

74. Power Press.—Fig. 65 (*a*) and (*b*) shows a plan and an end view of a simple type of steam-heated **power press**; *a*, *a* are two small cylinders provided with pistons *b*, *b*, carrying on their upper ends cross-bar *c*, normally held in the position shown by tension spring *d*, which is anchored to one side of the bedplate *e* by clamp *f*. Near the other side of the bedplate is fastened a head *g*, undercut to the desired coil dimension. One side of the coil *h* is forced partially into the undercut, and a stiff parallel bar *i*, of the size to enter the undercut with a close fit, is laid on the bedplate against the side of the coil. Head *g* contains a chamber *j*, into which lead two pipes, a steam pipe with a port, or opening, at *k* and a drain pipe with a port at *l*. By a suitable cock, steam can be admitted to the chamber *j*, thereby heating the coil under compression; the water of condensation passes off through drain pipe *l*. Through pipes *m* and *n*, compressed air or steam can be admitted to cylinders *a*, *a* behind pistons *b*, *b* causing the pistons to force



(a) (b)

Fig. 65

crossbar *c* against parallel bar *i*, which in turn will compress coil *h* into the undercut. When the pressure is released, spring *d* pulls the crossbar back to normal position, where the coil can be removed.

The use of a single spring in a central position makes it necessary to apply exactly the same pressure to both cylinders simultaneously, otherwise one end of the cross-bar may swing around and strike too hard a blow to one end of the coil. This tendency can be largely overcome by using a spring at each end instead of one in the center. Much larger and more complicated presses are used by manufacturers, in which both sides of a coil are pressed to the proper dimensions and the proper radial inclination at the same time.

75. The object of pressing armature coils is to smooth the sides and reduce them to proper uniform dimensions, so that the coils can be readily installed in the armature core slots. Forcing coils into slots not only endangers the insulation, but also renders the coils hard to get out. After an armature has been in service several months, the insulation is not nearly so pliable as when new, and the exercise of force to lift or remove a coil for repair purposes will, if the coil was a driving fit in the first place, so distort its shape or impair its insulation that the coil cannot safely be used again. If the insulation used on a coil and the width of the slot into which the coil is to go are such that there is plenty of margin, slight excesses in the thickness or depth of the coil sides will not prevent its being safely installed on the core. If there is plenty of marginal clearance, a simple hand press is all that is needed. In many shops, it is the custom to apply pressure against the sides of the coil, as shown by the arrowheads in Fig. 66 (*a*), to make the coil thinner and laterally uniform. This causes a bulging of the coil on the other sides, as indicated by the curved dotted lines. To overcome this bulging, the coil is

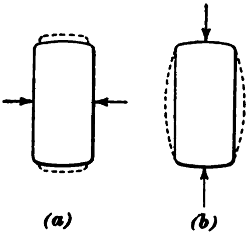


FIG. 66

next "squared up" by pressing it in the direction of the arrows in (*b*), which, of course, causes lateral bulging as indicated by the dotted lines. The effect of such pressing is to churn the interior of the coil, loosen it, and adapt it to almost any slot that is not too narrow; but the sides of the coil are neither rigid nor perfectly straight, nor will a lot of coils be of uniform dimensions, because there is nothing to limit the effect of the pressure applied in either direction.

76. A coil should be rigid, and should have a smooth surface and sides of absolutely standard dimensions throughout their length. For the best form of coil press, several conditions are necessary: (1) The lateral and radial pressures, Fig. 66, exerted by the press must be applied simultaneously in order to avoid all bulging; (2) the space into which the coil is compressed must be limited to the exact dimensions desired for the coil, the movement of the compressing plates being checked by suitable stops when the proper dimensions are reached; (3) both sides of the coil should be pressed at the same time, the method of supporting the coil in the press being such as to obtain the proper radial inclination to the sides; (4) the coil must be thoroughly warmed to make it pliable, so that all parts may easily take a set when the pressure is applied; (5) before releasing the pressure, the coil should be cooled by circulating cold water around the press, in hollow parts provided for that purpose; this treatment will harden the insulation and hold the coil absolutely to the shape and dimensions to which it has been pressed. Since the fit of a coil made in this way is absolutely assured, no allowances need be made for inequalities, for there will be none; therefore, for a given width of slot, the insulation of the coil can be made thicker.

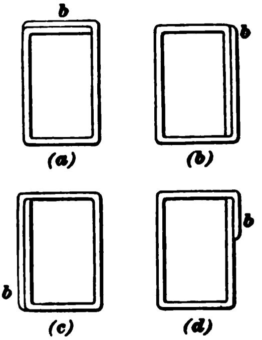


FIG. 67

77. On coils that are to be properly pressed, it is better to put the leatheroid case on last, as its surface is smooth and the corners will take a good finish. If the leatheroid cannot be bound with tape, the flap that folds over must be glued. The case should be so formed that the flap *b*, Fig. 67 (*a*) and (*b*), laps over on top of the coil or on the side flush with the top, but not as in (*c*) or (*d*), where the flaps *b* are turned in such a direction as to resist sliding the coil down into the slot.

ARMATURE REPAIR WORK

(PART 2)

WINDING AND CONNECTING ARMATURES

INTRODUCTION

1. Number and Position of Motor Brushes.—Modern electric railway-motor armatures are always of the series-connected or two-circuit types. This connection permits the use of but one pair of brush holders on each motor instead of two, although the motors, as a rule, are four-pole machines. The two brush holders are located where they can be easily got at whenever adjustments, repairs, and renewals are necessary. Some old-style railway motors employed two pair of brush holders, and the motors were left open at both top and bottom, so that the holders were not inaccessible. On modern motors, however, where an opening for inspecting the commutator is provided only on top of the motor, a second pair of brushes would be impracticable.

With the high voltages generally used for railway work, one pair of brush holders provides ample brush contact surface to carry the current, without making the commutator excessively long, even with carbon brushes. For successful operation, however, it is very necessary that the voltage for which the motors were built should be maintained. If allowed to drop, as it is on some roads, the motormen, in order to make schedule time, must run a greater part of the time with no resistance in series with the motors, or with the motors in parallel, thus using an excessively high current, with the result that the brushes and the commutators, as well as the motor windings, are damaged by overheating. Copper brushes would have greater carrying capacity than carbon, but would spark so badly that they could not be used.

EXPLANATION OF TERMS

2. In discussing the winding and connections of an armature, it is necessary to use certain terms that have a fairly well-defined meaning among practical men, but that are very confusing to beginners until their meaning is clearly understood. Among such terms are the *spread*, *span*, or *pitch* of a coil; the *spread* or *pitch* of the leads of a coil; and the *throw* of the leads of a coil, sometimes called the *lead* of a coil's terminals.

3. Pitch of Coils.—As all modern railway armatures are wound with formed coils that are comparatively rigid, the manner of placing the coils on the core is more or less restricted. Assuming that a coil is correctly placed on a core, the distance from one side of the coil, measured around the circumference of the core, to the other side is variously called the **span, spread,** or **pitch,** of the coil; it is also often called the **winding pitch.** Theoretically, in order that the opposite sides of an armature coil for a four-pole motor may always be in fields of correct polarity, the spread of the coil should be exactly one-fourth of the armature circumference; but, practically, the number of slots is seldom divisible by 4, and the span is usually made a little less than one-fourth the number of slots.

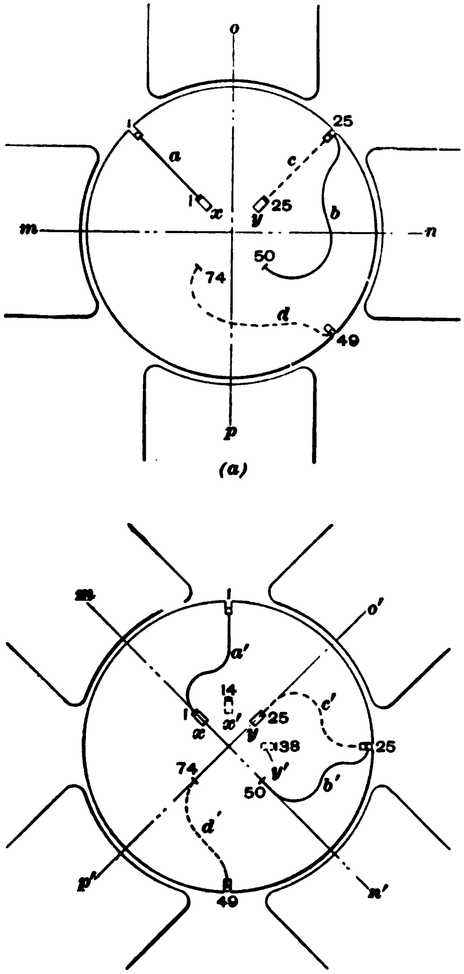
This rule, however, is not invariable, and it is impossible to give any rule that covers the practice of all winders. The instructions of the Westinghouse Company are to make the pitch about 80°. As 90° is one-fourth of a circle, these instructions mean a little less than one-fourth. The pitch of a coil is usually expressed by stating the number of slots between the two sides, including the slot in which one side of the coil lies. For example, a pitch of 24 slots means that if one side of a coil lies in slot *1* on a core, the other will lie in slot *25* (1 + 24).

4. Pitch of Leads.—The **spread,** or **pitch,** of leads to the commutator, often called the **connecting pitch,** may be expressed by stating the number of bars spanned by the leads of a coil. The connecting pitch for four-pole, series-connected, railway-motor armatures may be determined by the expression, $\frac{\text{number of bars} \pm 1}{2}$, the sign ± meaning plus or minus. For example, if a commutator has 87 bars, the connecting pitch may be $\frac{87+1}{2} = 44$, or $\frac{87-1}{2} = 43$; that is, if one lead of coil is connected to a bar called bar *1*, the other should be connected either to bar *45* or bar *44*, the counting in either case being done around the commutator past the center of the coil. The motor will operate properly with either connection, but with one connection the armature will rotate in the opposite direction from what it would with the other.

Using the shorter pitch 43, any bar being numbered *1*, a coil has one lead connected to bar *1* and the other to bar (1 + 43 =)*44*; another coil on the opposite side of the armature has one of its leads connected to bar *44* and the other to bar (44 + 43 =)*87*; that is, one bar behind bar *1*.

Using the longer pitch 44, a coil will be connected to bars *1* and *45* and another coil will be connected to bars *45* and *2*, the one next beyond bar *1*. The choice of bar *2* is explained by adding the pitch 44 to 45, which makes 89, but as there are but 87 bars, the one that would be bar *89* is really bar *2*. The connection using the shorter pitch is called *retrogressive*, and that using the longer pitch, *progressive;* both pitches are in use, as will be seen in the examples that follow.

5. Throw of Leads.—The expression **throw of leads,** as generally used, has reference to the number of commutator bars between the one directly opposite the center of a lead, at the point where it issues from a slot, and the bar to which the lead is connected. This will be made more clear in the following explanations of windings. The throw depends on the relative position of the pole pieces and the brushes. The coil under commutation must lie in the neutral region midway between the pole tips. If the opening in the frame for commutator inspection is squarely over the commutator, so that the brushes must both be accessible from above, as is usually the case, and if the poles are on horizontal and vertical diameters *mn* and *op*, Fig. 1 (*a*), one lead *a* to the commutator must come straight out in line with the side of the coil, so that the coil will be under commutation when its sides are in the neutral region. But if the brushes *x*, *y* and the pole centers are both on lines running diagonally, as *m′ n′* and *o′ p′*, Fig. 1 (*b*), the leads must be given a throw of approximately



(a)

(b)

FIG. 1

one-eighth of the circumference, or $\frac{\text{the number of bars}}{8}$; if this throw were not given, it would be necessary to move the brushes to the dotted positions $x'y'$, where one of them y' would be out of reach unless the commutator opening in the frame were moved. Giving the leads this throw is equivalent to giving the commutator one-eighth of a turn counter-clockwise around the shaft, assuming one lead to stretch from position a, Fig. 1 (a), to position a', Fig. 1 (b), and the other to contract from position b to position b'. The connections of the two leads $a\,b$ and $a'\,b'$ are shown for a 99-slot armature with a 99-bar commutator; the leads of another coil are represented by dotted lines $c\,d$ and $c'\,d'$ in each diagram. In order not to confuse the figure, the brushes are represented as rubbing on the inside of the commutator, but it must not be supposed that this is the practice. The armature conductors connected to the bars on which the brushes rest are in the neutral region in both views (a) and (b), and the brushes are near the top of the commutator, where they are easy to reach.

6. In Fig. 1 (a), the coil lead a has no throw, because the brushes naturally fall in the most accessible positions. The spread of the coil on the core is 24 slots, one side of a coil being in slot *1* and the other in slot *25*. The coil lead out of slot *1* is short and straight and goes into commutator bar *1* immediately opposite. The pitch of the leads in this case is $\frac{99-1}{2} = 49$, so the other lead is long and goes into bar *50* $(= 1 + 49)$.

In Fig. 1 (b), the spread or pitch of the coil is 24 slots, as before, the sides lying in slots *1* and *25*; the lead from slot *1* is not brought to the bar directly opposite slot *1*, but is given a throw of 13 bars; that is, it is placed in the fourteenth bar, counting away from the center of the coil from the bar directly opposite the center of the lead at the point where it issues from the slot, or, calling the bar to which lead a' is connected bar *1*, the bar directly opposite the point where lead *a′* issues from slot *1* must be bar *14*. The pitch of the leads is 49; hence, the other lead of the first coil is connected to bar *50*, counting from bar *1*, past the coil. When the leads have no throw, one is short and the other long; but giving them a throw of one-eighth of the circumference of the commutator makes them of nearly equal length. The throw of 13 bars is approximately the total number of bars divided by 8, or $99 \div 8 = 12\frac{3}{8}$. The throw of lead *a′* might be made either 12 or 13. It is necessary to determine the throw of the leads of but one coil, as the rest all have the same throw as this one.

7. In a few special cases, it has been found desirable, for convenience in working on the motor when it is installed on a crowded truck, to have the opening for inspecting the commutator a little to one side of a central position; the throw of the coil leads is then made less in proportion to the displacement of the brushes from the diagonal positions shown in Fig. 1. For a throw of one-sixteenth, instead of bringing the first lead installed straight down to the commutator bar, directly opposite the point where the lead issues from the slot, it is brought to bar *1*, located by counting the required throw, approximately one-sixteenth of the total number of bars, from the bar in the straight-out position. Probably, it will be less confusing if the bar to which the first lead is connected is called bar *1* and is located with reference to the slot from which the first lead issues, according to the throw required; this will be done in all cases in which some other designation is not perfectly clear.

8. According to the meaning of the term throw as sometimes used, the leads have no throw unless both leads of a coil connect to commutator bars that are not directly opposite the slots out of which the leads come; thus, in Fig. 1 (*a*), the leads may be said to have no throw, because the first lead is put into the commutator bar directly opposite, no counting off being necessary, except that needed to find the pitch of the leads. This use of the term throw, however, is by no means universally accepted. In many cases, it will be found that a winder, in referring to such a connection as that of Fig. 1 (*a*), will speak of the short lead as having no throw at all, and of the long lead as having a throw equal to the pitch, or spread, of the leads. Again, another may mean, by throw, the number of bars that must be counted, around the commutator in opposite directions and away from the coil in both cases, from the bar opposite the points where the leads issue from the slots in order to find the bars to which the leads must connect. For example, it might be said that lead *a*, Fig. 1 (*a*), has no throw and that lead *b* has a throw of 25 bars because it is connected to bar *50*, or 25 bars from bar *25*, directly opposite slot *25*, from which lead *b* issues; but in Fig. 1 (*b*) lead *a'* has a throw of 13 bars (14 – 1) one way, and lead *b'* a throw of 12 bars (50 – 38) the other way, calling the bar opposite the slot from which the lead issues bar *1* and counting in each case away from the coil.

9. When both leads of a coil have a throw, that is, when neither of them is brought out straight, it is essential that the number of bars in each case between the ones opposite the slots from which the two leads of a coil issue and the bars to which the two leads connect shall be as nearly alike as possible. For example, if the brushes are symmetrically placed on the top of the commutator it would not be good practice to carry lead *a'*, Fig. 1 (*b*), over to the left 14 bars and lead *b'* to the right 11 bars, although the pitch would be correct. Such a connection would be unsymmetrical and would cause sparking. The usual method is to locate one lead of a coil in a bar chosen according to the approximate throw required and then to count back past the coil to the proper pitch, determined as in Art. **4**, which locates the bar for the other lead of the same coil. If the connections thus made are symmetrical, all the other coil leads may be connected with the same throw as given these two; but if unsymmetrical, the two leads must be moved. This will be more fully explained in connection with the following descriptions of the processes of winding and connecting armatures. Owing to differences in the use of the term throw when applied to the leads from armature coils, it is best to make a sketch or diagram when specifying connections and indicate the position of a coil and its leads by numbering the slots as in Fig. 1.

10. Winding and Connecting Diagram.—Fig. 2 is a diagram representing the winding and connections on an armature with 93 slots, 93 coils, and 93 commutator bars. The pitch of the coils should be about $93 \div 4 = 23\frac{1}{4}$ slots, and is made the nearest whole number 23; that is, the first coil has one side in the bottom of slot *24* and the other in the

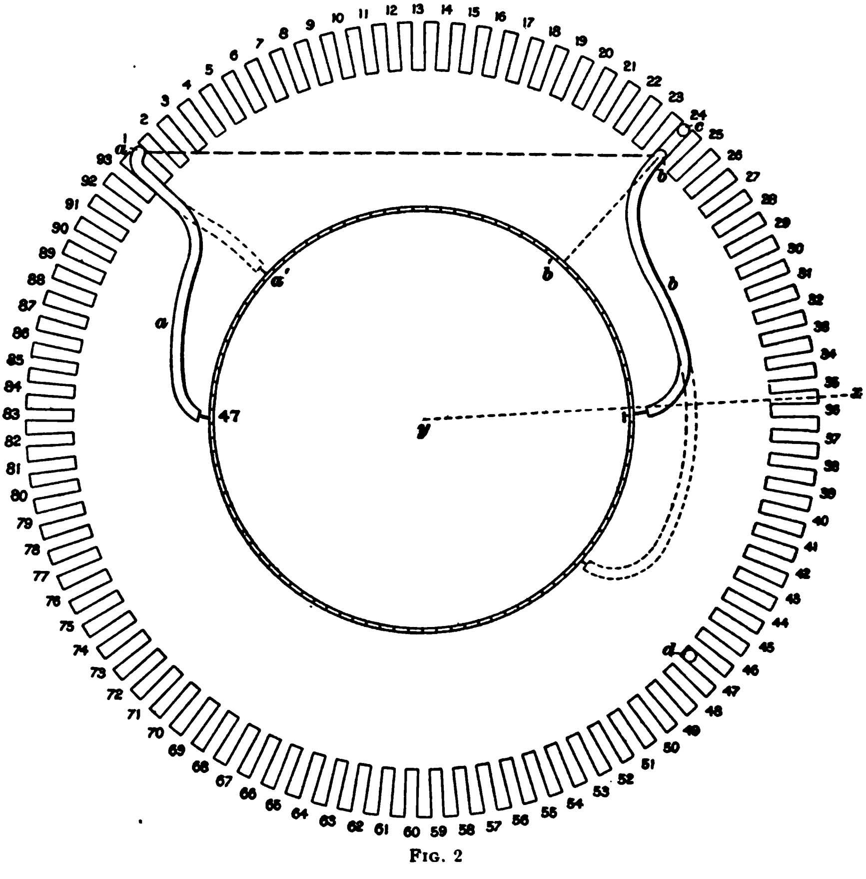


FIG. 2

top of slot *1*, the difference between these two numbers being 23. Only one coil, *a b*, is shown, as one coil can be used to determine the pitch of the coil, the throw of the leads, and the pitch of the leads. The coil is represented as having but one turn, though it may have any number without affecting its position or the position of its leads. The broken line from slot *1* to slot *24* represents the coil connection across the rear end of the core, that is, the end farthest from the commutator. The dotted line from the center of conductor *b* to bar *b'* is drawn radially to the commutator merely to locate bar *b'*.

11. If this armature were to operate in a motor whose poles were on vertical and horizontal diameters, one lead from coil *a b* would be connected to bar *a'*, directly opposite the center of conductor *a*, at the point where it leaves slot *1* and the other lead *b* would be carried around to the bar giving the proper connection pitch, as indicated by dotted lines. The connection pitch should be $\frac{93 \pm 1}{2} = 47$ or 46 bars and lead *b* could be connected to bar 47 or 48, bar *a'* being numbered 1 and counting past the center of the coil. In Fig. 2, a pitch of 46 is used. If the armature were to operate in a motor having its poles diagonal, lead *b* should be given a throw of approximately $93 \div 8 = 11\frac{5}{8}$ bars, or say 12 bars, counting away from the coil; that is, lead *b* should be connected to bar *1*, the thirteenth from bar *b'*. The pitch of the leads could be 46 bars, whether the leads have a throw or not, and this pitch should be counted back past the coil. In order that the coil shall span 46 bars, lead *a* must be connected to bar *47*, counting from bar *1* past the center of the coil.

As bar *47* is the twelfth from *a'* and bar *1* the thirteenth from *b'*, the connections are as nearly symmetrical as it is possible to make them with a connection pitch of 46; for if lead *b* is brought back to bar *12* from *b'*, lead *a* must be advanced to bar *13* from *a'* in order to keep the pitch 46. This throw also would answer, but the connections would be no nearer symmetrical than before.

This method of determining the throw of the armature leads is applicable to all series-connected armatures for four-pole motors with diagonal pole pieces. Some workmen, however, find the throw by temporarily laying on another coil *c d*, finding the center *x* of this coil, and stretching a string from the center *x* to the center *y* on the end of the shaft. The string may cross a bar or it may cross a mica body between two bars. If it crosses a mica body, lead *b* may be connected to the bar on either side of the mica.

12. The diagrams of windings and connections that follow are all drawn to the same scale, though they may represent motors of widely different capacities. Two motors may have the same number of core slots, the same number of commutator bars, the same winding pitch, connecting pitch, throw of leads, etc.; in fact, the same diagram and description of the process of winding and connecting may apply to each, and yet the two may differ very much in capacity. It must not, therefore, be assumed that because the windings and connections of two motors are described together or in the same terms, they are alike in capacity or that the armatures are interchangeable. The diagrams are made to show the slots about as they would appear when looking at the commutator end of the core, and also to represent the commutator bars; they also show a coil in position on top of the core facing the commutator end, and, with the exception of Fig. 3, the position of the brushes is not shown.

13. Methods of Working.—Armature winders in different shops do not all follow the same method in placing a set of coils on an armature, although it is the usual custom for all winders in the same shop to follow practically the same method. In one shop, a winder may stand beside the core and install the side of a coil nearest him first, pushing the other side over into place; in another shop, the practice may be to install the side of a coil farthest from the winder first, pulling the other side over until it will go into the proper slot. The latter method is probably the better one, and in the following instructions it will be assumed that the winder stands beside the core, so that the side of each coil farthest from him is placed first, and the side nearest him last. Care should be taken always to turn each coil so that its leads will project toward the commutator and not toward the pinion.

Nor is the same method used in all cases to determine the throw or to locate and connect the first lead. For example, if the individual coils are grouped in cell coils of three each, so that from each slot issues six leads—three from the top and three from the bottom—any one of the bottom leads may be the first to be placed, though the best practice is to place the middle one first.

14. In the instructions that follow, it will be assumed that the person connecting the leads to the commutator always stands facing the commutator end. An armature core, while being wound, is placed on a shaft and swung in a lathe or between trusses or horses, so that it can be rotated easily. Before installing the coils on the core, it is advisable, in many cases, to rub them with paraffin to make them slip into place more easily. For driving coils into slots and for placing the winding on the core ends, a wooden or leatheroid drift with all corners rounded and smoothed, and a rawhide mallet weighing 1½ or 2 pounds, are used, and great care is taken not to injure the insulation on the coils. The end plates of the core should have rounded corners, so that they will not cut the insulation.

15. When removing the old winding and insulation from a core, careful notes should be made of the methods of insulating the core and windings, as well as of the method of winding and connecting; and unless some of these methods are known to be faulty they should be followed in replacing the winding. Note should also be made of the size of copper wire, the number of turns per coil, etc., and if applicable the data should be used in rewinding.

WESTINGHOUSE NO. 3 ARMATURE

WINDING

16. The **Westinghouse No. 3 armature** has 95 slots, 95 individual coils, and 95 commutator bars. The coils are divided into two sets, 48 being known as short or bottom coils, and 47 as long or top coils. The pitch of the coils is 24, the whole number nearest to 95 ÷ 4. The winding

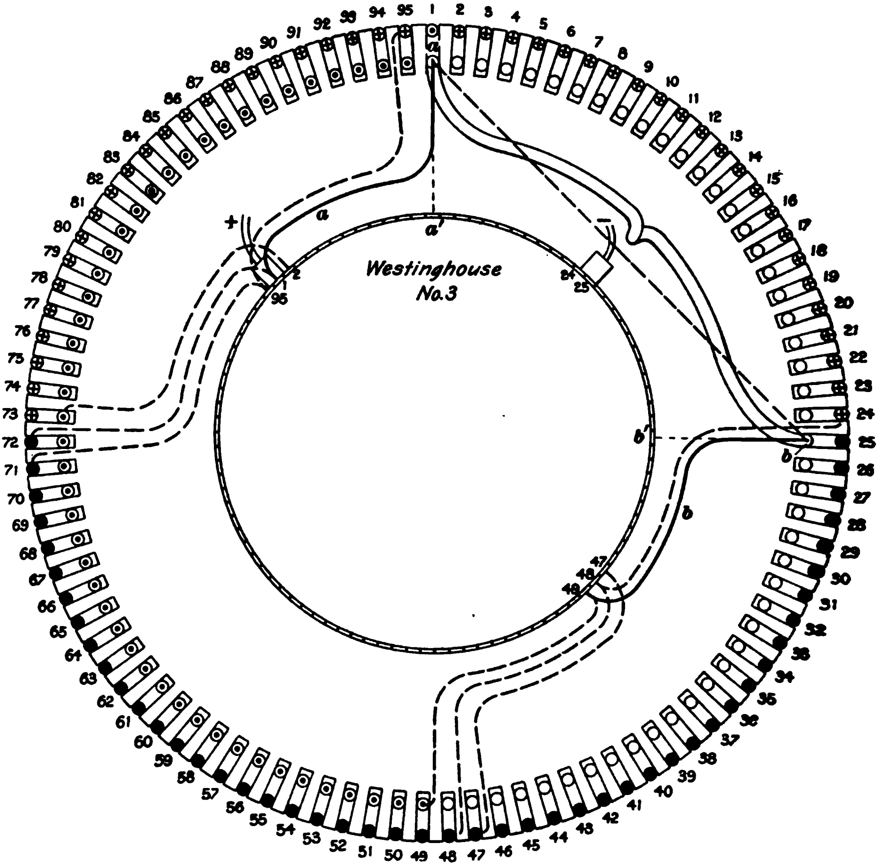


FIG. 8

and connections of this armature are somewhat peculiar, and are best explained by conceiving the coils to be put on in four divisions, or quarters.

Fig. 3 is a diagram of the winding and connections. Standing beside the core with the commutator end at the right, and calling any slot near him slot *1*, the winder reaches over and places one side of the first bottom coil in the bottom of slot *25* and then pulls the other side back and forces it to the bottom of slot *1*, taking care that the leads extend toward the commutator. This gives the required pitch, (25 – 1 =) 24. One side of coil *2* is then laid in the bottom of slot *26* and the other drawn back and forced to the bottom of slot *2*; coil *3* is placed in the bottoms of slots *27* and *3*, coil *4* in the bottoms of slots *28* and *4*, and so on until 24 coils, constituting the first quarter of the winding, are in place in the bottoms of slots *1* to *48*, inclusive.

17. The top of the core is then revolved toward the winder until slot *49* is near him, and the farther side of coil *25* is placed in the bottom of slot *73* and the nearer side in the bottom of slot *49*; coil *26* is placed in the bottoms of slots *74* and *50*, and so on until 24 more coils, the second quarter of the winding, are in place in the bottoms of slots *49* to *95*, inclusive, and the top of slot *1*. The last coil of the second quarter, that is, the last of the 48 bottom coils, lies in the top of slot *1* and the bottom of slot *72*.

18. The farther side of coil *49* is then placed in the top of slot *2* and the other side is drawn back and placed in the top of slot *73*. Coil *50* is placed in the tops of slots *3* and *74*, coil *51* in the tops of slots *4* and *75*, and so on until the next 23 coils, constituting the third quarter of the winding, are in place in the tops of slots *2* to *24* and *73* to *95*. This makes 71 coils in place at the end of the third quarter.

The top of the core is then revolved toward the winder again until he can reach over and place the farther side of coil *72* in the top of slot *49*. The other side is then drawn back and placed in the top of slot *25*. The remaining coils are laid on, filling the tops of the remaining slots, *50* to *72* and *26* to *48*, successively. The last 24 coils constitute the fourth quarter of the winding, and when these are in place every slot is full, having a side of one coil in its lower half and a side of another coil in its upper half.

19. Fig. 3 shows, by full lines, the position of the leads *a*, *b* of one coil and the connection across the front of the core; the connection of this coil across the rear end of the core is represented by a broken line *a b*. The coils of the first quarter, where they issue from the slots, are represented by white circles (○), those of the second quarter by circles with dotted centers (⊙), those of the third quarter by circles with crosses (⊕), and those of the fourth quarter by black circles (●).

CONNECTING

20. When the coils of an armature consist of more than one turn each, so that there are connections across the front end from slot to slot, the leads to the commutator must lie across the end connections. It is, therefore, necessary to use some insulation, in addition to the cotton covering on the conductors, to prevent short circuits between the end connections and the leads. On a Westinghouse No. 3, a strip or blanket of heavy oiled duck is laid over the end connections, the blanket extending from the core out as far as any crossing is likely to occur, and then the leads are brought down over this blanket.

21. The commutator is not installed until the core is wound. When the coils are made up, and before placing them on the core, one lead of each coil should be insulated with sleeving of one color and the other with sleeving of another color. If the colors used are black and white, for example, every coil should have black insulation on one lead, say the right-hand one when facing the lead end of the coil, and white insulation on its left-hand lead. If all the leads are insulated in this way, when all the coils are in place on the core the leads from the bottoms of slots *1* to *24*, inclusive, will be white and those from the tops of the same slots will be black. Slots *25* to *48*, inclusive, will have black leads protruding from the bottoms and white leads from the tops; slots *49* to *72*, inclusive, will have white leads from the bottoms and black ones from the tops; and slots *73* to *95*, inclusive, will have black leads from the bottoms and white ones from the tops.

22. Leads with insulation of one color should all be connected in one layer. The No. 3 motor operates with poles diagonal and both brushes near the top of the commutator; hence, the leads must have a throw of approximately $95 \div 8 = 11\frac{7}{8}$, or say 12 bars. Looking at the commutator end of the armature, all leads with white insulation swing to the left and all leads with black insulation swing to the right. It will assist in connecting if the leads of any one coil are marked by kinking or tagging them when the coil is laid on the core. This is not necessary, however, as the leads of a coil may be easily found by a simple test after they are all on the core. Before connecting any leads, it is best to bend those to be connected in the last layer back over the core out of the way; some of those to be connected in the first layer should also be bent up, so that a portion of the commutator is easily accessible to begin work.

23. Any lead may be the first to be connected. Assuming that the white lead *a* of coil *a b*, coming from the bottom of slot *1*, is first, it should be brought out to bar *1*, the thirteenth bar, counting to the left, or counter-clockwise, from bar *a'*; that is, lead *a* is given a throw of 12 bars, bar *a'* being the one located directly opposite slot *1*. The finishing lead *b* of coil *a b* may then be found by holding one terminal of a magneto-bell or a lamp test circuit to bar *1*, and touching one lead after another until the one is found through which a ring or a light is obtained. It will be remembered that the finishing lead sought must have black insulation and must issue from the twenty-fifth slot from the one from which lead *a* issues, so that lead *b* will not be hard to find. If the two leads *a*, *b* were marked when the coil was laid on the core, no tests would be necessary. The connecting pitch should be $\frac{95+1}{2} = 48$; hence, lead *b* is brought to bar *49*, counting past the coil *a b* from bar *1*. Bar *b'*, directly opposite the point where lead *b* issues from the slot, is then found, and as bar *49* is the thirteenth bar, counting away from the coil from bar *b'* as 1, and as bar *1* is the thirteenth, counting from *a'* as 1, the connections are symmetrical. Lead *b* is then marked by a kink or tag and bent back out of the way; bar *49* is also marked by a scratch or with a prick punch.

The white leads are then all connected in regular order and all with the same throw; that is, the white lead from slot *2* is brought to bar *2*, that from slot *3* to bar *3*, and so on around the armature. When the white leads are all connected, the appearance of the armature will be somewhat as shown in Fig. 4. The connected leads are then insulated by wrapping pieces of oiled duck and tape over them, especially near the core, where the greatest amount of crossing of leads will occur. The marked black lead *b* is then brought down over the insulation and connected to the marked bar *49*, and all other black leads are connected in regular order symmetrically with lead *b*; that from slot *26* to bar *50*, that from slot *27* to bar *51*; and so on around the armature. The connection of the black lead from the top of slot *24* to bar *48* completes the connections, and then each bar has connected to it one white lead and one black lead.

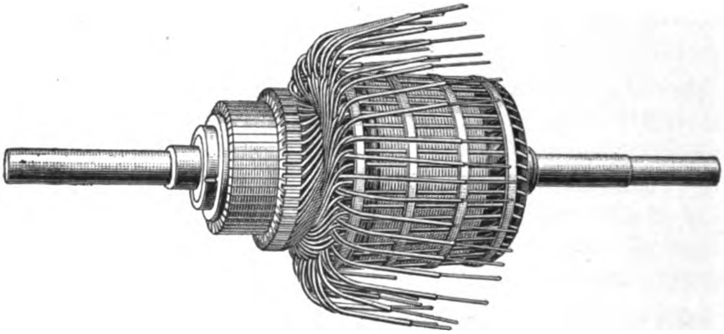


FIG. 4

24. The armature should be rotated as the work proceeds, so that the bars to which connections are being made are always on top. In connecting the leads of the lower layer, in this case the white ones, it is best to work from right to left, rotating the armature clockwise. Each successive lead then lies partially over the preceding one where it swings around the head; whereas, if the work were done the other way, it would be necessary to push each lead up under the preceding one. When connecting the upper layer of leads, the black ones, work should proceed from left to right, rotating the armature counter-clockwise. The work in all such cases should proceed in the direction toward which the leads are swung and the core should be rotated in the opposite direction.

25. Great care must be taken that the leads of a layer do not cross each other; they must be connected to the commutator bars in the order in which they leave the slots. After all the leads are placed in the bars, and before they are soldered, test terminals should be touched to each pair of adjacent bars all around the commutator. If the circuit, is open between any two bars, so that no ring or light can be obtained, the leads are crossed either on that side or on the side directly opposite. If the circuit is closed between every pair of bars, the leads may be soldered in place and the upper layer covered with insulation; the armature is then ready to go in the lathe for banding the core and turning off the commutator, if this is necessary. Very little acid should be used in soldering, and it should be kept away from the insulation; soldering acid will ruin any ordinary insulation with which it comes in contact. No melted solder should be allowed to drop between the leads or behind the commutator, where it may cause short circuits.

26. The commutator connections and the front-end connection of one coil are shown in Fig. 3 by full lines. The connections of a few other leads to the commutator are indicated by dotted lines, so that the two current paths may be traced as follows: One path starts from the brush on bar *1*, passes through lead *a*–coil *a b*–lead *b*–bar *49*–a coil lying in the bottoms of slots *49* and *73*–bar *2*; the next circuit in the same path will end in bar *3*, the third circuit in bar *4*, and so on to bar *24* under the –brush. The other path may be traced also from bar *1*, as follows: through a coil lying in the tops of slots *72* and *48*–bar *48*–a coil lying in the tops of slots *24* and *95*–bar *95*–a coil lying in the tops of slots *71* and *47*–bar *47*, etc. until bar *25* under the –brush is reached.

27. Instead of first connecting all leads having insulation of the same color, some winders connect in one layer all leads from the bottoms of slots as follows: Lead *a* of coil *1* is first connected with a throw of 12 bars, as already explained, and all starting leads of the first quarter of the winding, that is the leads issuing from the bottoms of slots *1* to *24*, are then connected successively to bars *1* to *24*. The finishing leads of the first quarter, those issuing from the bottoms of slots *25* to *48*, are then connected successively to bars *49* to *72*, making the pitch of leads 48 (= 49 – 1), as already explained. The leads now in place are insulated by a wrapping of oiled duck, and the starting lead from the bottom of slot *49* is brought back over the finishing leads already in place and connected to bar *49*. The other starting leads of the second quarter of the winding are connected successively to bars *50* to *72*; and the finishing leads of the same quarter, those from the bottoms of slots *73* to *95* and one from the top of slot *1*, are connected successively to bars *2* to *25*. The starting leads of the third quarter, those from the tops of slots *73* to *95*, are connected to bars *73* to *95*; and the finishing leads of the same coils, those from the tops of slots *2* to *24*, are connected to bars *26* to *48*. The starting leads of the last quarter, issuing from the tops of slots *25* to *48*, are connected successively to bars *25* to *48*, and the finishing leads, from slots *49* to *72*, to bars *73* to *1*, thus completing all the connections. By this method, the coils are connected in the order in which they were laid on the core; but there are probably fewer chances for making mistakes by following the method described in Art. **23.**

WESTINGHOUSE NO. 12A ARMATURE

28. Idle or Dead Coils.—Fig. 5 is a diagram of the winding and connections of an armature for a **Westinghouse No. 12A motor.** The core has 47 slots and the commutator 93 bars. There are 94 individual machine-wound coils, that is, 2 coils per slot, grouped into 47 cell coils each containing 2 individual coils. In speaking of laying coils on a core, cell coils are always meant if the individual coils are

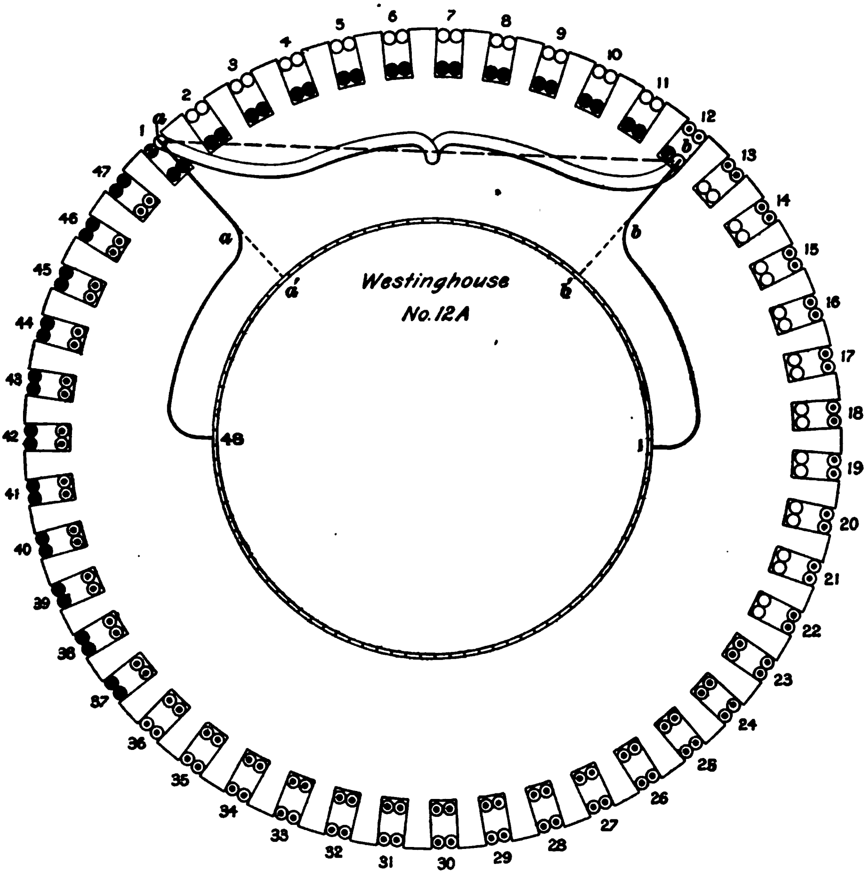


FIG. 5

so grouped. It is impossible to series-connect an even number of coils on an armature for a four-pole machine, because, the $\frac{\text{number of commutator bars} \pm 1}{2}$ must give a whole number. In the case of the Westinghouse No. 12A armature, $\frac{94+1}{2} = 47\frac{1}{2}$ and $\frac{94-1}{2} = 46\frac{1}{2}$; hence, one bar is omitted and one individual coil is left **idle,** or **dead;** that is, it is not connected to the commutator, and serves no purpose except to fill up the space in the slots and thus preserve mechanical balance. The idle coil is also sometimes called the **dummy coil.**

On any four-pole railway motor armature, when the number of commutator bars and the number of slots is the same, both can be made odd and there need be no idle coil; when the number of bars is twice the number of slots less 1, there must be one idle coil; when the number of bars is three times the number of slots, the numbers are so chosen that the number of bars is odd, and there is no idle coil.

WINDING

29. The winding of the Westinghouse No. 12A armature might be considered in four divisions, as was done with the No. 3, but as the coils are laid so that one side of every coil is in the bottom of a slot and the other in the top of another slot, they are all exactly alike, and are laid on the core in regular order; there are then but three logical divisions to the winding.

30. First Division.—The coil pitch is 11, and calling any slot *1* and numbering the slots over from the winder, the farther side of the first cell coil is driven to the bottom of slot *12*; the other side of the same coil is placed temporarily in the top of slot *1*. The second cell coil is placed with one side in the bottom of slot *13* and the other temporarily in the top of slot *2*; and so on until the first 11 coils are in place, each with its farther side in the bottom of a slot and its nearer side temporarily in the top of a slot. This completes the winding of the first division; the active coils are indicated in the figure by white circles (○).

31. Second Division.—Coil *12* is placed in the bottom of slot *23* and permanently in the top of slot *12*, coil *13* in the bottom of slot *24* and the top of slot *13*, and so on, until coil *36* is placed in the bottom of slot *47* and the top of slot *36*, thus completing the second division, the conductors of which are indicated by circles with dotted centers (⊙). Slots *12* to *36* are now completely filled, each slot *37* to *47* has a side of a coil in the bottom, and each slot *1* to *11* has a side of a coil placed temporarily in the top.

32. Third Division.—The winder must now raise the sides of coils *1* to *11* and place the farther sides of coils *37* to *47* successively in the bottoms of slots *1* to *11*, and the nearer sides in the tops of slots *37* to *47*. Coils *37* to *47* constitute the third division, and are indicated by black circles (●). After the bottoms of slots *1* to *11* are filled, the sides of the first eleven coils can be put back permanently in the tops; the winding will then be complete.

33. The winding of nearly all modern armatures may be considered in three divisions: The first division consists of the coils only one side of which can be permanently placed until all other coils are in place; the second division consists of the coils that are permanently placed when first laid on the core, without disturbing any others; the third division consists of the coils each of which has one side laid under a side of a coil of the first division; that is, one side of each coil of the first division is lifted while placing the coils of the last division. The coils are all alike, however, and the divisions are made only to call attention to the method of laying the coils on the core.

CONNECTING

34. One individual coil is to be idle; hence, the leads of one coil are cut off near the armature core and the ends protruding from the slots are taped, so that they cannot make contact with any other conductors or with the core. Any coil may be taken for this purpose, but before cutting the leads a test should be made to make sure that both leads belong to the same coil. The usual way is to touch one terminal of a test circuit to any lead, and the other terminal to one lead after another, until a lead is found through which the magneto-bell will ring or the test lamps light. The two leads on which the test terminals then rest belong to the same coil and may be cut off. Fig. 5 represents the individual coil in the left-hand side of the top of slot *1*, and the same side of the bottom of slot *12* to have been selected for the dead coil; and the ends from which the leads were cut are shown in cross-section.

35. Any lead may be used for starting the connecting; in the following discussion, it is assumed that lead *b* of coil *a b* is the first one to be connected. It will aid in connecting if the leads of the coils are insulated with two colors of sleeving, the two leads of each individual coil in a complete cell coil having the same color, and the leads of the other individual coil in the same cell a different color. The bottom leads should be connected first. All bottom leads swing one way and all top leads the other; that is, when facing the commutator end and gradually rotating the armature so that the leads being connected are always on top of the core, those from the bottoms of the slots all swing to the right and those from the tops to the left.

The No. 12A motor operates with poles diagonal and the opening in the frame for inspecting the commutator is on top; hence, the leads must have a throw of approximately $93 \div 8 = 11\frac{5}{8}$ bars. In this case, the throw is made 13 bars in order to make the connections symmetrical, and bar *1*, to which lead *b* from coil *a b* should connect, is therefore the fourteenth from bar *b'*, directly opposite the point where the center of conductor *b* issues from the slot.

36. The connecting pitch is made $\frac{93+1}{2} = 47$; that is, lead *a* of coil *a b* is connected to bar *48*, counting from bar *1* past the center of the coil. Bar *48* is the thirteenth from *a'*, directly opposite the point where lead *a* issues from a slot; that is, lead *a* has a throw of 12 bars. As lead *b* has a throw of 13 bars, the connections are as nearly symmetrical as they can be made. For all practical purposes, the throw of *b* could as well be 12 bars and that of *a* 13 bars. It is not necessary to locate a top lead until all the bottom leads are connected, and practical men do not do so. All that is necessary is to locate the proper bar for any bottom lead, *b* for example, as just described, and then to connect all bottom leads consecutively, those from the bottoms of slot *13* to bars *93* and *92*, and so on. When all bottom leads have been connected, each commutator bar will have one lead connected to it. This layer of leads should then be covered all the way back to the core with an insulating blanket of oiled duck or similar material, especially near the core, where the greatest amount of crossing of leads occurs; but for the sake of better ventilation the covering may sometimes be omitted near the commutator, where the top and bottom leads are more nearly parallel.

37. If a bar for a top lead has not previously been located and marked, as bar *48* for lead *a*, one may easily be located as follows: (1) Place one terminal of a test circuit on any lead and slide the other terminal over the bars until the bar is found to which the other lead of the same coil is connected; for example, if lead *a* is selected, the test will locate bar *1* to which the other lead *b* is connected. (2) Connect lead *a* to bar *48*, counting past the coil from bar *1*.

After locating one top lead, all others may be connected symmetrically with this one—those from the top of slot *47* to bars *49* and *50*, etc., taking particular care that the leads connect to the commutator bars in the order in which they leave the slots. In connecting the lower leads, work should proceed to the right, the armature being turned counter-clockwise; in connecting the upper leads, work should proceed to the left, the armature being turned clockwise.

38. Great care must be taken not to cross the leads of a layer. When the coils are made up, the two leads of one individual coil of each cell coil should be insulated with white sleeving, and those of the other coil of the same cell coil with black sleeving. If these sleeves are put on always in the same order, the leads can be put into the commutator in regular order, black, white, black, white, etc.; then there will be much less chance for mistakes. As one lead from the top of a slot and one from the bottom of a slot (those of the idle coil) have been cut off, there should be one point, and only one, in each layer of leads where two leads with similarly colored insulation lie side by side. After the connections are complete, tests should be made between each pair of adjacent bars, and if the circuit is open between any two bars the leads have been crossed either on that side of the armature or on the one directly opposite. If the test shows all connections to be properly made, the leads are then soldered into the commutator ears.

WESTINGHOUSE NO. 49 ARMATURE

WINDING

39. Fig. 6 is a diagram of the winding and connections of a **Westinghouse No. 49 armature**, which has 59 slots, 117 commutator bars, and 118 individual coils, grouped into 59 cell coils. As the number of individual coils is even, one must be idle, as explained in Art. **28**; hence, the use of only 117 commutator bars.

40. Standing beside the core with the commutator end to the right and numbering any convenient slot *1*, place the farther side of the first cell coil in slot *14*, counting over the top of the core from slot *1*, and the nearer side temporarily in the top of slot *1*; that is, the coil pitch is 13 slots. The coils are then laid on successively, the farther side of each in the bottom of the next empty slot, and the nearer side in the top of the next slot not already filled.

The sides of the first 13 coils, constituting the first division of the winding, are placed in the bottoms of slots *14* to *26* and temporarily in the tops of slots *1* to *13*. The process of winding, except that a different coil pitch is used, is very

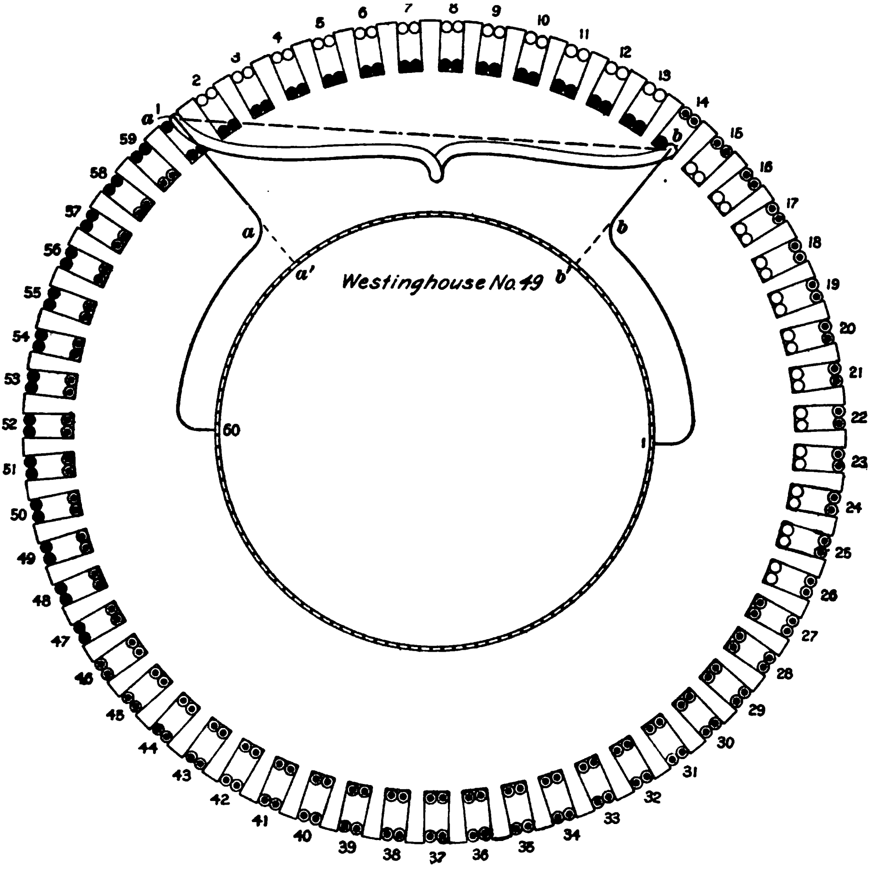


FIG. 6

similar to that of winding a No. 12A armature. The coils of the first division are indicated in the figure by white circles (○), as before. Coils *14* to *46*, the second division, are indicated by circles with dots in the centers (⊙); their sides are laid successively in the bottoms of slots *27* to *59* and in the tops of slots *14* to *46*. Coils *47* to *59*, the third division, are indicated by black circles (●); the sides of these coils are laid successively in the bottoms of slots *1* to *13* and in the tops of slots *47* to *59*. The sides of the first 13 coils, which were temporarily laid in the tops of slots *1* to *13*, are lifted while placing the sides of the last 13 coils in the bottoms of the same slots, and are permanently replaced when the other coils are all in position.

41. It should be noticed that when installing the coils on a modern four-pole railway-motor armature, such as the Westinghouse No. 12A or No. 49, each coil installed after the coils of the first division are laid completes the filling of a slot; for example, in winding the No. 49 armature, coil *14* completes the filling of slot *14*, coil *15* completes the filling of slot *15*, etc., while some of the slots are still only one-half full and others are entirely empty.

CONNECTING

42. As the No. 49 motor operates with poles diagonal and the brushes on top of the commutator, the armature leads must be given a throw of approximately one-eighth of the circumference; in this case, the throw of lead *b* is made 17 bars. The pitch of the leads is $\frac{117+1}{2} = 59$. After finding the leads of any individual coil, cutting them off, and insulating the ends of the coil for the idle coil, the connecting may be started with any other individual coil.

Suppose that the coil whose sides lie respectively in the left-hand side of the top of slot *1* and the left-hand side of the bottom of slot *14* is selected for the idle coil, and that the leads of coil *a b*, the other coil of the same cell coil, is the first to be connected. It is assumed that the winder is facing the commutator end, as is usual in connecting, and that the core is placed so that coil *a b* is on top. Lead *b* is connected to bar *1*, the eighteenth counting from *b′* as 1, bar *b′* being located in the usual way directly opposite lead *b* at the point where it issues from a slot. With the proper throw, 59 bars, counted past the center of coil *a b*, lead *a* will come to bar *60*, the seventeenth counting from *a'* as 1; the connections are then as nearly symmetrical as possible, lead *b* having a throw of 17 bars to the right and lead *a* a throw of 16 bars to the left. These could as well be reversed, making the throw of *b* 16 bars and of *a* 17 bars.

43. Knowing the proper throw and connecting pitch, a practical winder will count the bars to locate the first lead, *b* for example, and will then connect all lower leads in regular order, those from the bottom of slot *15* to bars *117* and *116*, etc., working toward the right and rotating the armature counter-clockwise as he proceeds. If the leads of the individual coils of each cell coil are insulated in regular order by black and white sleeving, it will be easy to bring the leads down to the proper bars in regular order, black, white, black, white, etc.; so that at only one place, where the lead from the idle coil is missing, will two leads with similarly colored insulation appear side by side. When the lower layer of leads are all in the proper bars, they should be insulated, and the upper leads, which were previously bent back out of the way, brought down one by one in regular order and connected. If bar *60* and lead *a* have been previously marked, this connection can be made first, and it will serve as a guide for all the others in the top layer; if the proper connection for a top lead has not previously been found, one terminal of a test circuit should be placed on any top lead and the other rubbed over the bars until the test indicates the bar to which the other lead of the coil is connected, and the lead tested should then be connected to the bar *60*, counting past the coil, from the bar thus found as 1. For example, if a test circuit terminal were placed on lead *a*, a ring or a light would be obtained when the other terminal was touched to bar *1*; lead *a* should then be connected to bar *60*, counting over past the coil from bar *1*. After one upper lead is located, the others are connected in regular order, working this time from right to left and rotating the core slowly to the right as the leads are connected; that is, the leads from the top of slot *59* are connected to bars *61* and *62*, etc. There should be but one place in the upper layer where two leads with similarly colored insulation lie side by side.

44. On account of the small space occupied by each commutator bar, it may be difficult to bring out the leads of a layer, especially the lower one, side by side; in this case, alternate leads of a layer are connected to alternate commutator bars first, and the remaining leads of the same layer are then brought to their proper bars. For example, calling the first lead installed lead *1* and the bar to which it is connected bar *1*, leads *3*, *5*, *7*, etc. will be connected to bars *3*, *5*, *7*, etc. entirely around the commutator, and then leads *2*, *4*, *6*, etc. will be connected to bars *2*, *4*, *6*, etc. This is less often necessary with the upper layer of leads, because, being on the outer and larger circumference, there is more room.

WESTINGHOUSE NOS. 68 AND 68C ARMATURES

WINDING

45. Fig. 7 is a diagram of the winding and connections of a **Westinghouse No. 68** or a **No. 68C railway-motor armature,** either of which has 55 slots and 109 commutator bars. There are 55 cell coils, each containing 2 individual coils, making a total of 110 individual coils; as but 109 of these can be connected, 1 must be idle or dead. The winding is almost exactly like that of the No. 49. The coil pitch is 13, the 13 cell coils of the first division being laid in the bottoms of slots *14* to *26* and the tops of slots *1* to *13*. The coils of the second and third divisions of the winding are laid on exactly the same as on the core of the No. 49 armature, except that the second division has 29 coils instead of 33—four less than the second division of the No. 49 armature. The coils are indicated in the usual manner, the first division by white circles, the second by circles with dotted centers, and the third by black circles.

CONNECTING

46. The process of connecting the leads of a No. 68 armature to the commutator is also very similar to that of a No. 49. The No. 68 motor operates with the poles diagonal and brushes on top of the commutator; hence, the lower leads are given a throw of 15 bars, or about one-eighth of the circumference, to the right. After selecting any coil for the idle one, cutting off its leads and taping the projecting ends of

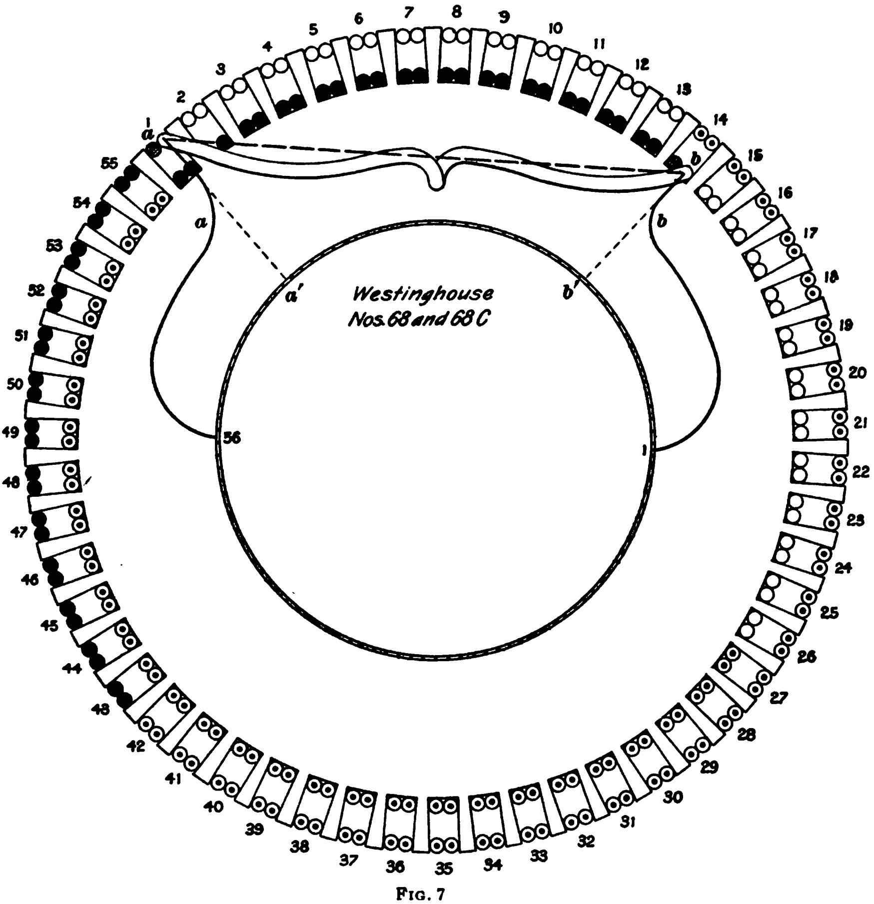


FIG. 7

the coil, the connecting may start with any other coil, possibly with the other individual coil in the same slot cell with the idle one. Thus, if coil *a b* is the first one to be connected, bars *a′*, *b′*, directly opposite conductors *a*, *b* as they issue from the slots, are located, and lead *b* is brought to bar *1*, the sixteenth from bar *b′*, counting away from the center of the coil. Unless it is known that this will make the connections symmetrical, the connecting pitch $\frac{109+1}{2} = 55$ bars, is counted back past the coil from bar *1* to bar *56*. As this is the fifteenth bar from bar *a′*, the connections are as nearly symmetrical as possible, and all the bottom leads from slots *15*, *16*, etc. may be connected successively to the bars *109*, *108*, *107*, *106*, etc., rotating the core counter-clockwise, facing the commutator end, as the connecting proceeds. It will be necessary to remove lead *a* from bar *56* in order to connect the lower leads under it; but before removing it both lead *a* and bar *56* should be marked, or else it will be necessary to test a coil and count the coil pitch again after the lower leads are all connected. Lead *a* and bar *56* may be connected when the bottom leads are properly insulated, and all succeeding leads from the tops of slots *55*, *54*, etc. may then be connected successively to bars *57*, *58*, *59*, *60*, etc., rotating the core clockwise as the connecting proceeds.

The rule concerning the regularity of the lead connections is the same as for all armatures with similar windings; namely, the leads of either layer must not be crossed. If the leads from the cell coils are insulated alternately with black and white sleeving, the two colors should occur alternately, except where a lead of the idle coil is missing in each layer.

WESTINGHOUSE NOS. 56 AND 81 ARMATURES

WINDING

47. Fig. 8 is a diagram of the winding and connections of a **Westinghouse No. 56** or a **No. 81 armature.** The core of each of these armatures has 39 slots, 117 commutator bars, and 117 individual coils—three times as many coils as slots, or 3 coils per slot. The coils are therefore grouped

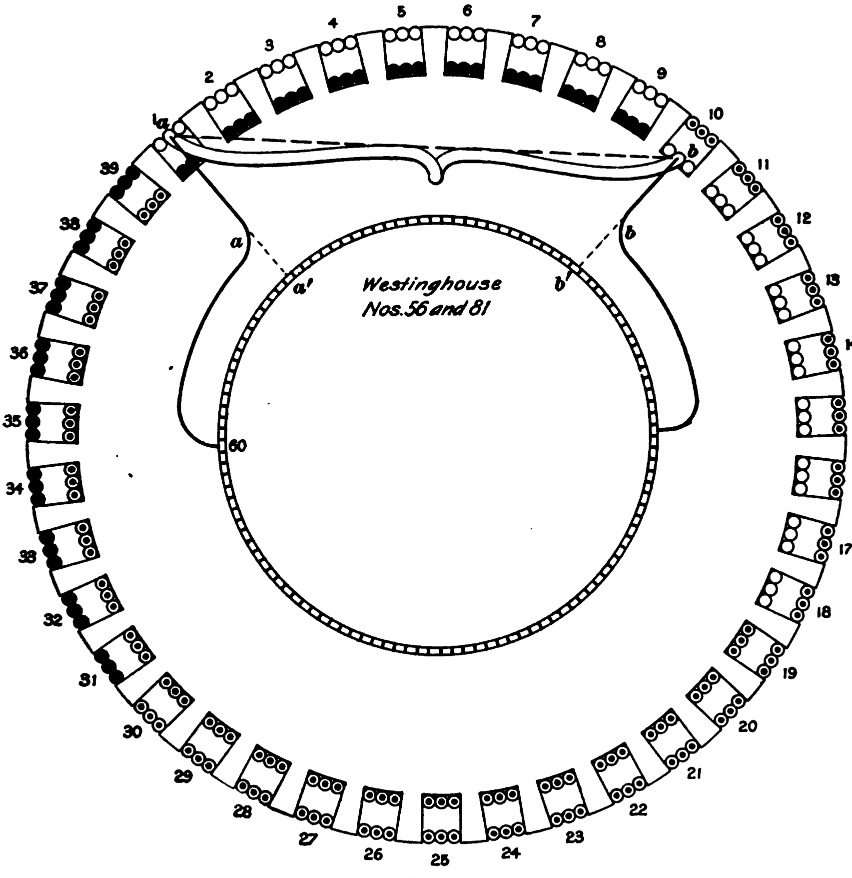


FIG. 8

into cell coils, each containing 3 individual coils. As the number of individual coils and the number of commutator bars are the same, there is no idle coil.

48. The coil pitch is 9, the first coil lying in the bottom of slot *10* and the top of slot *1*, any slot being numbered *1*. The cell coils are laid on in regular order, the same as on a No. 12A, No. 49, or No. 68 armature the side farthest from the winder, standing facing the side of the core being placed in the bottom of the next succeeding empty slot beyond the one whose bottom half is already filled, and the side nearest him in the slot next beyond the one whose top half is already filled; the second coil, for instance, should lie in the bottom of slot *11* and in the top of slot *2*, the third coil in the bottom of slot *12* and in the top of slot *3*, and so on around the core. It will be necessary to lift the sides of coils lying in the tops of the first 9 slots when placing sides of the last 9 coils in the bottoms of those slots, and then to replace the sides lifted after all the bottoms of the slots are filled. The coils are indicated in three divisions, as usual.

CONNECTING

49. Both the No. 56 and the No. 81 armatures have diagonally placed poles and brushes on top of the commutator; hence, the leads are given a throw of 16 bars, or about one-eighth of the circumference, to the right. When the number of coils per slot is odd, a middle lead from the bottom of a slot should be the first one connected; hence, lead *b* may be connected to bar *1*, the seventeenth from bar *b'*, directly opposite the point where lead *b* issues from the slot. To determine whether this will make the connections symmetrical, the connecting pitch, $\frac{117 + 1}{2} = 59$, is counted back past coil *a b*, bringing lead *a* to bar *60*; as this is the seventeenth from *a'*, the connections are symmetrical. This determination is never necessary when the winder is familiar with the connections; for if he already knows that a throw of 16 bars is correct for lead *b*, he can find bar *1* and proceed at once with the connections of all the lower leads.

50. Having located one lead *b*, all the other leads from the bottoms of slots are then connected. They are usually brought out to the bars in two layers, as described in Art. **44**, except that two leads from the bottom of each slot are first connected, leaving every third lead and every third bar unconnected, and then rotating the core again and connecting the third leads in regular order to the vacant bars. After the bottom leads are in place and properly insulated, the leads from the tops of slots are all connected symmetrically with lead *a*, already located. If the connection for a top lead was not located prior to putting the lower leads in place, any lead may be properly placed by finding bar *60* over to the left, as the coil lies on the top of the core, from the bar to which the other lead of the same coil is connected; that is, after the lower leads are in place, the process of finding the bar to which any top lead should be connected is the same as described in Art. **37**, except that the pitch is 59 instead of 47 and the lead selected should, therefore, be connected to bar *60* instead of to bar *48*. The utmost care should be taken not to cross the leads in a layer.

WESTINGHOUSE NOS. 38 AND 38B ARMATURES

WINDING

51. Fig. 9 is a diagram of the winding and connections of an armature suitable for either a **Westinghouse No. 38** or a **No. 38B motor.** The armature has 45 slots and 3 coils per slot, or 135 coils, and hence 135 commutator bars. Three coils per slot means that there are three times as many coils as there are slots, each slot containing halves of six coils. There is no idle coil, since an armature with an odd number of coils can always be series-connected, or two circuit, for a four-pole machine without having an idle coil.

The coil pitch is 10, and the process of placing the coils on the core is very similar to that described for Nos. 12A, 49, 68, etc. Facing the side of the core and regarding any slot as *1*, the first cell coil is placed in the bottom of slot *11* and temporarily in the top of slot *1*, the second in the bottom of slot *12* and temporarily in the top of slot *2*, and so on for the 10 coils of the first division. The remaining coils are placed in the same manner, except that after reaching slot *11* the bottoms of the slots nearest the winder are filled, so that

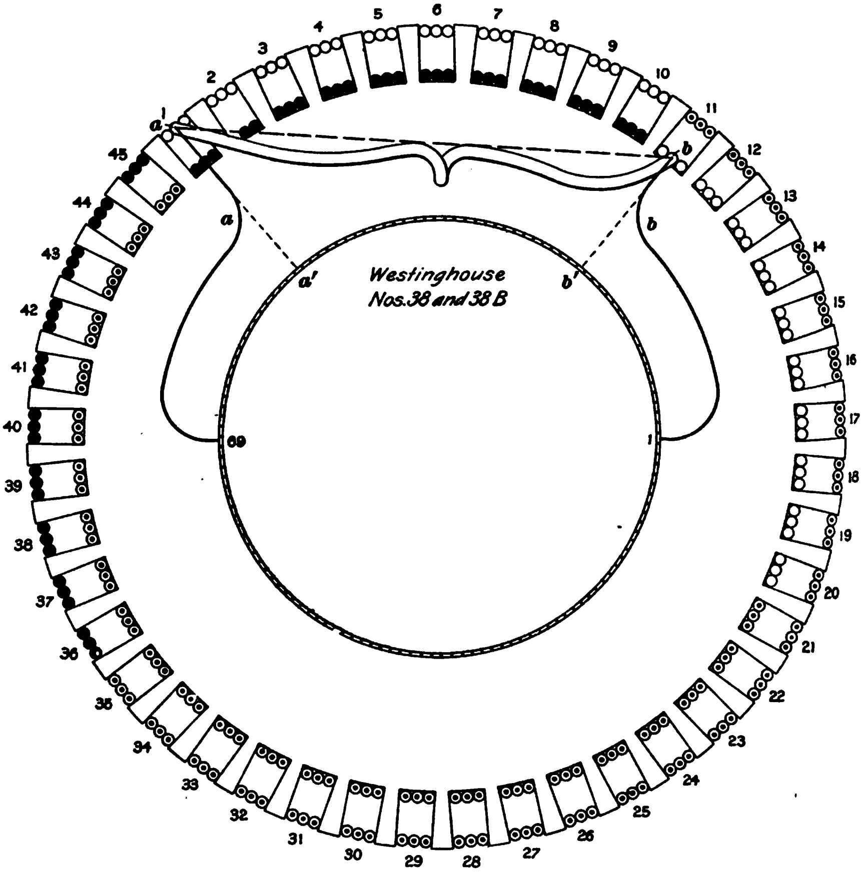


FIG. 9

both sides of each coil are placed permanently. The sides of the first 10 coils, temporarily placed in the tops of slots *1* to *10* when first laid, are lifted when placing the last 10 coils and replaced permanently after all others are in position. The three divisions are indicated as usual.

CONNECTING

52. The No. 38 and 38B motors operate with poles diagonal; hence, the coil leads have a throw of 19 bars, or about one-eighth of the circumference. The connections may begin with any middle coil of a cell coil, say *a b*, and lead *b* is connected to bar *1*, the twentieth from *b′*. The symmetry of the connections may be determined in the usual way by counting the connecting pitch, $\frac{135 + 1}{2} = 68$, back past coil *a b* to bar *69* for lead *a*, and then noting that bar *69* is the twentieth from *a′*. If the throw were made 17 bars, the number nearest to one-eighth the total number, the connections would be unsymmetrical. All this counting is unnecessary if it is known at the start that a throw of 19 bars is correct for lead *b*. Having connected one bottom lead, all the others are connected in succession to bars *135*, *134*, *133*, etc., care being taken not to cross any leads.

When the bottom leads are all in place and properly insulated, one test-circuit terminal is touched to any lead and the other to bar after bar in succession, until the one is found through which a ring or a light is obtained; the lead is connected to the sixty-ninth bar from this one, counting past the center of the coil. Having connected one top lead, all the others are brought down in regular order and connected, crosses being carefully avoided.

WESTINGHOUSE NO. 50L ARMATURE

53. Fig. 10 is a diagram of the winding and the connections of a **Westinghouse No. 50L railway-motor armature.** The diagram and the following description are also applicable to several other armatures of the 50 class, including 50C, 50E, and 50F. These differ from each other only in mechanical details, all having the same style of armature winding. A 50L armature has 55 slots, 3 coils per

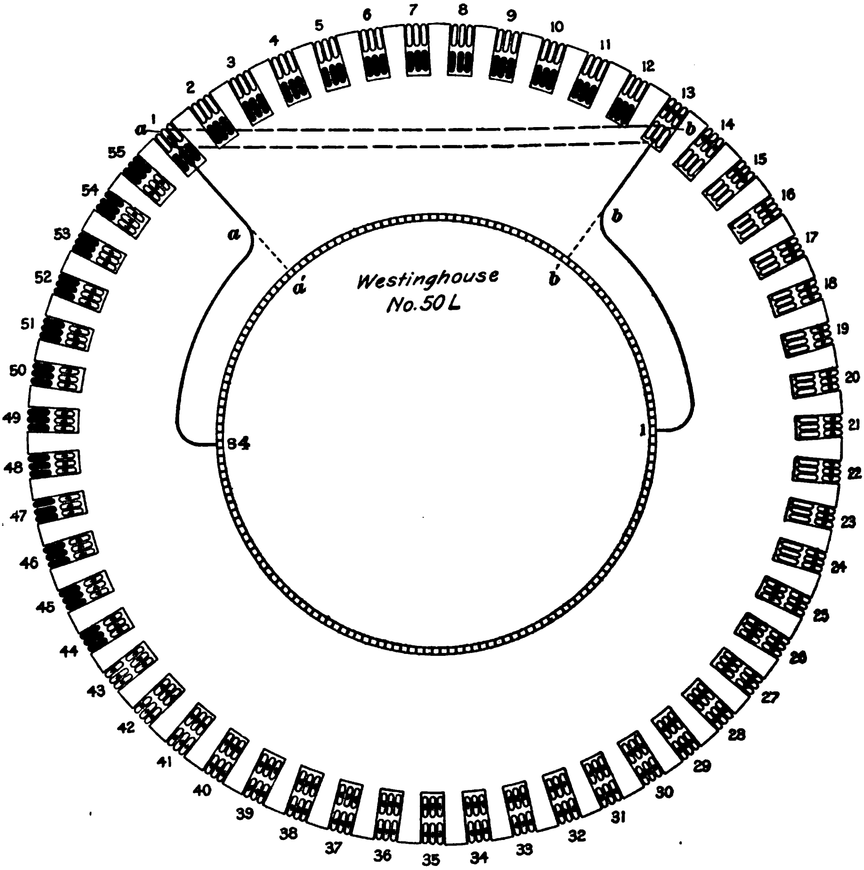


FIG. 10

slot or 165 individual coils, and 165 commutator bars. The coils are formed of copper strip, and are arranged in 55 groups or cell coils.

WINDING AND CONNECTING

54. The coil pitch is 12, the first cell coil being placed in the bottom of the slot *13* and the top of slot *1*, the second in the bottom of slot *14* and the top of slot *2*, and so on around the core, lifting the sides of coils *1* to *12* in order to place sides of coils *44* to *55* in the bottoms of slots *1* to *12*, after which the lifted sides are replaced. All the coils are exactly alike, but are indicated in three divisions. The connection pitch is found in the usual way, $\frac{165 + 1}{2} = 83$.

55. Before winding an armature with coils formed of copper strip, it is customary to install the commutator on the shaft; for if the coils were placed first, it would be difficult to push the stiff leads out of the way so as to force on the commutator. The commutator being in place, it is possible to place the lower leads in the proper commutator bar slots as fast as the coils are laid. The poles are diagonal and the brushes are on top of the commutator; hence, the lower leads have a right-hand throw of 24 bars, or about one-eighth of the circumference. As soon as the first cell coil is in place, the middle lead *b* is placed in bar *1*, the twenty-fifth from bar *b*′; the other two lower leads from the same cell coil, as well as all other lower leads, as fast as the coils are placed on the core, are placed in the bar slots symmetrically with lead *b*.

When all the coils are in place and their lower leads properly connected and insulated, any upper lead is placed in bar *84*, counted back past the coil from bar *1*, to which the lower lead of the same coil is already connected. After connecting one upper lead, all the rest are connected in regular order.

The coils on the 50L armature have but one turn; hence, there is no connection from slot to slot across the commutator end of the core. The broken line from *a* to *b* represents the connection across the rear end, or the end farthest from the commutator.

Fig. 11 shows the appearance of an armature core partially wound with coils formed of copper strip, the coils in this case being so formed that the left-hand side of each coil when looking at it from its lead end is the low side and goes to the bottom of a slot, the right-hand side belonging in the top of another slot. Coils may be formed and put on the core either way, as it makes no difference in the operation of the machine.

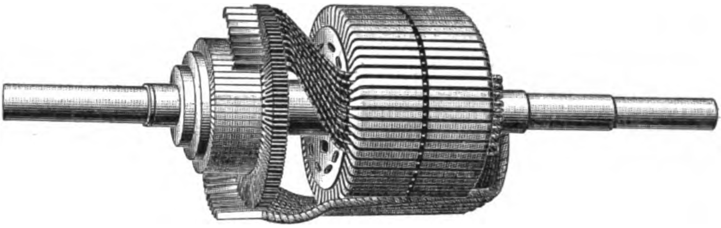


FIG. 11

WESTINGHOUSE NO. 101 ARMATURE

WINDING

56. **The Westinghouse No. 101 motor armature** has 37 slots, 3 coils per slot, and 111 commutator bars. Nos. 101B and 101C differ from No. 101 only in mechanical details, the armature windings being the same for all three. The 111 individual coils are grouped into 37 cell coils of equal size. The winding and connections are shown diagrammatically in Fig. 12. The winding pitch is 9; that is, the first cell coil is laid with one side in the bottom of slot *10* and the other in the top of slot *1*. The 9 coils of the first division are laid successively, with their farther sides permanently in the bottoms of slots *10* to *18* and their nearer sides temporarily in the tops of slots *1* to *9*. Both sides of the coils of the second and third divisions are permanently placed as soon as the coils are laid on, and in laying the 9 coils of the third division, the sides of the 9 coils, temporarily placed in the tops of slots *1* to *9*, are lifted until all the other coils are in place; they are then permanently replaced.

CONNECTING

57. The throw of the leads is made suitable for diagonal poles, 14 bars, or about one-eighth. The connecting pitch is $\frac{111-1}{2} = 55$. Facing the commutator end, any middle

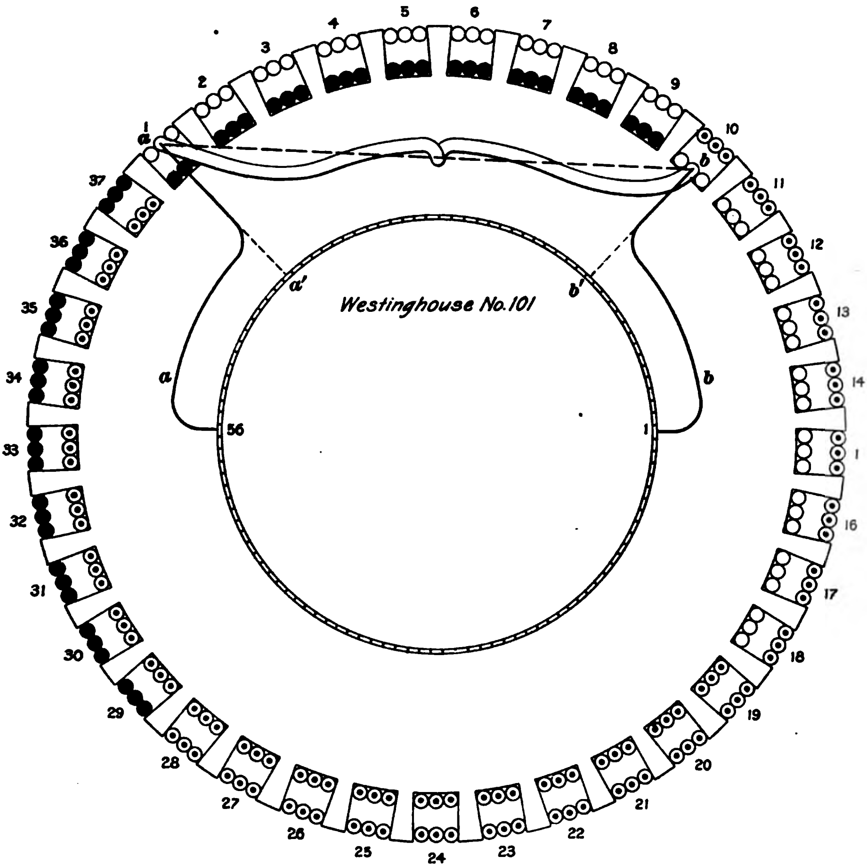


FIG. 12

bottom lead of a cell coil, *b* for example, is connected to bar *1*—the fifteenth regarding *b'* as *1*, and counting from the coil. Bar *b'* is selected in the usual way by taking the bar directly opposite the point where lead *b* issues from the slot. All lower leads are then connected in regular order to consecutive bars. Any top lead is connected to bar *56*, counting past the coil from bar *1*, to which the other lead of the same coil is connected. All the other top leads are then connected symmetrically with this one, thus completing the connections.

ARMATURE WINDING DATA

WESTINGHOUSE DIRECT-CURRENT RAILWAY MOTORS

58. Table I gives data that will be useful for men employed in repair shops, where various types of Westinghouse railway motors may come for repairs. The application of the figures in the several columns will be readily understood after studying the preceding pages. Data is given not only for the armatures mentioned in the text, but also for several others; the complete table covers nearly all Westinghouse railway-motor armatures in common use.

The lead connections are given on the assumption that the count is made from bar *1*, to which one lead of a coil connects, past the center of the coil to the bar for the other lead. The throw of leads is given in the number of bars between the bar directly opposite the point where the first bottom lead to be connected issues from a slot and the bar to which the lead should connect, counting away from the coil.

TABLE I

ARMATURE DATA

Motor No.	Number of Slots	Coils per Slot	Number of Commutator Bars	Coils Lie in Slots	Leads Connect to Bars	Throw of Leads
3	95	1	95	1–25	1–49	12
12A	47	2	93*	1–12	1–48	13
49	59	2	117*	1–14	1–60	17
68 and 68C	55	2	109*	1–14	1–56	15
56 and 81	39	3	117	1–10	1–60	16
38 and 38B	45	3	135	1–11	1–69	19
50L	55	3	165	1–13	1–84	24
101	37	3	111	1–10	1–56	14
69	35	3	105	1–10	1–54	13
76	39	3	117	1–10	1–60	16
85	39	3	117	1–10	1–60	16
89	45	3	135	1–11	1–69	19
92A	41	3	123	1–10	1–62	17
93A	45	3	135	1–11	1–69	19
112	45	5	225	1–11	1–113	31

*Armatures have one idle coil.

ARMATURE REPAIR WORK

(PART 3)

GENERAL ELECTRIC ARMATURES

G. E. 800 ARMATURE

1. The pitch of coils, the pitch of leads, the throw of leads, etc. on General Electric railway-motor armatures may all be determined by the rules given in connection with Westinghouse armatures. Also, the coils are placed on the core in the manner already described; in fact, the methods already given are general for four-pole railway-motor armatures of all types.

Fig. 1 is a diagram of the winding and connections of a **G. E. 800 armature;** it has 105 slots and 1 coil per slot, or 105 coils, and hence 105 commutator bars. The coils are not grouped into cell coils because with 1 coil per slot this would be impossible. Grouping individual coils into cell coils is never done unless there is more than 1 coil per slot.

WINDING

2. The winding may be considered in three divisions, or sections, although the coils are all alike and are all laid on in the same manner, except that one side of the coils of the first section must be lifted when placing the coils of the last section. The coils are made up and laid on the core in a manner somewhat different from that followed with Westinghouse armatures thus far considered, but the difference is not important. Looking at any coil from its lead end, its right side should lie in the top of a slot and its left side in the bottom of a slot; whereas, the reverse has been true of coils previously considered.

Assume that the winder stands with the commutator end

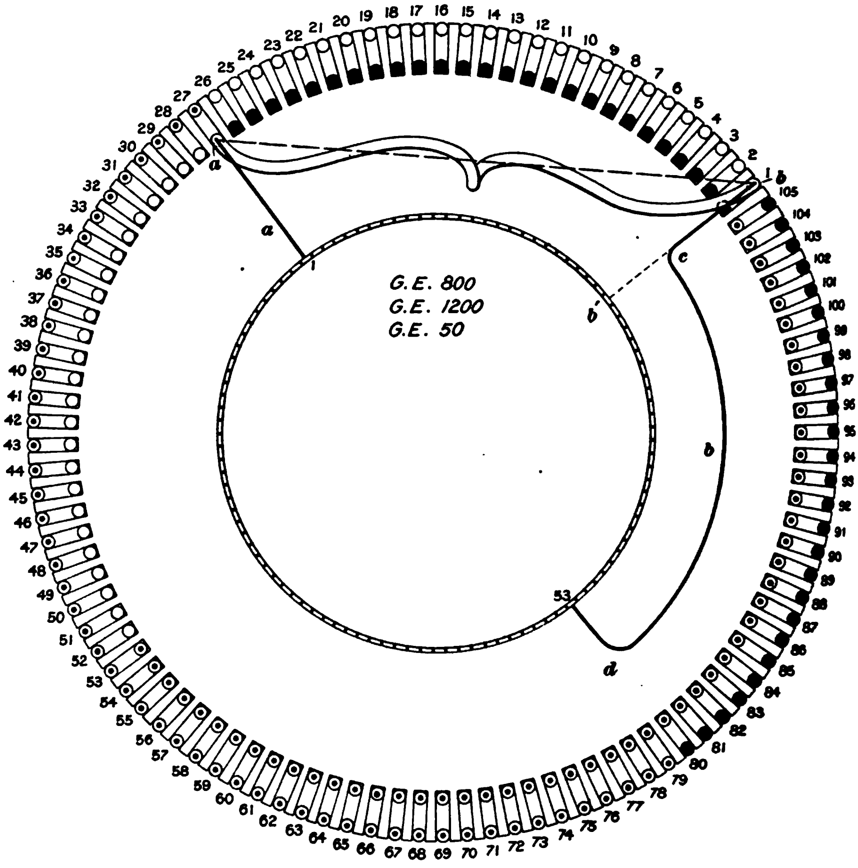


FIG. 1

of the core at his left, so that he can push the farther side of a coil to the bottom of a slot and then pull the nearer side back to the top of the proper slot. The pitch of the coils is 26, the whole number nearest to one-fourth of the total number of slots; hence, numbering any slot *1*, the farther side of the first coil is pushed down to the bottom of slot *27* and the top placed temporarily in the top of slot *1*. The front cross-connection and the leads of coil *1* are shown in the figure by full lines, and the connection across the rear end of the core is represented by a broken line. Coils *2*, *3*, *4*, etc. are placed successively with one side in the bottoms of slots *28*, *29*, *30*, etc. and the other sides temporarily in the tops of slots *2*, *3*, *4*, etc., until the first 26 coils constituting the first division of the winding are in place, the top of the core being revolved toward the winder as the work proceeds. The farther side of coil *27* is placed in the bottom of slot *53* and the nearer side in the top of slot *27*, both sides being put permanently in place. This fills slot *27*, the bottom being already filled with a side of coil *1*, and as succeeding coils are placed, slots *28*, *29*, *30*, and so on around the core, are filled, the farther side of each coil as it is laid on being placed in the bottom of the next empty slot.

The second division is completed when coil *79* is placed. In placing the farther side of coil *80* in the bottom of slot *1*, it is necessary to lift the side of coil *1*, temporarily placed in the top of slot *1*; the nearer side of coil *80* fills the top of slot *80*. The remaining coils of the last division are laid in the same manner as coil *80*, it being necessary each time to raise the side of a coil of the first division in order to fill the bottoms of the first 26 slots. When coils *80* to *105* are all in place, the sides of coils *1* to *26*, which were lifted, are replaced permanently in the tops of slots *1* to *26*, and the winding is complete. The coils of the first division are indicated by white circles in the slots, those of the second section by circles with dotted centers, and those of the third section bv black circles.

CONNECTING

3. The G. E. 800 motor operates with the poles vertical and horizontal and the opening for inspecting the commutator is on top; hence, one lead of each coil has no throw and the other has throw enough to make the pitch of the leads correct. The coils are therefore made with one short lead, which projects from the bottom of a slot when the coil is in place on the core, and one long lead, which projects from the top of a slot. After the coils are all installed, the leads are all bent back over the core, the short leads, in some cases, being bent back first and tied down by wrapping a piece of cord around the core and over them.

A test is made with a magneto or a lamp test circuit to determine the two leads of any coil; the short lead is marked by a kink or a tag, and the bar directly opposite the point where the center of the short lead issues from the slot is also marked by a slight scratch or prick-punch mark. Assuming that coil *a b* is the one tested, lead *a* and bar *1* are marked. The pitch of the leads is made $\frac{105-1}{2} = 52$, and the long lead *b* of coil *a b* is connected to bar *53*, counting past the coil from bar *1*. Every alternate top lead is then connected to every alternate commutator bar, the core being rotated counter-clockwise as the connections are made; for example, the lead from the top of slot *104* is connected to bar *55*, the lead from the top of slot *102* to bar *57*, and so on. A layer of insulation is then wrapped over the leads already connected, after which the remaining top leads are brought down and connected to the empty bars, the lead from the top of slot *105* to bar *54*, that from the top of slot *103* to bar *56*, and so on until the top leads are all connected, one to each bar, the core being again rotated counter-clockwise as work proceeds, so as to keep the work on top. Another insulating layer of canvas or other material is then wrapped over all the top leads, after which the marked short, or bottom, lead is connected to the marked bar, and then all the other short leads are connected in regular order.

4. When the leads from the top of a core swing to the right, it is always best in installing the connections to work from left to right and rotate the core counter-clockwise as work proceeds. This makes each succeeding lead, as it wraps around the armature head, lie above its predecessor;

whereas, if the connections were made from right to left and the core rotated clockwise, it would be necessary to push each lead up under its predecessor on the head. When the leads swing to the left, the reverse is true; and when they come straight out, it makes no difference which way the work proceeds.

5. Great care must be taken that the leads are connected in the order in which they leave the core slots; that is, there must be no crossing of leads. The peculiar manner in which the leads are connected, namely, the top leads first, in two layers, with insulation over each layer, and the bottom leads last, does not cross leads, but interweaves them together near the core, so that they are prevented from vibrating and both layers of leads are held firmly in place. It has been found that if the lower leads are brought straight out to the commutator first, as would seem most natural, the severe vibration to which the motors are subjected soon causes the lower leads to break off close to the core, because from the core to the commutator they have no support. The upper leads, which are connected first, could as well be laid in one layer instead of two, were it not for the fact that there is not space enough on the head to lay the long leads side by side in one layer where they wrap around the head as at *c*, *d*. The short leads run straight out, and hence require less room, so that they can be laid in one layer.

G. E. 1200 AND G. E. 50 ARMATURES

WINDING AND CONNECTING

6. The number of slots, number of coils, number of commutator bars, method of winding and connecting, are the same on the G. E. 800, G. E. 1200, and G. E. 50 armatures, and the description given for the G. E. 800 armature applies as well to either of the other two. The same diagram, Fig. 1, can be used for all three.

G. E. 1000 ARMATURE

WINDING

7. The **G. E. 1000 armature** has 93 slots, 93 commutator bars, and 93 individual coils. The coils are made up

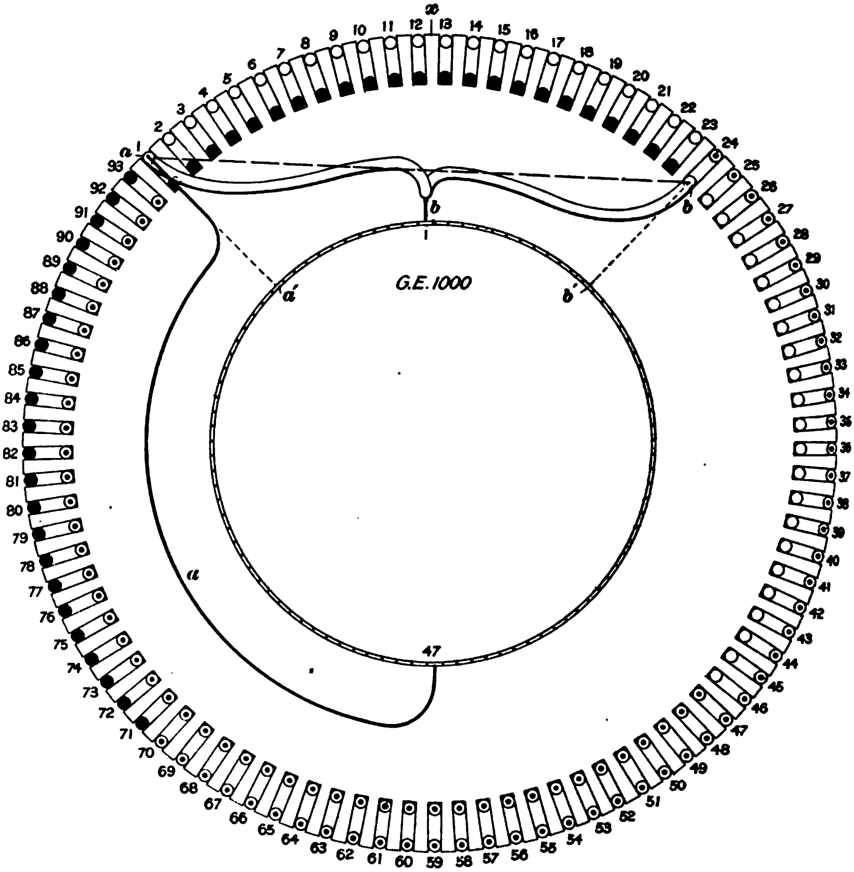


FIG. 2

the same as for a G. E. 800 armature, except that the leads are brought out at the opposite end of the coil from those of the G. E. 800, which makes the left side of the coil, when facing its lead end, the high side, and the right side the low side. The pitch of the coils is 23, the whole number nearest to one-fourth the total number of slots. Fig. 2 is a diagram of the winding and connections.

In winding a G. E. 1000 armature, assume that the winder faces the side of the core with the commutator end on the right. The winding may be considered in three divisions: the first division, composed of the first 23 coils, is marked by white circles in the slots; the second, composed of coils *24* to *70*, inclusive, by circles with dotted centers; and the third division, the last 23 coils, by black circles.

The farther side of the first coil is placed in the bottom of slot *24*, numbered over the top of the core from any slot *1* near the winder, and the other side is drawn back and placed temporarily in the top of slot *1*. The sides of the second coil are placed in the bottom of slot *25* and temporarily in the top of slot *2*; and so on for the 23 coils of the first division, the last one going in the bottom of slot *46* and temporarily in the top of slot *23*. The sides of coil *24* are placed in the bottom of slot *47* and the top of slot *24*, both sides being put permanently into place; the sides of coil *25* are placed permanently in the bottom of slot *48* and the top of slot *25*, etc., until coil *70*, the last of the second division, is placed permanently in the bottom of slot *93* and the top of slot *70*. The laying of the coils of the last division is a continuation of the process of laying those of the second division, except that the sides of coils *1* to *23*, which were temporarily placed in the tops of slots *1* to *23*, are lifted as the farther sides of coils *71* to *93* are placed in the bottoms of the same slots. When the coils of the last division are all in place, the lifted sides of those of the first division are put back permanently in the tops of the slots and the winding is complete. Before beginning the connecting, it is well to bend all the long leads back over the core out of the way.

CONNECTING

8. The G. E. 1000 motor operates with poles diagonal and the commutator is inspected from the top; hence, the leads must be given a throw of approximately one-eighth of the number of bars in the commutator. This throw, however, is not counted away from the center of the coil, as is usually the case, but one lead, the short one, is brought back to a bar directly opposite the center of the coil, and the other is carried on around the commutator in the same direction to a bar that will give the proper pitch of leads. In making up the coils, the short lead is taped in with the end of the coil to the center, and is brought out at the center directly opposite the bar to which it is to connect. If these leads are accurately brought out there will be no need of counting off to locate the bar to which the first short lead should connect, but any short lead may be connected to the bar directly opposite the point where the lead issues from the end of the coil.

9. To avoid any uncertainty as to the first connection, the center of any coil—for instance, coil *a b*, whose sides lie, respectively, in the top of slot *1*, and the bottom of slot *24*—may be found by measuring the distance between the two slots over the top of the core with a flexible tape and locating the center *x* as one-half of the distance; or the same point *x* may be found by laying a string over the core from slot *1* to slot *24*, and then doubling it to find the middle, which will be *x*. A string drawn between the point *x* and the center of the shaft will cross either bar *1*, to which the short lead *b* of that coil should connect, or a mica body. If it crosses a mica body, the bar either side of the body may be used, that toward the high side of the coil being preferable as it is nearer the exact center of the coil. Bar *1* may also be found by selecting the central bar between bars *a'* and *b'*, directly opposite slots *1* and *24*. This method will show that bar *1* might have been located one bar farther to the right and still have been as near central between *a'* and *b'* as it is now;

either location will do. Having located one short lead, all the others are connected in regular order, the short lead from coil *2* to bar *2*, that from coil *3* to bar *3*, and so on. When the short leads are all connected they are covered with a layer of insulation.

10. The pitch of the leads should be $\frac{93-1}{2} = 46$; that is, if a short lead is connected to bar *1*, the long lead of the same coil should be connected to bar *47*, counted past the side of the coil from which the long lead issues. Any long lead may be the first one to be connected, and the bar to which the short lead of the same coil is connected may be found by a test made in the usual way. The long leads are connected in two layers, because if laid side by side in one layer, where they pass around the head, they would spread over too much space. Every alternate top lead is first connected symmetrically to the first one located; that is, the lead from the top of slot *92* to bar *49*, that from the top of slot *90* to bar *51*, and so on, rotating the armature in a clockwise direction as the connecting proceeds. The leads are insulated where they lie in a mass, after which the intervening top leads are connected regularly to the bars that were skipped during the first round. This makes the connections complete, every bar having connected to it one long and one short lead. If a test shows no crosses or open circuits, the leads are then soldered in and the armature is ready to go in the lathe for turning off the commutator.

G. E 52 ARMATURE

WINDING

11. The **G. E. 52 armature** has 29 slots, 3 coils per slot, or 87 coils, and 87 commutator bars. The coils are grouped into 29 cell coils, and are so made that when viewed from the lead end the right side is low. Fig. 3 is a diagram of the winding and connections. Standing beside the core and numbering any convenient slot *1*, the sides of the first cell coil are placed in the bottom of slot *8* and temporarily in the top of slot *1*. This makes the coil pitch 7, and determines the position of all the other coils, which are laid on successively and in order, the top of the core being drawn toward the winder as each coil is laid. The sides of coils *1* to *7*, temporarily placed in the tops of slots *1* to *7* when first laid, are lifted when placing the sides of the coils of the last division in the bottoms of the same slots, and are replaced afterwards, thus completing the winding. The

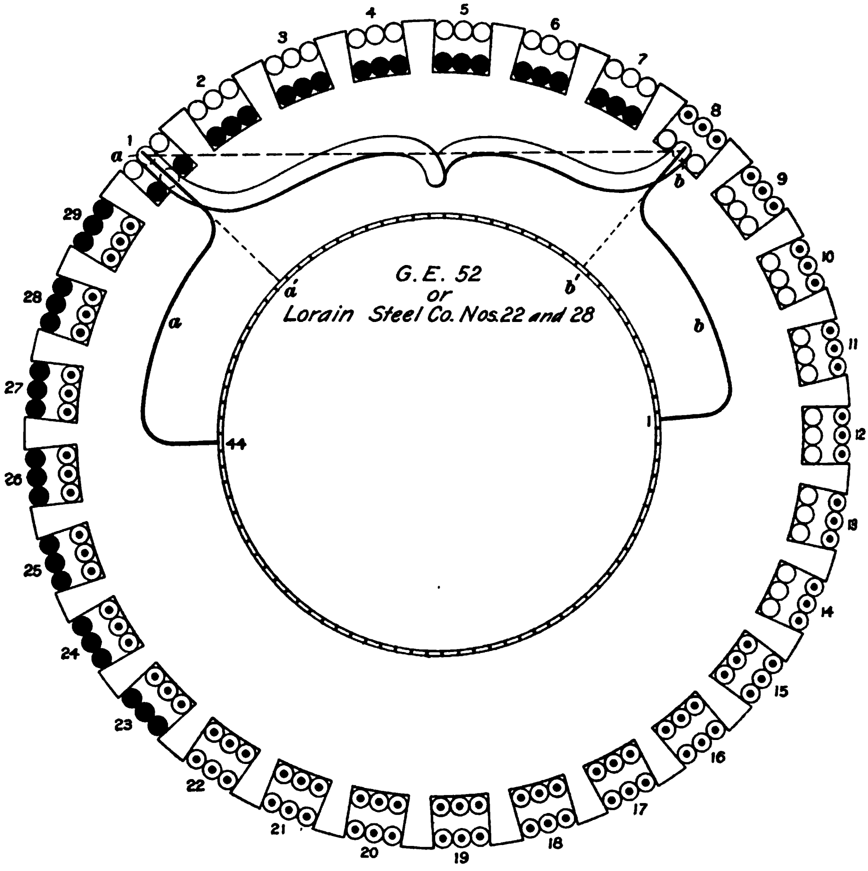


Fig. 8

coils of the three divisions of the winding are indicated in the usual way by white circles, circles with dotted centers, and by black circles.

CONNECTING

12. The throw should be suitable for diagonal poles with the commutator opening on top, or about $87 \div 8 = 10\frac{7}{8}$. A throw of 11 bars makes the connections symmetrical; hence, any lower lead, say *b* of coil *a b*, is connected to bar *1*, the twelfth counting bar *b′* number 1. All lower leads are then connected in regular order, rotating the core slowly counter-clockwise to keep the work on top.

The pitch of the leads is $\frac{87 - 1}{2} = 43$, and the bottom leads being all connected, any top lead is connected to bar *44*, counting past the coil from bar *1*, to which the other lead of the same coil is connected. For example, if lead *a* is the first top lead to be connected, the test circuit will show that the other lead of the same coil is connected to bar *1*, and lead *a* should be connected to bar *44*, counting over past the coil from bar *1*. The connection of one top lead determines the location of all the others, and they are then connected in regular order, the core being rotated clockwise, so as to keep the work on top.

G. E. 53, 37-SLOT ARMATURE

WINDING

13. The **G. E. 53, 37-slot armature** has 3 coils per slot, or 111 individual coils, and 111 commutator bars. The individual coils are grouped into 37 equal cell coils. Fig. 4 is a diagram of the winding and connections. Standing beside the core and numbering any near slot *1*, the first coil is placed in slots *10* and *1*, thus making the coil pitch 9. The farther side of each coil is placed in the bottom of a slot, and the nearer side in the top of another. The nearer sides of the first 9 coils are at first placed temporarily in the tops of slots *1* to *9*, as they are lifted when placing the coils of the last division and replaced permanently after the others are in place.

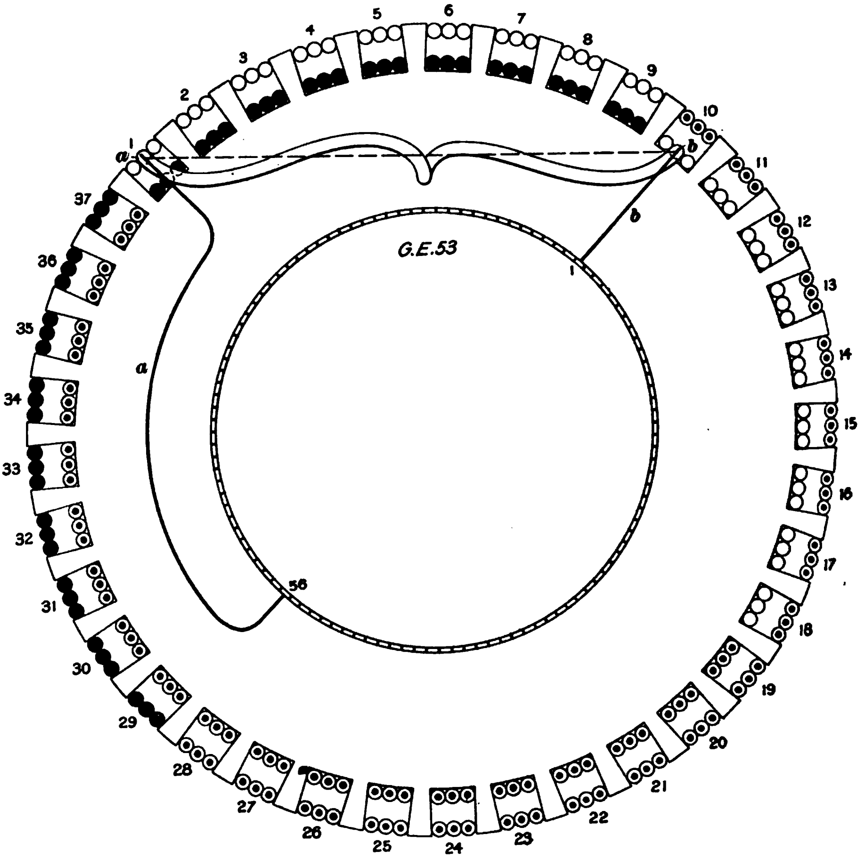


FIG. 4

CONNECTING

14. The poles of the G. E. 53 motor are vertical and horizontal and the commutator is inspected from the top; hence, the bottom leads have no throw. The coils are therefore made with one short lead and one long lead similar to those of the G. E. 800. The short lower leads of the G. E. 53 are connected first, and the connecting is started by bringing any short lead out to the bar directly opposite the point where the center of the lead comes from the slot; for example, lead *b* is connected to bar *1*. All the short leads are then connected in regular order, each straight out to a bar.

The pitch of leads is $\frac{111-1}{2} = 55$, and after the lower leads are all connected any top lead is connected to bar *56*, counted over past the coil from bar *1*, to which the short lead of the same coil is connected. Bar *1* is found in the usual way by means of a test circuit. The location of one top lead determines that of all; but, on account of the space required by the long leads in wrapping so far around the head, the upper leads are connected in two layers. Every alternate lead is connected to every alternate bar first and then the remaining leads are connected to intervening bars, the core being rotated clockwise in each case to keep the work on top. When the connections are complete there will be two leads connected to each bar, as usual, and there will be three layers of leads on the head—one layer of lower leads and two layers of upper leads. Over each layer should be a wrapping of insulating cloth.

G. E. 53, 33-SLOT ARMATURE

15. The **G. E. 53, 33-slot armature** has 3 coils per slot, or 99 individual coils, and 99 commutator bars. The individual coils are grouped into 33 cell coils. The method of winding and connecting is the same as that just described for the 37-slot armature, except that the winding pitch is 8 and the connecting pitch 49.

G. E. 54 ARMATURE

WINDING

16. The **G. E. 54 armature** has 29 slots, 4 coils per slot, or 116 individual coils, and 115 commutator bars. The 116 coils would require 116 bars, but as an even number of bars cannot be series-connected on a four-pole machine, one bar is omitted and one individual coil is left idle. The

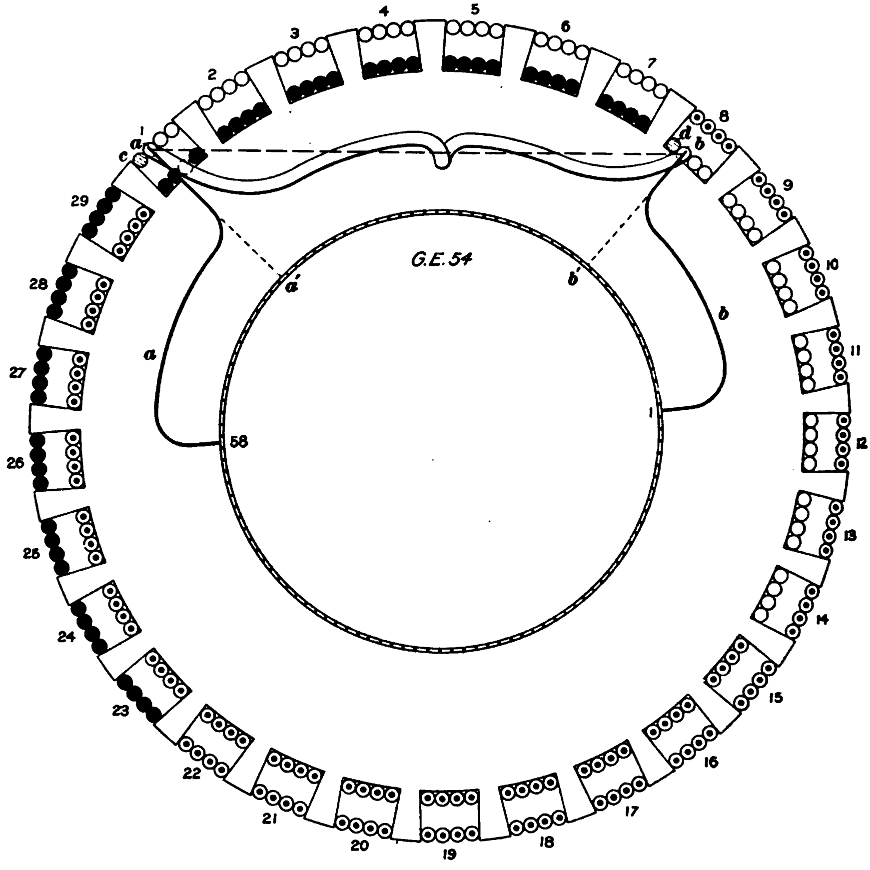


FIG. 5

116 individual coils are grouped into 29 equal groups or cell coils, and bound together by insulating tape, etc. Fig. 5 is a diagram of the winding and connections. The right side of the coils, facing the lead end, is the low side, and the coil pitch is 7. Assuming that the winder stands beside the core with the commutator end to the right, he places the farther side of cell coil *1* in the bottom of slot *8* and the other side temporarily in the top of slot *1*, near him. The other coils are all placed in a similar manner, each with its farther side in the bottom of the next empty slot and its nearer side in the top of the slot next beyond the one filled by the last preceding coil. The nearer sides of the 7 coils of the first division are placed temporarily in the tops of slots *1* to *7*, and are lifted while placing the farther sides of the 7 coils of the last division in the bottoms of the same slots. The lifted sides are then replaced and the winding is complete.

CONNECTING

17. Each slot has four leads protruding from the top and four from the bottom. To select the idle coil, start with any lead and test to determine the other lead of the same coil; the two leads thus found are cut off a short distance from the core, and the projecting ends taped so that they cannot make contact with anything else. Supposing coil *c d* in slots *1* and *8* to be the idle coil; the connecting can begin with lead *b* of coil *a b*, although a start could as well be made with any other lead. The throw should be 14 bars. The pitch of the leads should be $\frac{115-1}{2} = 57$. Lead *b* is, therefore, connected to bar *1*, the fifteenth regarding bar *b'* as 1, and all bottom leads are connected symmetrically with lead *b*. Any top lead, *a* for example, is then connected to bar *58*, counting past coil *a b* from bar *1*, to which the other lead *b* of the same coil is connected. Bar *1*, with which the count begins, is found in the usual way by means of a test circuit.

G. E. 55 ARMATURE

WINDING

18. The **G. E. 55 armature** has 47 slots, 3 coils per slot, or 141 individual coils grouped into 47 equal cell coils, and 141 commutator bars. Fig. 6 is a diagram of the winding and connections. The winding pitch is 11; hence, the farther side coil *1*, which may be any coil, is placed in the bottom of

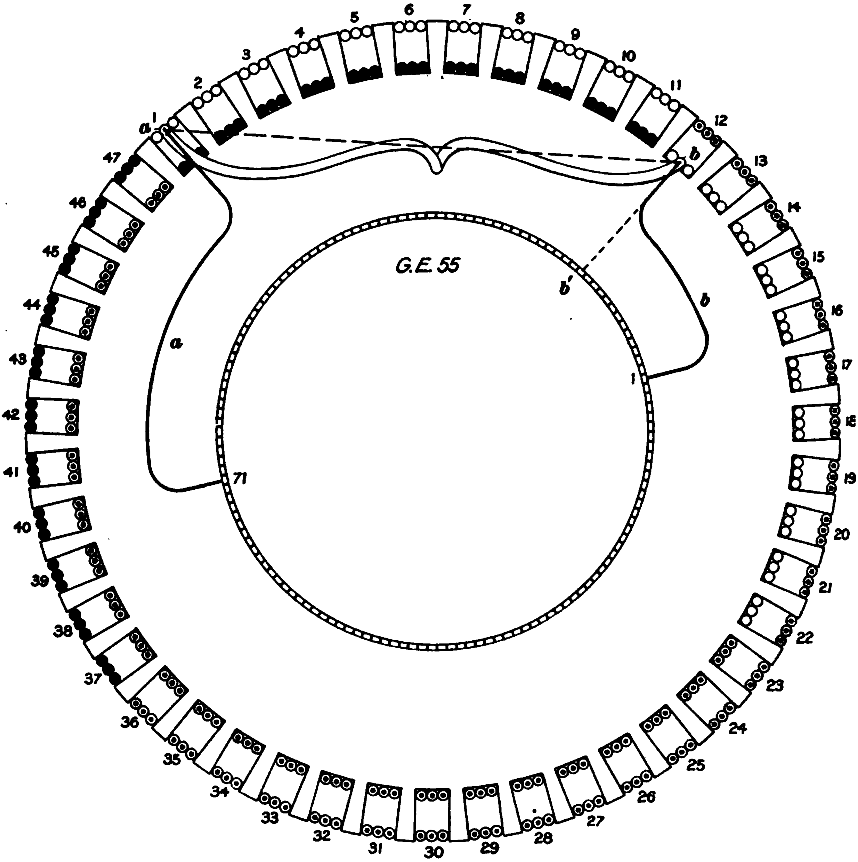


FIG. 6

slot *12* and the other side temporarily in the top of slot *1*. Succeeding coils are placed in regular order, each with its farther side in the bottom of the next succeeding empty slot and its nearer side in the top of the slot next beyond the one last filled, the top of the core being drawn over toward the winder after the placing of each coil. The tops of the 11 coils of the first division are, at first, placed temporarily in the tops of slots *1* to *11*, for they must be lifted while placing the farther sides of the 11 coils of the last division in the bottoms of the same slots and replaced after all other coils are in place.

CONNECTING

19. The poles of the G. E. 55 motor are vertical and horizontal, and if the opening in the frame for inspecting the commutator and brushes were placed directly above the commutator, one lead of each coil would require no throw. The opening, however, is placed at such an angle from the horizontal that the short leads from the bottoms of the slots must be given a throw of 13 bars. Any short lead, b for example of coil $a\,b$, is first located in the fourteenth bar to the right of the one directly opposite the point where the lead issues from the slot, and then all the other bottom leads are connected symmetrically with this one, working toward the right and turning the commutator counter-clockwise as work proceeds. A test is then made from any top lead, a for example, and various bars, until the bar is found to which the other lead b of the same coil is connected, when, calling this bar *1*, lead a is connected to bar *71* (connection pitch $\frac{141-1}{2} = 70$), counted over past the coil $a\,b$. All other top leads are then connected symmetrically with lead a, working from right to left and turning the armature clockwise as work proceeds.

G. E. 57, 37-SLOT ARMATURE

WINDING

20. The **G. E. 57 railway-motor armature** may have either 37 slots or 33 slots, the complete motor remaining practically the same in either case. The 37-slot armature has 3 coils per slot, or 111 individual coils; hence, there are 111 bars in the commutator. The 111 coils are grouped into

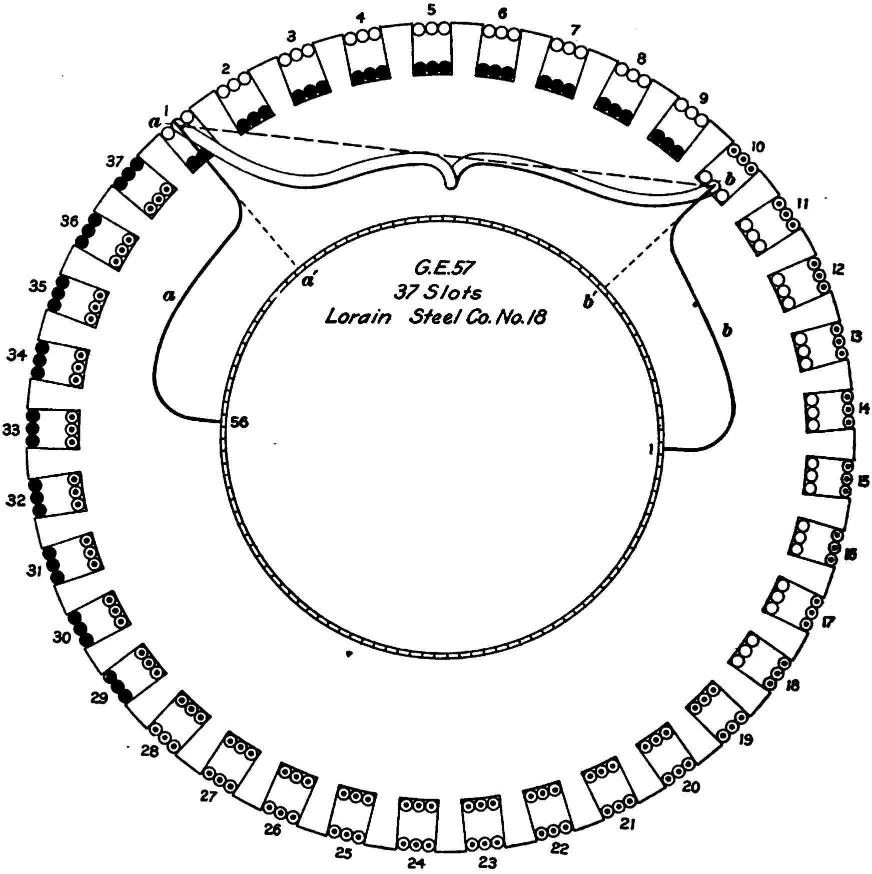


FIG. 7

37 cell coils. Fig. 7 is a diagram of the winding and connections. Standing beside the core with the commutator end to the right, and numbering any slot *1*, the first 9 coils, constituting the first division of the winding, are laid with their farther sides in the bottoms of slots *10* to *18* and the nearer sides temporarily in the tops of slots *1* to *9*. This makes the coil pitch 9, the whole number nearest to 37 ÷ 4. Succeeding coils are placed in the usual way, the farther side in the bottom of the next empty slot and the nearer side in the top of the slot next beyond the one last filled. The second division ends with the placing of coil *28*. The sides of coils *1* to *9*, temporarily placed in the tops of slots *1* to *9*, are lifted one by one as the last 9 coils are put in place, and are replaced after all the others are down.

CONNECTING

21. The poles of the G. E. 57 motor are diagonal and the commutator opening is on top; hence, the leads are given a throw of 14 bars. Any bottom lead, *b* for example, is first connected to bar *1*, the fifteenth from bar *b'* (regarded as 1), bar *b'* being found in the usual way. All other bottom leads are connected in regular order, rotating the armature counter-clockwise as work proceeds. The connection pitch is $\frac{111-1}{2} = 55$. Any top lead is then connected to bar *56*, counting past the coil from bar *1*, to which the other lead of the same coil is connected. Bar *1* is found by means of a test circuit. All other bottom leads are then connected in regular order and symmetrically with the one thus located.

G. E. 57 and 58, 33-SLOT ARMATURES

22. The **G. E. 57 and 58, 33-slot armatures** are alike, so far as the method of winding is concerned. Each has 3 coils per slot, or 99 individual coils, which are grouped into 33 cell coils. Each commutator has 99 bars. The winding and connecting processes are the same as for the

G. E. 57, 37-slot armature, except that the winding pitch is 8, the connecting pitch 49, and the throw of the bottom leads 12; that is, lead *b*, Fig. 8, is connected to the thirteenth bar from *b'*. The lower leads are all connected first in one layer, which is then insulated, after which the upper leads are connected in one layer. The G. E. 58 motor is made for narrow-gauge roads.

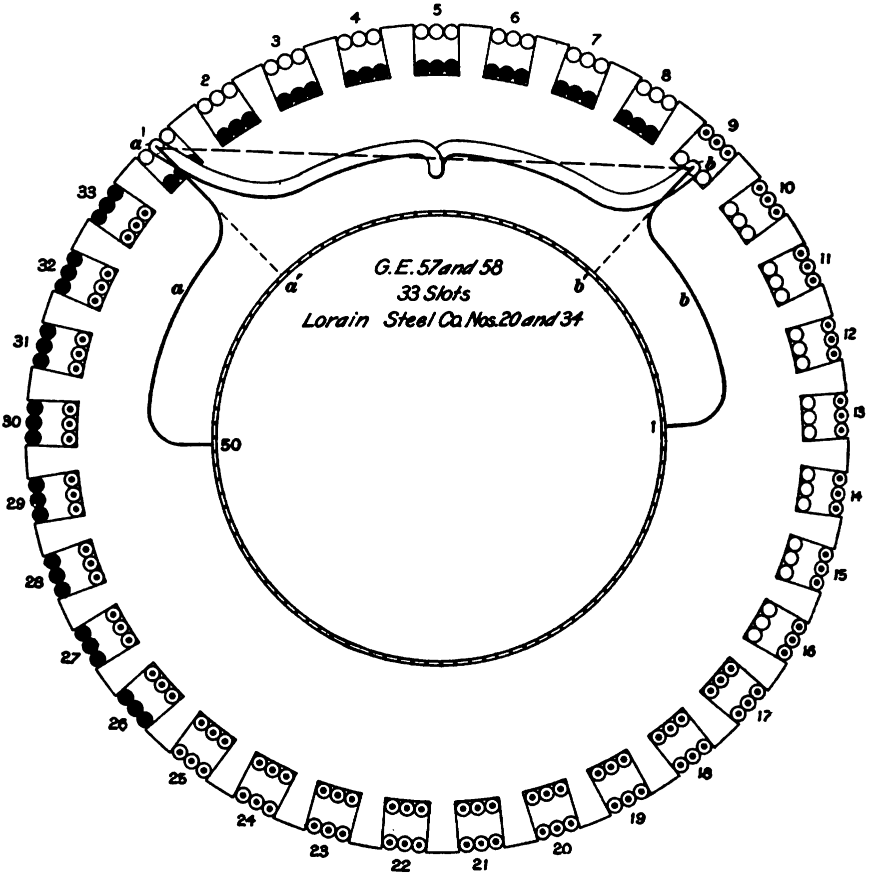


FIG. 8

G. E. 60 ARMATURE

23. The **G. E. 60 motor** also is made for narrow-gauge roads. The armature has 37 slots, 3 coils per slot, or 111 individual coils, and 111 commutator bars. The 111 coils are insulated in 37 cell coils. The winding pitch is 9, the connecting pitch 55, and the throw 14; in fact, the diagram and description of the winding and connections of the G. E. 57, 37-slot armature applies also to the G. E. 60.

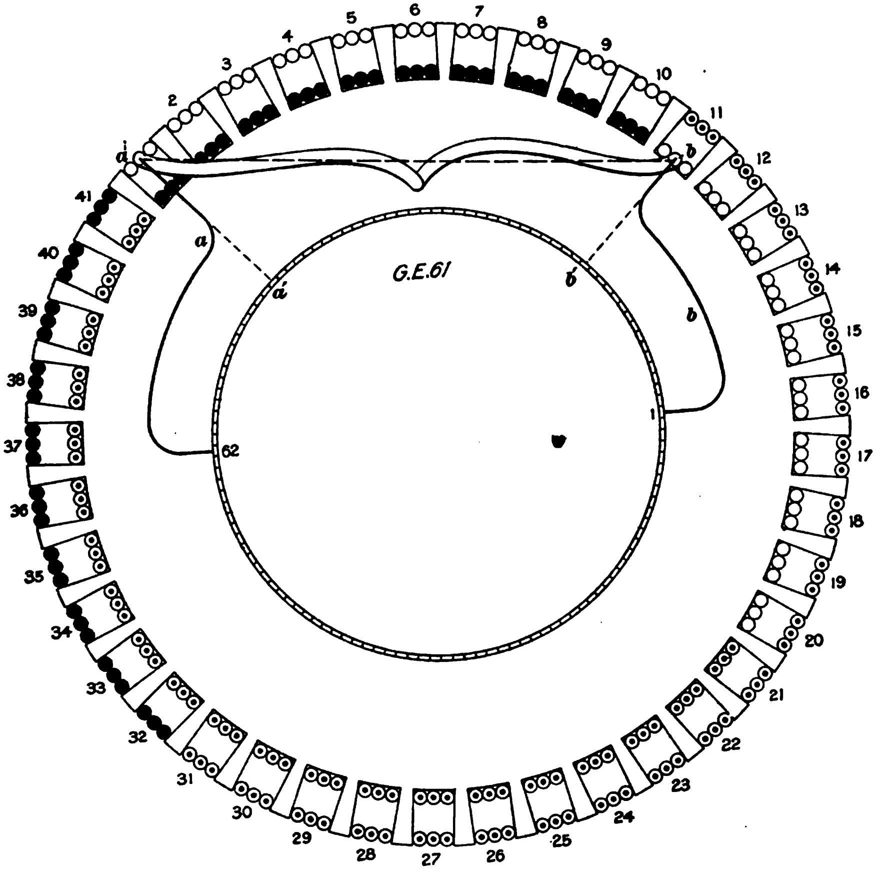


FIG. 9

G. E. 61 ARMATURE

WINDING

24. The **G. E. 61 armature** has 41 slots, 3 coils per slot, or 123 individual coils grouped into 41 cell coils, and 123 commutator bars. Viewed from the lead end, the right side of each coil belongs in the bottom of a slot; hence, it is assumed that the winder faces the side of the core with the commutator end at his right. Fig. 9 is a diagram of the winding and connections. The coil pitch is 10 slots, the first coil being laid in slots *11* and *1* and all succeeding coils in consecutive order, each with its farther side in the bottom of the next empty slot and its nearer side in the top of the next slot not already filled. One side of each of the coils of the first division is lifted when placing the coils of the last division, and replaced permanently when all other coils are in place.

CONNECTING

25. The poles are vertical and horizontal; the opening for inspecting the brushes is not directly over the commutator, but has its center on a line 45° from the vertical; hence, the leads must have the same throw, 15 bars, as if the poles were diagonal and the opening on top. Any lower lead, *b* for example, is connected to bar *1*, the sixteenth regarding bar *b'* as 1, and counting away from the coil. All lower leads swing to the right and are connected in regular order, the core being rotated counter-clockwise so as to keep the work on top.

The pitch of the leads is $\frac{123-1}{2} = 61$, and any top lead is connected to bar *62*, counting past the coil from bar *1*, to which the other lead of the same coil is connected. The connection of one upper lead determines the connections of all the others, for they are all connected in regular order.

G. E. 65 ARMATURE

WINDING

26. The **G. E. 65 armature** has 55 slots, 3 coils per slot, or 165 individual coils, and 165 commutator bars. The individual coils are grouped into 55 cell coils. Fig. 10 is a diagram of the winding and connections. The coil pitch is 13, the sides of the first coil going in the bottom of slot *14*

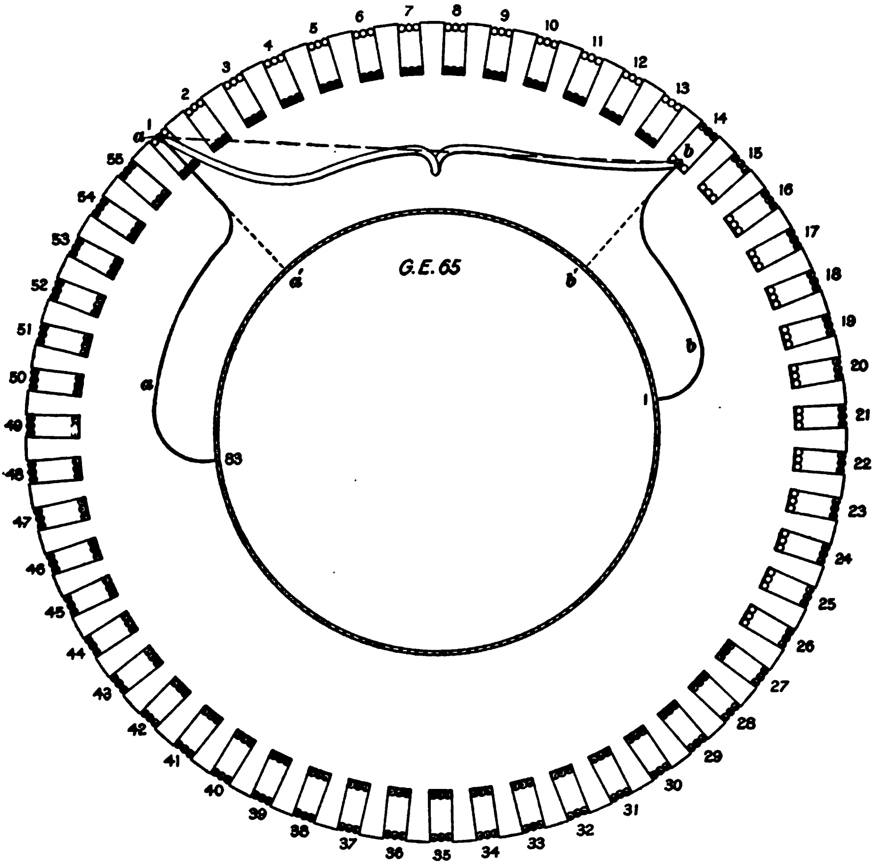


Fig. 10

and temporarily in the top of slot *1*. Designating the position of one coil is enough to tell a practical winder how to place all the coils, as all go on in regular order, each successive coil filling the bottom half of the next empty slot and the top half of slot next beyond the one last filled. The coils are shown in three divisions, as usual.

CONNECTING

27. The throw of the bottom leads is 18; that is, if lead *b* is the first lower lead connected, it is placed in bar *1*, the nineteenth from bar *b'* regarded as 1. The pitch of the leads is $\frac{165-1}{2} = 82$; hence, lead *a* belongs in bar *83*, counting past the coil from bar *1*. This makes the connections suitable for vertical and horizontal poles and a commutator opening a little to one side of the top.

Ordinarily, no attention is paid to any upper lead until all bottom leads are connected; any lower lead is placed with the proper throw, after which all lower leads are connected in regular order. Any top lead is then connected in bar *83*, counting past the coil from bar *1*, to which the other lead of the same coil is connected, after which all top leads are connected in regular order. While connecting the lower leads, the core is rotated counter-clockwise in the same direction as when laying on the coils; and while connecting the upper leads, it is rotated clockwise.

MISCELLANEOUS ARMATURES

THE STEEL MOTOR COMPANY'S C AND C3

WINDING

28. C and C3 steel motors are still in use, although the company that made them has passed out of existence. The armature has 99 slots, 1 coil per slot or 99 coils, and 99 commutator bars. Fig. 11 is a diagram of the winding and connections. The coil pitch is 25, the sides of the first coil being laid in the bottom of slot *26* and temporarily in the top of slot *1*, the second coil in the bottom of slot *27* and temporarily in the top of slot *2*, etc., until all coils are in place, both sides being permanently placed after passing coil *25*. The temporarily placed sides of coils *1* to *25* are lifted when placing the 25 coils of the last division, and are replaced after all others are in place.

CONNECTING

29. The poles of the C and C3 steel motors are vertical and horizontal, and the opening for inspecting the brushes is directly over the commutator; hence, one lead of each coil has no throw, but is brought straight out to a commutator bar directly opposite the point where the lead issues from the slot. Each coil, therefore, has one short lead and one long lead. The short leads project from the bottoms of the slots, and are connected first. The connecting pitch is $\frac{99-1}{2} = 49$, and after all the short leads are placed in the commutator necks any long lead, *a* for example, is brought to bar *50* counting past the coil *a b* from bar *1* to which the other lead *b* of the coil is connected. By testing between lead *a* and various bars, bar *1* is easily located. The remaining long leads are then brought down and connected in two layers, the first layer containing alternate leads, which are connected to alternate commutator bars, and the second containing the remaining leads, which are connected to intervening bars. The long leads, in wrapping around the head, would occupy too much room in one layer.

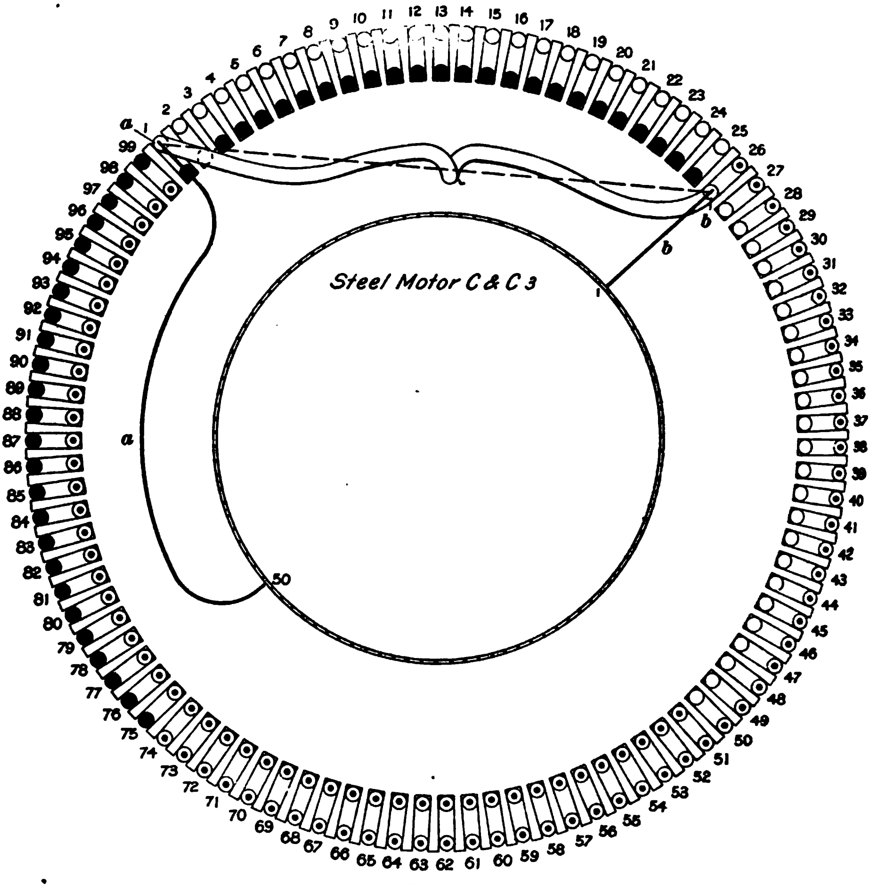


FIG. 11

LORAIN STEEL COMPANY'S NOS. 22 AND 28

WINDING

30. The armatures of the **Lorain Steel Company's Nos. 22 and 28 motors** have 29 slots, 3 coils per slot, or 87 individual coils, grouped and insulated as 29 cell coils, and 87 commutator bars. Fig. 3 is a winding and connecting diagram, the process being the same as on the G. E. 52. Facing the core, with the commutator end to the right, the sides of the first cell coil are placed in the bottom of slot *8* and temporarily in the top of slot *1*; the second coil in the bottom of slot *9* and temporarily in the top of slot *2*, etc., until all the coils are in place. After the 7 coils of the first division are laid, all the others have both sides put permanently in place when they are laid. The sides temporarily placed in the tops of slots *1* to *7* are lifted when placing the 7 coils of the last division, and are then permanently replaced.

CONNECTING

31. The leads are given a throw suitable for diagonal poles, that is, 11 bars, or approximately one-eighth of the total number. The bottom leads are connected first. Any bottom lead, *b* for example, is connected to bar *1*, the twelfth from bar *b'*. All bottom leads are then connected in regular order. The pitch of the leads is $\frac{87-1}{2} = 43$. Any top lead, *a* for example, is connected to bar *44*, counting past the coil from bar *1*, to which the other lead *b* of the same coil is connected. The bar from which to count is located by means of a test circuit. All top leads are then connected in order.

LORAIN STEEL COMPANY'S NOS. 20 AND 34

WINDING

32. The armatures of the **Lorain Steel Company's Nos. 20 and 34 motors** have 33 slots, 3 coils per slot, or 99 individual coils, grouped and insulated in 33 cell coils, and 99 commutator bars. Fig. 8 may be used for a winding and connecting diagram. The coil pitch is 8, the sides of the first cell coil being placed in the bottom of slot *9* and the top of slot *1*, etc. The coils are all laid on in the usual manner, the nearer sides of the first 8 coils being placed at first temporarily in the tops of the first 8 slots, lifted when placing the 8 coils of the last division, and then permanently replaced.

CONNECTING

33. The bottom leads are connected first. The throw is made suitable for diagonal poles, 12 bars, or approximately one-eighth of the total number. Any lower lead, *b* for example, is first connected to bar *1*, the thirteenth from bar *b′*, and all other lower leads then connected in consecutive order. The pitch of the leads is $\frac{99-1}{2} = 49$. When the lower leads are all connected, any top lead, *a* for example, is connected to bar *50*, counting past the coil from bar *1*, to which the other lead *b* of the same coil is connected and all other top leads are connected symmetrically with the one thus placed.

LORAIN STEEL COMPANY'S NO. 18

WINDING

34. **The Lorain Steel Company's No. 18 motor armature** has 37 slots, 3 coils per slot, and 111 commutator bars. The 111 individual coils are grouped into 37 cell coils. The winding and connections are according to Fig. 7. The coil pitch is 9, and the coils are laid on the core in the usual manner, the first in slots *10* and *1*, the second in slots *11* and *2*, etc. The nearer sides of the 9 coils of the first division are not permanently placed until those of the last division are installed.

CONNECTING

35. The throw of the leads is suitable for diagonal poles, or 14 bars, and the connecting pitch is 55; the lower leads are connected first. Any lower lead, *b* for example, is connected to bar *1*, the fifteenth regarding bar *b'* as 1 and counting away from the coil *a b* to which lead *b* belongs; all other lower leads are then connected consecutively. Any top lead, *a* for example, is then connected to bar *56*, counting past the coil from bar *1*, to which the other lead *b* of the same coil is connected, and all top leads are connected symmetrically with the one thus located.

CHRISTENSEN AA1

WINDING

36. The **Christensen AA1 motors** are used to drive air compressors to supply air for brakes, or for cleaning, lifting, etc. The armature has 29 slots, 3 coils per slot, and 87 commutator bars. The 87 individual coils are grouped into 29 cell coils. The armature is much smaller than the usual railway-motor armature. The winding and connections are represented diagrammatically by Fig. 12. The coils are made so that, viewed from the lead end, the right side of each coil lies in the top of a slot and the left side in the bottom; hence, it will be easier to stand facing the side of the core with the commutator end to the left. The coil pitch is 7 and the first cell coil is placed with the farther side in the bottom of slot *8* and the nearer side temporarily in the top of slot *1*, the second coil in the bottom of slot *9* and the top of slot *2*, and so on around the core, lifting the sides of the seven coils of the first division from the tops of slots *1* to *7* while placing the coils of the last division, and then replacing permanently the lifted sides.

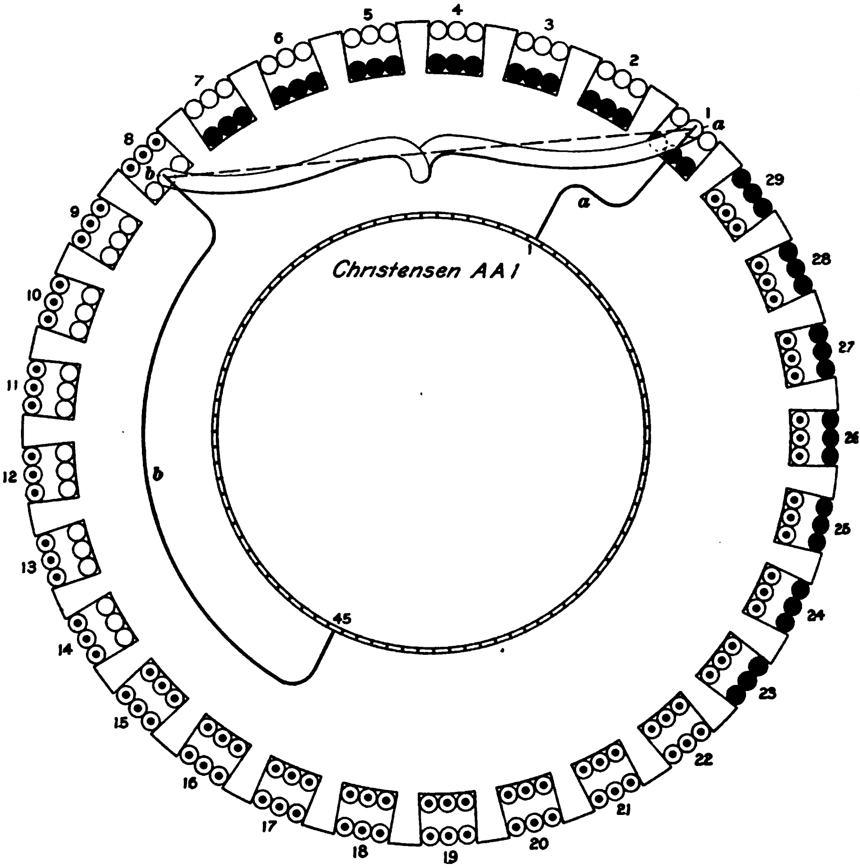


Fig. 12

CONNECTING

37. The poles are vertical and horizontal, but the commutator opening is slightly to one side of the top; hence, a little throw of leads is necessary. The connecting pitch in this case is $\frac{87+1}{2} = 44$. The bottom leads are connected first, but the throw is peculiar and is determined by locating a top lead first. Facing the commutator end, any top lead issuing from the center of a slot, and the bar directly opposite the center of the next slot toward the center of the coil are both marked, the lead by a kink and the bar by a slight scratch or a prick-punch mark; for example, lead *a* and bar *1* are marked. Lead *b*, of the same coil as lead *a*, is then connected to bar *45*, counting past the coil from bar *1*, and all bottom leads are then connected in regular order. The bottom leads being connected, the marked top lead is connected to the marked bar and all other top leads are then connected consecutively.

CHRISTENSEN B2 AND C3

WINDING

38. The **Christensen B2 and C3 air-compressor motors** are not of the same capacity, but the armature windings are so nearly alike that they can be described together. Each armature has 47 slots, 2 coils per slot, or 94 coils, but only 93 commutator bars; that is, one coil is idle, because an even number of coils cannot be series-connected for a four-pole machine. Fig. 13 is a diagram of the winding and connections. The coils are made as for the AA1 armature; that is, with the high side to the right when facing the lead end. The coil pitch is 11; and assuming that the winder faces the core with the commutator end at his left, the farther side of the first coil is placed in the bottom of slot *12* and the nearer side in the top of slot *1*. The other coils are all similarly laid, the divisions being distinguished in the usual way.

CONNECTING

39. The poles are vertical and horizontal, but the commutator opening is a little to one side of the top; hence, all leads have some throw. The leads of any coil, *c d* for example, are first found by test, cut off, and the projecting ends of the coil taped, leaving this coil idle. The remaining lead from the top of the slot containing a side of an idle coil, lead *a* in this case, as well as bar *1*, the fourth toward the center of coil *a b* from bar *a′*, are marked and lead *b* is then

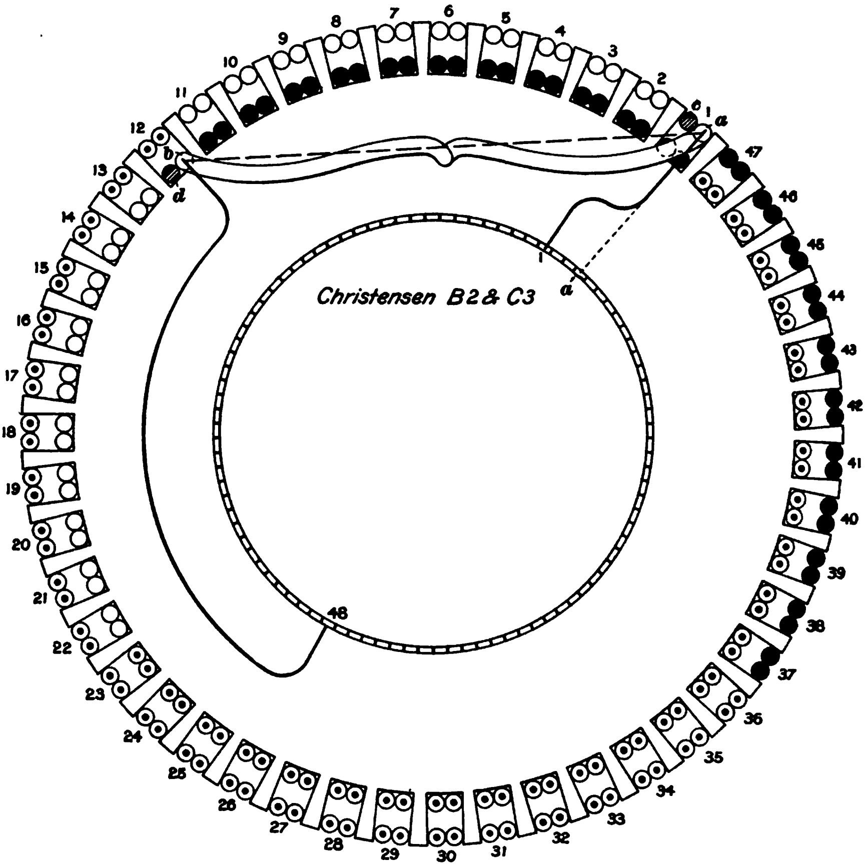


Fig. 18

connected to bar *48*, counting past the coil from bar *1*, making the pitch 47. All bottom leads are then connected

TABLE I

Motor		Armature Data					
		Number of Slots	Coils per Slot	Number of Commutator Bars	Coils Lie in Slots	Leads Connect to Bars	Throw of Leads
General Electric Co.	800	105	1	105	1-27	1-53	26
	1200	105	1	105	1-27	1-53	26
	50	105	1	105	1-27	1-53	26
	1000	93	1	93	1-24	1-47	12
	51A	37	3	111	1-10	1-56	14
	52	29	3	87	1- 8	1-44	11
	53	37	3	111	1-10	1-56	0
		33	3	99	1- 9	1-50	0
	54	29	4	115*	1- 8	1-58	14
	55	47	3	141	1-12	1-71	13
	57	37	3	111	1-10	1-56	14
		33	3	99	1- 9	1-50	12
	58	33	3	99	1- 9	1-50	12
	60	37	3	111	1-10	1-56	14
	61	41	3	123	1-11	1-62	15
	65	55	3	165	1-14	1-83	18
	66	39	5	195	1-10	1-98	16
	67	37	3	111	1-10	1-56	14
	70	37	3	111	1-10	1-56	15
	73	39	3	117	1-10	1-59	11
	74	39	3	117	1-10	1-59	15
	80	37	3	111	1-10	1-56	15
Steel Motor Co.	C and C3	99	1	99	1-26	1-50	0
Lorain Steel Co.	22 and 28	29	3	87	1- 8	1-44	11
	20 and 34	33	3	99	1- 9	1-50	12
	18	37	3	111	1-10	1-56	14
Christensen	AA1	29	3	87	1- 8	1-45	3
	B2 and C3	47	2	93*	1-12	1-48	3

*Armature has one idle coil.

symmetrically with lead *b*, after which the marked top lead *a* and the marked bar *1* are connected; this furnishes a guide for connecting all the other top leads.

ARMATURE-WINDING DATA

DIRECT-CURRENT RAILWAY MOTORS

40. The winding data given in Table I will be found useful for rewinding the most commonly used General Electric direct-current railway-motor armatures, as well as a few of those of other manufacturers. The column headings have the significations explained in the preceding pages.

The throw of leads is given in the number of bars between the bar directly opposite the slot from which the first lead to be connected issues and the bar to which the lead should connect. The throw is counted away from the coil, except in case of the G. E. 1000 and 51A and the Christensen motors, which are counted toward the coil.

MAINTENANCE OF EQUIPMENT

INTRODUCTION

1. The work of maintaining the equipment of a street-railway system is usually separated into two main branches or divisions: The system of inspection necessary to detect weaknesses before they reach a serious stage; and the systematic renewal or repair of parts that have deteriorated in the course of ordinary usage and wear, or as the result of misuse or accident.

2. On large electric-railway systems all inspections and all smaller repairs are usually made at depot shops provided with stores of the smaller repair parts. Heavy truck and body repairs are made in the main repair shop, which is equipped with facilities for handling such work. On small railway systems, the inspection and repair work is conducted from a centrally located combined shop and depot, in which all unused cars are housed, and from which all cars in commission operate. On such roads, the running time of cars usually allows a rest of several minutes at terminals, during which the operating parts most likely to become disordered may be inspected, either by the crew of the car or by an inspector stationed there for the purpose.

3. Terminal inspection is a most important feature of every thorough inspection system. A skilled inspector can, in a very few minutes, detect such things as loose brush holders, brushes stuck in the holders, weak brush-holder springs, loose gear-casing, hot bearings, loose or cracked motor suspensions, hot resistance coils, etc., any of which, if neglected, may cause more serious trouble. With efficient inspection, and with the proper minor repairs made before the trouble has progressed so far as to be serious, it is seldom necessary for a car to be thoroughly overhauled in the main repair shop, except at regular intervals.

STREET-RAILWAY REPAIR SHOPS

MAIN SHOP

4. The shop space in the main repair shop may be conveniently divided into several departments; namely, *pit shop*, *machine shop*, *winding room*, *controller benches*, *babbitting bench*, *blacksmith shop*, *carpenter shop*, *paint shop*, *curtain loft*, *register room*, *closets*, *lavatories*, *office*, and *storeroom*. In the main shop of a large system, each department may have a separate room; in smaller shops the working spaces may not be so definitely divided, but systematic and thorough supervision requires that the work of each class should be confined, as far as possible, in a space separate from that used for any other class of work. For example, the different classes of bench work, such as the repair of controllers, brush holders, fuse boxes, circuit-breakers, lightning arresters, resistances, registers, commutators, etc., should be kept apart by bench partitions. The bench bins devoted to the small repair parts of one equipment device should not be filled with a miscellaneous collection of repair parts belonging to other equipment devices. The promiscuous scattering about of repair parts should not be permitted. Suitable bins or receptacles should be arranged with a sufficient number of subdivisions, so that each part may have a definite place, in which it should invariably be found when wanted. Much valuable time can be saved by a systematic arrangement of repair parts.

5. The ideal disposition of shop space is that by which the various departments are so arranged that a car, on entering at one end of the shop, can pass through the several departments and leave at the other end ready for service without going back at any stage of its course. Two practical conditions, however, prevent the realization of this ideal. First, the cost of ground is usually so great that it is not practicable to spread out all the departments on one floor; second, in order to complete the work on a car in the least possible time, several of its parts must be repaired or replaced simultaneously. Again, most roads that employ both open and closed cars change from one to the other by changing car bodies only, the same trucks and motors being used in all seasons. The result is that all systematic painting and carpenter work is conducted on car bodies at the season of the year when they are not needed for service, and when, being without trucks, they must rest either on temporary trucks or stationary supports, thus making shop progression impractical.

PIT SHOP

6. The **pit** is an excavation between the rails of a length of track, provided for the inspection and repair of the running gear of cars from beneath. Short pits are desirable at terminals to facilitate the adjusting of brake riggings, feeling for hot boxes, and inspecting motor connections. The length of pit required in a main shop depends on the prevailing method of handling the motor parts. Some modern repair shops, instead of digging pits, elevate a stretch of their shop tracks, as shown in Fig. 1. This would seem to be the better practice, for it allows easy access, good light, etc.

7. Until the last few years, the most common practice was to conduct all inspections and make all renewals from underneath the car, and the motors were constructed accordingly; that is, the lower half of the shell of each motor, with or without the armature, could be lowered into the pit. A considerable pit length was then necessary to permit the proper inspections, adjustments, and renewals to be made. More recently, however, some large systems have adopted the practice of making inspections, renewals, etc. from above; that is, by running the trucks out from under the car and having the motor openings made on top. This practice permits the use of a shorter pit.

Inspection from the top offers the advantage of better light, which results in better inspection. If it were certain that after such an inspection, adjustment, and repair, a car would operate without a breakdown until time for it to be again thoroughly gone over, the advantages of the method would be unquestionable; but as cars only recently overhauled are almost as liable to some classes of trouble as are those nearly due for regular inspection, and as considerable time is required to raise a car body and run the trucks out, the advantage of inspecting from above is less pronounced. It seems doubtful that the advantage of the better light and

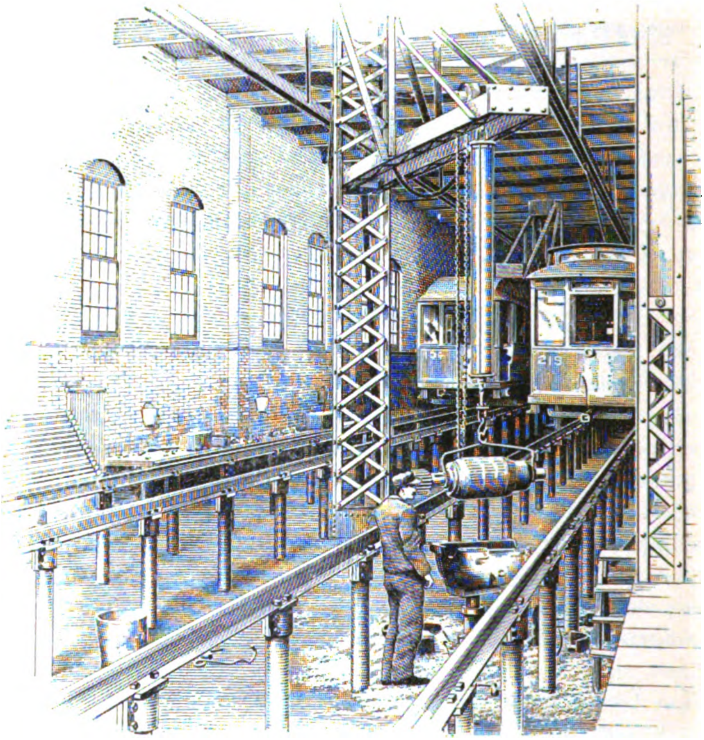


FIG. 1

better view of parts outweigh the advantage of being able to do in 10 minutes underneath a car at a depot a job that may require 2 hours if the trucks must be run out, or that possibly, if all car hoists are busy, may delay repairs for a day or more. The advantage of the saving in time is largely in favor of pit inspections, and if the pits are properly lighted, the view of the various parts from below is fairly good.

8. Pit work is one of the most responsible divisions of car work, because the failure of a defective part that the pitmen should have repaired or replaced may cause a most serious accident. Among the conditions absolutely necessary to reliable pit work are *good order*, *good light*, *good tools*, and *good men*.

9. Good Order.—In most cases, the general appearance of the pits will be a correct indication of the quality of the work done in them. Pits and their surroundings should be kept clean and orderly. To promote this as far as possible, the body, truck, and motors of each car that comes in for a complete overhauling should be cleaned before the car is run over the shop pits. All shop-pit floors should be cemented and sloped toward screened drains. No unused parts should be allowed to lie in the pits; if not needed for immediate use, they should be sent at once to the stock room, the repair shop, or the scrap heap, according to their condition. Dirty waste should be placed in cans provided for that purpose, and the cans should be emptied and cleaned at proper intervals by an employe appointed for that duty.

10. Good Light.—All pits should be provided with stationary side lights and with drop lights. These, in conjunction with the car lights, which shine down through the open trap doors, should provide sufficient illumination without the aid of daylight. The lamps used should be of high enough candlepower to give sufficient light; if the light from a series of 110-volt lamps across the trolley circuit is too yellow, substitute a series of 100-volt lamps. The general diffusion of the light is helped considerably by painting the pit walls white and cleaning or repainting them as soon as they become blackened by smoke or dirt. Also, the amount of light given from a clean lamp is much greater than that from a dirty one; therefore, keep the lamps clean.

If daylight is depended on, there should be an ample provision of large windows on all possible sides, and the glass should be kept clean. If the light must come through skylights, they should be so arranged that the glass can be conveniently cleaned at frequent intervals; only frequent cleanings will prevent the accumulation on shop lights and shop windows of a greasy film of dirt, which, unless removed, soon becomes baked on.

The temperature of the shop pits should be made comfortable for the workmen in cold weather; good work cannot be done continuously where the workman is uncomfortably cold.

11. Good Tools.—Too much cannot be said of the importance of providing each pit crew with a full complement of tools adapted to the work to be done. No two types of motors or equipments can be handled to the best advantage with exactly the same tools; and for handling each, the workman should have the proper shaped wrenches, chisels, screwdrivers, hammers, etc. Pitmen should be encouraged to study the details of their work with the object in view of determining the shapes or kinds of tools best adapted to perform the most troublesome operations and to suggest improvements in tools or methods employed.

12. On roads operating fifty cars or more, modern devicés should be provided for raising the car bodies from their trucks. The method of jacking and blocking not only takes time that might be more profitably devoted to other purposes, but it renders the equipment liable to abuse, and in many cases is actually dangerous. A simple and effective modern equipment for raising car bodies consists of five overhead chain hoists, running on three overhead rails. The two outer rails carry two hoists each, and are so placed that a hoist can be brought over each corner of the car.

Wooden skids with suitable eyebolts or links for receiving the hooks of the hoists are placed crosswise under each end of the car body and connected to the four hoists. The other rail carries a fifth chain hoist, to be used for handling the motor parts after the trucks are run out. Hoisting can be accomplished with only two chain hoists by raising and blocking each end alternately until the body is sufficiently high to clear the wheels.

Fig. 2 shows a car elevated on a pneumatic hoist consisting of two pair of air cylinders, the pistons of each pair supporting a cross-rail under the car body. Fig. 3 (*a*) shows the four air cylinders beneath the car floor and the air pipes leading to them. Compressed air is admitted under the pistons, one of which is shown at its lowest position in the sectional view (*b*), and when they are raised to the desired height they are held by pins *a*. Fig. 3 (*c*) also shows a section of a cylinder with the piston elevated. This device is more expensive than chain hoists, but car bodies can be hoisted by it so much quicker and easier that in large shops it will no doubt justify the extra cost.

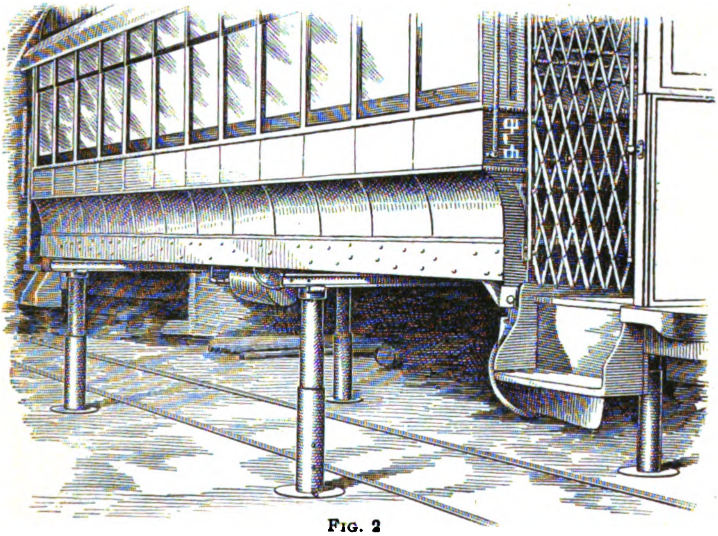


FIG. 2

13. After the car body has been raised, two men with pinch bars can sometimes move the trucks out into a working space, clear of the car body. Usually, however, it is necessary to get several men to help, or else to apply power to one of the motors on the truck. Calling other men from

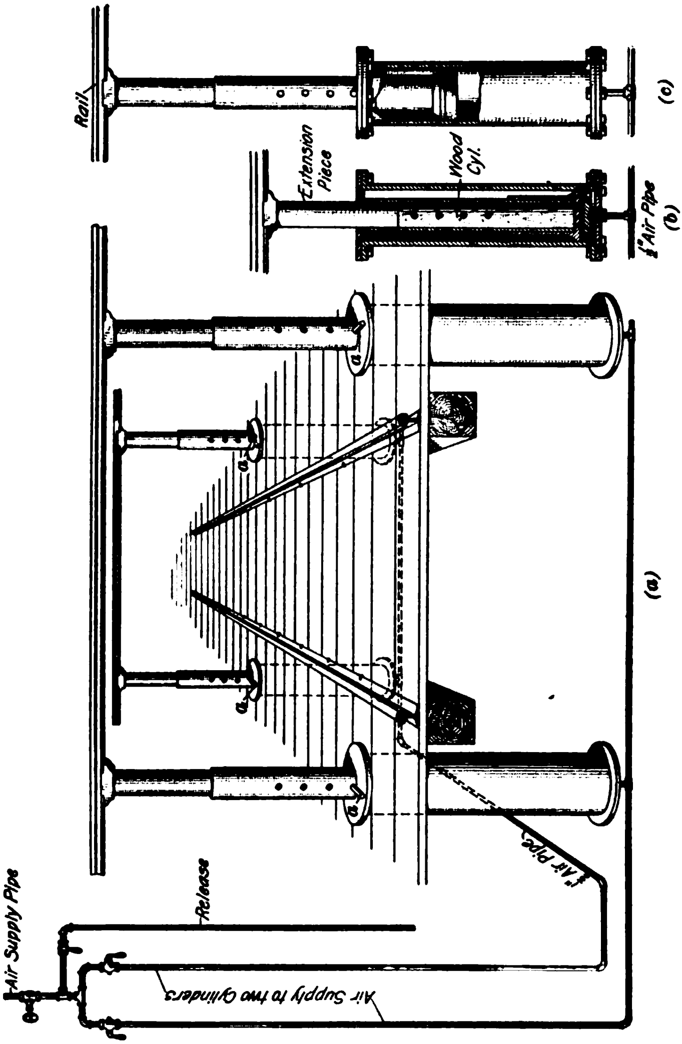


FIG. 8

their work to help move out the motor trucks is objectionable. One of the motors can be used by connecting one field terminal to an armature terminal, grounding the other field terminal and applying the trolley voltage to the remaining armature terminal. To avoid unnecessary danger of burning the operator, a resistance should be used in series between the trolley and the motor. There is little danger of burning, provided that the trucks move easily and start with little current; but if they start hard, the current will rise to such a value as to make the arc dangerous when the operator breaks the connection. In some shops, a special motor is installed for withdrawing car trucks by means of ropes and pulleys. Sometimes this may be done by running a rope from a crane motor around a pulley secured between the rails on which the truck rests.

14. Good Men.—Railroads have a hard time getting good men in the pits, because, with but few exceptions, the wages are too low to attract and hold good men. A good pitman is one that quickly recognizes a dangerous condition, that knows how to remedy it, and that will never turn in a car until he knows that the pit work has been properly done. A pitman of experience and of a mechanical turn of mind is of great value to a street-railway company. Many of the troubles from breakdowns may be traced to the employment of careless or incompetent men in the pits.

MACHINE SHOP

15. The size and scope of the **machine shop** required by an electric railway depends almost entirely on local conditions, among them being the number of cars operated, the extent of the repairs it is necessary to make, and on whether any manufacturing is to be done. The size and equipment of a railway repair shop and the force employed must be based on emergency work; that is, the shop must be prepared as nearly as possible to meet any emergency that may arise in connection with railway operation. For this reason, if the choice of tools is limited to a few, these should be selected for their adaptability to the widest possible range of work; for example, a useful shop equipment for a moderate-sized shop would consist of a speed lathe, a 10-inch engine lathe, a planer, a drill press, a power saw, an emery wheel, a grindstone, and several bench vices. It is now customary to install a wheel press, even in small shops, and if this is done a lathe for turning up axles and boring out wheels is desirable; in large shops, the wheels are bored in a boring mill. In addition to the machines just named, the largest railway shops have punch presses, turret lathes, special lathes, screw-cutting machines, slotting machines, shapers, bending machines, shears, milling machines, and insulating machines. The first list given would be a fair initial equipment for any electric-railway repair shop.

The advisability of any addition to the shop equipment may be determined by comparing the cost of having the work done elsewhere with what it will cost after purchasing the necessary machinery, allowing for the interest on the additional investment necessary and the yearly cost of keeping the additional equipment in good condition. A very important argument in favor of keeping a railway-shop equipment as full as possible is the greater certainty of keeping cars in operation. If the machine shop is not fully equipped, cars are sometimes kept out of service for want of machine parts that cannot be promptly obtained through outside channels. For example, during a shortage of rolling stock, eight or ten cars may be out of service, possibly for several days, for want of armature pinions, when if the shop had a gear-cutting machine, the pinions could be cut and the cars promptly sent out, thus putting them into service when most needed, increasing the revenues of the company and holding the good will of the people.

WINDING ROOM

16. The **winding-room space** is devoted principally to the winding and insulating of railway-motor field coils and the winding, insulating, and banding of railway-motor armatures. But other classes of work and winding are frequently done in it; for example, in the absence of a regular commutator department, the renewals and repairs of commutators are best done in the winding department; all winding repairs of power-station and substation apparatus, such as winding field coils and armature coils for generators, rotary converters, hoist and crane motors, transfer-table motor, and shop-tool motors, may be done either in the winding department or by a force detailed therefrom; blowout coils for controllers, coils for circuit-breakers and fuse boxes, resistance coils, etc. may also be wound here. The amount of such work depends on the size of the road and on the policy of the management—whether it is to keep all possible work in the shop or to send much of it outside to be done.

17. Armature Winding.—Armature winding for all modern railway motors consists of, at least, three distinct processes; namely, winding, insulating, and forming the coils, placing the coils on the cores, and making connections to the commutators. Formed coils ready to place on the cores can usually be purchased, either from the manufacturer who made the motor or from repair shops that make a specialty of railway-motor armature coils. Smaller railway companies purchase many of their armature coils ready formed, but the larger companies find it cheaper and more satisfactory to make their own coils. The subject of armature winding is treated with considerable detail in *Armature Repair Work*, Parts 1, 2, and 3.

18. The Winding Former.—The greatest difficulty to overcome in making the coils for an armature core is to make a coil former such that coils made from it will go into the core slots without distortion and occupy the least possible space on the ends, all without undue forcing. It is practically impossible to make such a former on the first trial, unless the drawings and specifications used by the concern where the armature was built are available. By using a perfect factory coil as a model from which to work, in conjunction with a core the teeth of which are in perfect alinement, and by working carefully and making frequent trials, a satisfactory former can be made. In making a former in this way, allowance must be made for the thickness of insulation, or else a coil wound on the new former and then insulated will be too small in every particular.

After a trial former is made, several coils should be wound on it and tried on the core; if they promise well, insulate them after the standard method in use and again try them on the core. It will usually be found that the first trial coils are too thick in some places and too thin in others, that some of the curves are not properly made, and possibly that the leads do not come out in exactly the right place. The trial former is then scraped, shaved, or padded by sticking on a wood or fiber lining, as the case may seem to require; and more coils are wound, insulated, and tried, and further changes made if necessary, until a satisfactory coil is produced. When wires are tightly wound around a bend, measures must be taken to hold them in place, or else, when the winding tension is removed, the curved part of the wires will spring out of place; this may be prevented by lapping and gumming a stiff-paper sheathing around both sides of the coil and holding this in several places by stiff metal **U**-shaped clips. Care must be taken that the final trial coils from which the shape of the former is determined are shaped to the former, insulated, pressed, etc. before being tried on the core prior to making the final changes in the former.

The completed coils can be placed on the core and connected by unskilled labor. In factories and large repair shops, boys and girls are employed, not only to wind and insulate, but also to place and connect the coils of small armatures; but in small shops, every man employed must have sufficient skill and experience to be able to do any kind of work that may come into the shop.

19. Armature Banding.—Only the best grade of band wire should be used in **armature banding**, and it should be put on under a uniform tension sufficient to keep the bands in place at all temperatures. If too loose, the bands will be thrown off when the armature is rotating; and if too tight, the excessive stress caused by the expansion of the core when it gets hot in service will break the band wire. In either case, loose or broken bands in the air gap will usually grind or cut through the insulation on the armature coils and cause grounds or short circuits.

The armature to be banded is rotated between lathe centers and the band wire wound on. In small shops, a windlass on the end of the shaft is turned by hand; in larger shops, the rotation is caused by a belted connection to the line shaft, or sometimes by a special motor connected to the lathe by belts or gears. The tension is made uniform by passing the band wire, just before it runs on to the core, through a tension regulator that may, if desired, be made to indicate the exact tension being used.

20. Commutator work is generally conducted in or near the armature department, on account of the convenience of having the armatures and commutators together; but the commutator space should be enclosed to protect it from the steel dust of grindstones and emery wheels, neither of which should be permitted inside the commutator room. Particles of metal getting into the shellac and between or under the bars in course of assembly pierce through the mica insulation when the commutator is pressed together and cause short circuits. The first step toward removing such short circuits from a completed commutator generally consists in trying to burn them out with current through a lamp circuit; if this method is not successful, the commutator must be taken apart.

21. Much skill is required to properly burn out a short circuit between commutator bars. A small particle of steel or copper may be embedded in the mica segment, possibly not far enough to cause a short circuit under the low voltage occurring between the bars when in service, but far enough so that if 500 volts is applied between the two bars, the current will break through the remaining insulation. An arc will then be started that will carbonize the surrounding insulation, thus wholly destroying its insulating qualities or leaving it so weakened that an early breakdown is almost sure to result. If more than one voltage is available, it is best to burn out the defect at as low a voltage as will drive the necessary current through it. If, when the 550-volt test terminals are applied to adjacent bars, the lamps glow at full brilliancy, the terminals should be left on but a very short time. A lower voltage should then be tried, or if none is available, it is usually best to take the commutator apart. A low voltage with several lamps in parallel will make it possible for a comparatively large current to flow with less danger from arcing.

22. Finished commutators must be carefully shielded from blows or bruises of any kind. Careless handling is responsible for many defects that are usually not noticed until it becomes necessary to undo a lot of work, or possibly until a serious breakdown has been caused. A place should be provided for storing all completed commutators as well as commutator parts where they will be safe from accidents and secure from thieves. Workmen are sometimes tempted to carry away copper parts and dispose of them for their own advantage.

23. Field Winding.—In a well-equipped repair shop, provision is made not only for rewinding and insulating motor field coils, but also for reinsulating the wire removed from old coils; this requires an insulating machine. There are two ways in which a railway-motor field may become disabled: it may be grounded, or the insulation on the wire may be so roasted by long use that it no longer insulates the turns from each other. In the first case, if the ground is on the outer surface of the coil, only the surface layers of the winding need be renewed; but if the ground is on the inner surface, next to the pole, all the wire must be taken off and the field rewound. If the insulation is still in good condition, the wire removed may be replaced without more change than that necessary to repair the part where the ground occurred.

24. In the case of a general roasting, however, all the field wire must be removed from the coil and cleaned of all insulation. If the insulation is not already so charred that it can be removed easily with a stiff brush, the coil should be placed in an oven and heated until the insulation becomes carbonized and powdery. If the field coil was wound on a machine, the wire, after being cleaned, is straightened, insulated, and either wound on to a reel to become a part of the regular wire stock, or wound directly into a field coil, thus saving time and labor; but if the coil is hand-formed of heavy wire and of comparatively few turns, the usual practice now is to reinsulate the wire without straightening it, every effort being made when removing the old insulation to preserve the bends intact.

25. The method of winding a field coil depends on whether it is composed of small wire, large wire, or ribbon. If composed of wire that is too small to be profitably or conveniently wound on by hand, a machine is used. A field-winding machine is simply a rotating shaft supported in bearings at a convenient height from the floor, and carrying a pulley at one end and the coil shell, or former, at the other end. The pulley is driven by a loose belt provided with a foot-operated idler, by means of which the belt can be tightened or loosened, and the shaft thus started and stopped. The reel containing the field wire is lined up on trunnions behind the field winding machine, and its rotation is impeded by the friction of a rope in a groove around one of the reel flanges, the tension on the rope being regulated by a weight or spring. As long as the winder keeps foot-pressure on the lever that actuates the idler, the belt engages the pulley, the field winding machine rotates, and wire is wound with the proper tension from the reel on to the former; on removing the foot-pressure, however, the belt slackens and the tension on the wire stops all rotation at once.

26. Some railway-motor fields are wound on brass or iron shells or bobbins, machined to fit suitable seats inside the motor frame; others have no such shells, and must be shaped on temporary metal or wooden formers, which are removed after winding, the field coil being held in shape temporarily by tying until it is firmly bound with insulating cloth. If field shells or spools are used, they are thoroughly insulated and dried until the insulation is hard enough to hold its shape under the tension of the wire. The flange insulation is cut with flaps that are folded over the top of the finished coil and sewed together. During the process of winding, the flaps are tied down outside of the flanges, so as to be out of the way, and the shell is bolted to the winding machine. Since both terminals of the completed coil must be on the surface, the first step in winding a coil is to solder to the inner end of the wire, or the end with which the winding is to begin, a terminal strip, which comes out along one side of the coil to the outside surface. Most shells have cast in one end flange a pocket, or wide shallow groove, through which a flat copper terminal strip can be brought out and insulated, so that it cannot easily short-circuit to turns of wire that are subsequently wound against it. After soldering the copper terminal on, it is put in place and insulated in a manner to be determined by experience or by inspecting an old field coil. The terminal is next securely tied, so that the tension of winding will not displace it, and winding is begun.

27. The tension required to get the proper number of turns into place is usually much greater than an inexperienced man would suppose it to be; the correct number of layers of wire and of turns per layer can be determined from an old coil, and each layer of the new coil should be made to contain the correct number of turns before proceeding with the next layer. If this rule is followed, the coil cannot come out far wrong; but even then, unless the layers are wound on each other with sufficient tension, there may not be room enough for the last one or two layers. The wires cannot be forced into position without a serious amount of pounding; but a careful, experienced winder with proper tools very seldom damages the insulation, even though he may seem to be doing so. The necessary pounding is done with a hammer and a piece of fiber, which should always be thicker than the diameter of the wire; the fiber should have rounded edges, so as to minimize the chances of cutting the insulation. The width of the fiber should be as great as can be handled conveniently, because great width presents great surface to the wire, distributes the force of the blows, and diminishes the likelihood of kinking the wire or gashing its insulation; a wider piece can be used on a coil of large diameter than on one of small diameter.

28. As each layer is installed, it is served with a coating of shellac, which lubricates the surface so that the wires of the succeeding layer can be more easily forced into position, and which dries and holds the wires more securely together. In some shops, instead of shellac, a sticky mixture of chalk and japan is liberally applied; when this mixture dries, the coil is a hard mass, as solid and compact as a brick, and is said to be mummified.

29. Machine winding on a former is very similar to winding on spools or bobbins, except that before the winding is begun four strong cords are inserted at the corners of the former; after the winding is completed, the cords are securely tied around the coil before the former is removed. The coil is thus held in shape until it is wrapped with tape, after which the cords are no longer necessary, and are removed. The former is so constructed as to give correct shape to the field coil, and is split so that the coil can be easily removed after completion.

30. Hand winding of field coils is now preferred in many cases to machine winding. When an old field coil is to be rewound by hand, the insulation is first carefully removed without springing the bends out of shape and the wire is reinsulated by winding on cotton or linen ribbon by hand. This work, in large shops, is advantageously done by girls, who can do it quicker and better than men, who are heavier handed. The coil can be rewound by one man, but a man and a helper are preferable. A winding former having but one flange is screwed, flange-end downwards, to a heavy stand, above which is suspended the old field coil, with a few of its turns hanging down like a corkscrew. The whole coil cannot be allowed to dangle from one end, because its weight would spring the turns out of shape and because the point of suspension would have to be too high; accordingly, most of the turns are tied together, only enough to form one layer of the winding being allowed to hang.

The former is of the same size and shape as the inside of the uninsulated coil. The first turn is laid on the former so as to bring the inside coil terminal in the same position that it occupies on a finished coil, and the other turns of the layer are successively placed in position. Enough turns may then be let down to fill the second layer; these may be recognized, because the corner bends will be a little more open than those of the first layer. This change in the size of the turns that constitute the respective layers, serves as a check to aid the winder to get the old turns on to the former in the same order and number that they had in the old coil. The successive turns and layers must be held after being placed, or they will spring out of place; two men can therefore work to better advantage than one, the helper following the operations of the winder and holding the turns in place until they are tied.

Where the wire from the last turn of one layer is brought to the first turn of the layer above, it must be tied down in position. After all turns have been placed, they are tied together, when the coil is ready to be insulated. Coil winding by hand is difficult until the winder has learned to lay the turns so that they do not tend to spring open.

31. The field coils of some of the large modern motors are wound with flat copper ribbon, wound on edge so as to increase their heat radiating qualities, the turns being insulated from each other with clear mica. So much force is required to bend the heavy copper ribbon used in some coils in the direction of its edge that the bends must be put in with a forming tool. After a field coil of this kind is wound, there is little danger of its getting seriously out of shape. If the field requires more turns than can be got into a single layer, two separate coils are wound, one being small enough to set inside of the other concentrically so as to form a two-layer coil. The two coils or layers are connected in series by soldering the proper ends together, and are insulated from each other by micanite or something equivalent.

32. Insulation of Field Coils.—There are many methods of insulating field coils, but all methods aim at the same results; namely, to protect the winding electrically and mechanically, and to make it waterproof. The severest test of the external insulation of a field coil is the presence of water in the motor. The motors are so exposed, being kept wet at times by the water or slush thrown on them by the car wheels, sometimes even being nearly submerged in water, that it is almost impossible to keep them dry inside. The presence of water around the field coils is very likely to cause grounds, but the danger of this can be considerably reduced by connecting the motor fields next to the ground, because the difference of potential between the ground and the positive end of the motor field is then only a few volts.

33. But even with the precautions just mentioned, it is necessary to render all field coils as nearly waterproof as possible. The general method of doing this consists in binding the coil with layers of linen tape, oiled linen, friction tape, friction cloth, and insulating compounds. The body of the coil is rendered practically waterproof by covering the outside of the insulated coil with a coat or two of an insulating compound that takes on a high glaze on cooling; but it is much more difficult to keep water from entering where the coil leads come out of the coil. The leads should always be brought out so that when the coil is in the motor there will be no pockets formed to hold water that may finally penetrate the coil; that is, all leads should point downwards.

The difficulty of waterproofing the coils at the places where the terminals leave is illustrated by the following experiment: Eight field coils were waterproofed, baked, and tested; they were then allowed to lie under water for a week, the insulation between the winding and the water being tested at frequent intervals, both when cold and after the coils had been heated by passing current through the windings: in all cases, the tests showed that the insulation was almost perfect. The coils were then taken out, thoroughly dried, put in motors, and installed on a car. The first time the car was run through a stretch of deeply flooded track, the water being 8 inches deep, two of the coils gave ground troubles where the leads came out. This may have been due to the cracking of the insulation near the terminals, caused by the continual shaking of the car, so that water entered.

34. Perhaps the most effective method of thoroughly waterproofing fields is a comparatively new one, known as the **vacuum treatment.** The field coil to be treated is placed in a reservoir, to which are connected a vacuum pump and a tank holding liquid insulating compound. Communication between the reservoir and the insulation tank is first cut off with a valve, and that between the reservoir and the vacuum pump is established by means of a second valve. The pump is then started and the air is exhausted from the reservoir, even the air within the pores of the field coils themselves coming out as the air around the coil becomes more rare. This action continues until the final result is to produce a vacuum both within and around the field coils.

Communication with the vacuum pump is then closed and the valve leading to the insulation compound is opened. The compound, impelled by atmospheric pressure, then rushes into the vacuum, thoroughly permeates every pore of the field coil, and effectively closes every opening through which water could enter. The treatment is then made still more effective by reversing the pump and forcing air into the reservoir until the fields are subjected to a pressure of 60 or 70 pounds per square inch.

CONTROLLER REPAIRS

35. On the smaller roads—roads operating from five to twelve cars—all **controller repairs,** except for a complete burn-out, are usually made without removing the controller from the car. On large roads, carrying heavy loads under short headway and using both open and closed cars, it is desirable at each yearly change of equipment to remove all controllers from the cars and to thoroughly overhaul them. A number of spare controllers should be kept available to take the place of any that must be removed for repairs. The following discussion assumes the necessity of a complete overhauling, which in many cases will not be required, and which can be modified to suit local conditions.

36. In overhauling a controller the first step is to open the controller and blow it out thoroughly, using a compressed-air blast, if possible, or a hand bellows. If any of the cars have air brakes, it is a simple matter to run a line of rubber hose from the controller bench to a pipe fitting attached to the car air-brake equipment and thus obtain an air blast. After a thorough blowing out, the internal appearance of the controller will be much improved. The water guard is now taken off and the top removed and, if necessary, cleaned, either by hand or by dipping in acid; after cleaning, it is given a coat of lacquer. The tops of controllers that are in continuous service are usually kept very clean by the rubbing received from the motorman's glove.

If the door has had any holes burned in it, it must be patched or replaced; if necessary, the door must be relined with asbestos. It is then hinged and fitted to the controller so perfectly that it may be easily opened and closed. After seeing that the fastenings are in perfect working order, the door is taken off, painted inside and out, numbered, and set aside to dry.

37. The drums are removed and cleaned, by scraping if necessary, and the scraped surfaces are then shellacked, care being taken that no shellac is left on any conducting surface.

The power drum is tested for looseness and, if loose, tightened, and all burned tips are renewed. In making minor repairs in depots, it is customary to reverse short tips; but in overhauling, it is better to renew them. The tips must be lined up as indicated in the connection diagram, prints of which should be obtained from the controller manufacturers. It is easy to aline controller tips if they are all punched exactly alike, as they should be, but with hand-made tips, alining is more difficult. The tape that is wound on the drum to minimize the likelihood of arcing between neighboring castings must be renewed and shellacked. After the drum is done, the tips are wiped off with vaseline, of which but very little is left adhering. All gumminess is cleaned off the index and its mechanism by rubbing with a cloth saturated with a light oil, such as kerosene.

38. If it is necessary to put a new lining in the controller back, both the finger and connecting boards are removed; the connecting board must be taken out in any case, so that the condition of the connections behind it may be inspected. The surfaces between the fingers of both finger boards must be thoroughly cleaned, either by the ordinary process of scraping, or, if the controllers are sufficient in number and if the proper facilities are at hand, by directing a high-speed sand blast on them. The sand blast can be easily arranged wherever compressed air is available. After cleaning the boards, they are given a coat of thick shellac that will glaze on drying. In order to improve appearances, all finger stands are sometimes removed and dipped in acid to clean and brighten them. All burnt, buckled, and worn fingers are replaced by new ones. The connecting board is thoroughly cleaned and, if necessary, its connections are resweated. If the board is in such a condition that it is not practical to use it again, a new factory-made board from stock must be used. The factory-made boards have all wires installed, and of the lengths necessary to reach their respective positions on the finger boards. The cut-out switches must be adjusted to work easily. If the magnetic blow-out coil is good enough to be used again, it should be cleaned and repainted; if not, a new one must be substituted.

39. In reassembling the parts after all have been thoroughly cleaned, the controller drum bearings should, if necessary, be babbitted to fit the shaft. After assembly, the connections must be tested to see that they are correct and are insulated from the frame. The action of the index and the interlocking devices must be satisfactory and the fingers must be again tested for alinement.

CIRCUIT-BREAKERS AND FUSE BOXES

40. Circuit-Breakers.—The **circuit-breakers** used in power houses and substations are stationary and sufficiently open to permit of their contacts being kept properly cleaned and in good condition; but the breakers used on cars are of the enclosed type, and are in a comparatively inaccessible place, where they cannot be given such attention. They are therefore periodically tested without removing them from the cars; if a breaker is found to be in need of repair, it is removed and sent to the shop to be overhauled, and a breaker known to be in good order is substituted. At the time of changing from summer to winter or from winter to summer cars, the circuit-breakers on the cars to be stored should be overhauled and adjusted.

41. In overhauling a circuit-breaker, any one or more of the following operations may be necessary: Remove all deposits caused by arcs; renew or trim the arcing contacts; renew the locking device for holding the breaker closed; renew the spring that opens the breaker or the spring by which the operation of the breaker is adjusted; renew the blow-out and operating coil. It is not probable that all these operations will ever be needed on the same breaker, but the condition of each part should be closely inspected and renewals or repairs made if necessary.

42. Perhaps the two most serious defects that may develop in a circuit-breaker are the failure of the locking device that holds the breaker closed, and the roasting of the operating coil. Either of these will render a circuit-breaker useless, for if it continually flies open, even when little current is flowing, it must be tied or otherwise fastened in a closed position, or else cut out of circuit before the car can proceed. If the operating coil is roasted, if the breaker handle is tied or if the breaker is cut out, the motors are no longer protected. Tying a breaker handle is sometimes resorted to by ignorant or careless motormen, but this usually results in further damage, either causing the operating coil of the breaker to be roasted or, perhaps, burning out a motor.

The operating coil in some circuit-breakers also acts as the blow-out coil, and if it is roasted, not only is a greater current necessary to open the breaker, but the ability of the coil to promptly extinguish the arc is much decreased.

43. After being overhauled and repaired, each circuit-breaker should be thoroughly tested, as already explained, before being turned into the storeroom. If, when the breaker operates at the proper current, the sighting plate shows nearly the right indication, the conditions are good; but if the indication of the sighting plate is very different from the current required to operate the breaker, as indicated by an ammeter in the circuit, something is wrong. The operating coil may be roasted or otherwise short-circuited, or it may be wound with the wrong size of wire; the tension spring may not have the proper strength; or the armature may be stuck, or sluggish in action. Inspection will show what is wrong and the necessary corrections should be made.

44. Fuse Boxes.—Fuse boxes, if properly handled, seldom cause trouble; but if, in place of a blown fuse, a piece of wire is substituted, some portion of the equipment that the fuse is intended to protect may be burned out or, on account of the difficulty in securely clamping the wire under the screws for holding the fuse, the wire may work loose and thus cause destructive arcing. An arc in a fuse box usually destroys the fuse terminals, and these are the parts that most frequently need repair. Fuses with magnetic blow-out coils are not only liable to have their terminals burned, but also to have their blow-out coils short-circuited. These blow-out coils are generally wound with bare, flat copper, and insulated with clear mica. They will last a long time, even with seyere abuse; but excessive heat, caused by constant overload, will, in time, disintegrate the mica and allow the turns to short-circuit. The coil then ceases to promptly extinguish the arc when the fuse blows, and the accompanying demonstration is likely not only to destroy the fuse-box terminals, but also to alarm the passengers. The blow-out coils of such fuse boxes have been known to burn out as a result of gradually increasing the size of the equipment to be protected, and hence of the fuse, without increasing the current-carrying capacity of the embedded blow-out coil.

RESISTANCE COILS

45. The repair of a grid-type resistance coil consists merely in taking out a bent, burnt, or broken grid and putting in a new one. The main points to be observed in overhauling are to get the terminals back into their correct relations and to get the coil compactly screwed together after assembly.

BABBITTING

46. When it is necessary to renew worn bearing linings, the old bearing metal is all cut out of the journal-box, and the journal or a mandrel about the size of the journal is placed in the box and lined up to the position it should occupy; all openings into the box, except those through which the metal is to be poured and those for vents, are plugged with clay or putty, and the melted metal is poured in. Fig. 4 shows a mandrel that may be used for babbitting boxes with machined ends. The mandrel consists of a cylinder *a* of the required diameter and length, with a disk *b* at each end to fit against the machined ends of the box. One disk is held in place by a capscrew *c* and is removable. The mandrel is put in position in the box and a liner *d* of pasteboard or sheet iron is placed against each side of it and the cap bolted on. The melted bearing metal enters from above the cylinder, through the oil holes or slot in the cap, and passes through the notches *e* in the side linings *d* to fill the space under the mandrel. The two parts of the bearing are separated by driving a wedge under the cap. If a solid sleeve bearing is required, the linings *d* are omitted, the mandrel being inserted and removed endwise from the box by removing the disk on one end. Wooden mandrels are sometimes used. Iron mandrels should be warmed before pouring the metal. The clay or putty used for plugging the openings must not contain too much water, as steam will be generated and the metal blown out; ample vents must also be provided for the escape of heated air from the inside. The metal should be poured at as low a heat as possible and as rapidly as possible, pouring from two or more ladles if the bearing is a large one. The surface of the mandrel or journal, as the case may be, should be covered with a film of oil; if a journal is used, it is sometimes covered with thin paper.

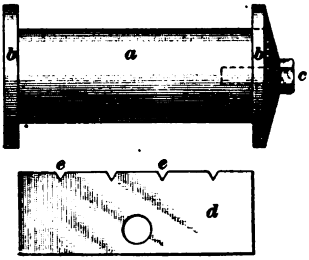


FIG. 4

47. It pays to use only a good grade of bearing metal; cheap substitutes require more attention and cause more trouble, and hence are more expensive in the end. There are many grades of metal, and the exact one to be used depends on conditions of service, and is best determined by experiment. For heavy motors, a strong, hard grade of genuine Babbitt metal must be used; for smaller motors, softer metals sometimes give good results. For melting the metal, no more heat should be used than is necessary; high temperatures may injure its quality. The hot metal should not be exposed to the air longer than is necessary, because some of its ingredients will entirely disappear, thus causing the metal to loose its life, or wearing qualities. The same metal can be used many times, and by marking each bearing when cast, and by trying different grades of metal, the number of times a metal may be cast, as well as the best metal to be used, can soon be determined. When a grade of metal has been selected, it is best to use for each melting about two-thirds old metal and one-third new metal.

48. The bearing may be cast the exact size required, or it may be cast small and bored out to size; as little turning as possible should be done, as a cast surface is slightly chilled and gives longer life than a turned surface. For this reason some companies cast all their bearings to exact size; this requires skilled workmanship. If the babbitted bearing is to be bored out, the work must be very carefully done; the bearing must be accurately centered and alined, and must be bored to make an accurate fit on the journal. The lathe should, if practical, be provided with a self-centering device. The air gap of most motors is small, sometimes less than $\frac{1}{8}$ inch, and if the bearings are not accurately centered, the armature core may rub against the pole pieces. The centers of the bearings are sometimes bored or cast a trifle above the exact center line of the pole-face circle, as most of the wear is downwards. The end flanges must be of proper thickness to insure the correct end play of the armature, and the oil grooves must be properly cut, or the bearing will not get sufficient lubrication and will run hot in service. All journals and bearings, so far as possible, should be kept to a standard size; it is often necessary, however, to turn a worn journal down to a smaller diameter; in which case a special bearing is required. Special bearings are likely to cause trouble and delays, for it is not practical to carry a reserve supply in stock, and when a new bearing is needed it must be specially made.

THE BLACKSMITH SHOP

49. The **blacksmith shop** of an electric-railway repair shop is usually equipped not only to do work necessary to keep the rolling stock in repair, but also to repair apparatus in the power house and to make repairs or new parts for linework and trackwork. The work involved in rolling-stock repairs is to make, mend, or patch any of the wrought-iron or steel rods, chains, braces, angle irons, springs, etc. used about the cars, as well as to forge pieces to take the place of broken castings when new ones cannot be obtained promptly; to make and temper shop tools, forge mandrels for babbitting bearings, shoe the company's horses, and keep the company's wagons, towers, etc. in repair. Except on the smallest roads, where all heavy work is done outside and the remaining work on hand forges, the variety of work is such that the services of a good mechanic are required, and in many cases some outlay for power tools is warranted.

50. The forge-room fans, if motor-driven, should have an independent motor, so that the forges will not be affected by shut-downs in other parts of the shop. The forge room must be effectively separated from the paint shop, so that newly varnished cars will not be subjected to smoke and sulphur fumes. The racks for holding stock must be conveniently located; so also must the coal and water supply. Most blacksmiths prefer a dirt floor to a cement floor.

51. The output of a large- or medium-sized blacksmith shop is considerably increased by the installation of a power hammer for heavy forging and power shears for trimming and cutting off stock. There should be at least a hand-drill press; if there is very much drilling to be done, a power-drill press is much better. When a large number of pieces of intricate or exact shape are to be bent, it generally pays well to make forming tools for bending them. The blacksmith should work to drawings, even if he has to make rough drawings himself. The drawing should be marked for identification and put on file for future reference. This precaution may often save time and labor if duplicate parts are wanted, especially for work that is to be installed some distance from the shop.

THE CARPENTER SHOP

52. A complete wood-working shop for railway-repair purposes contains horizontal and vertical planers, cross-cut, rip, and hand saws; mortising and molding machines, gang drills, and various devices for bending panels and bonnets. A small road does not require any of these power devices, as there are not enough pieces of any one kind to be made to warrant the purchase of machines for making them. The few repairs to the woodwork can be made by hand, or new parts can be obtained from the car builders.

THE CURTAIN LOFT

53. Car curtains, rollers, latches, guide wires, etc. occasionally get out of order, and their repair or renewal, on large systems, is looked after from a separate room designated as the **curtain loft.** Every summer, while the winter cars are stored, and every winter while the summer cars are stored, the curtain men must examine the curtains on each car, repairing slight defects, and putting in new curtains, rollers, latches, springs, etc. wherever required. As soon as the curtains of any car look old or patched, a new set is substituted, and the old ones used for isolated renewals or repairs on other cars. The repair of straps and other leather fixtures is usually a part of the duties of the curtain-repair department.

THE REGISTER ROOM

54. On the largest street-railway systems, an especially skilled workman is employed to keep the registers in repair. The mechanism of a register is somewhat delicate, and none but a good mechanic should be allowed to attempt to repair it. He should be strictly honest also, as it is within his power, by tampering with the registers in collusion with dishonest conductors, to defraud the company.

THE WHEEL-GRINDING PIT

55. With high speeds and quick starts and stops, flat wheels are soon developed. A flat spot, too small to cause noticeable pounding on the street tracks, becomes noticeable in effect when the car crosses a bridge. Slight flat spots are often ground out by the brake shoes in normal operation.

56. To increase the grinding effect of the brakes, the **wheel-turning brake shoe** has been invented. This consists of metal shells filled in with some abrasive material that bears against the wheel during applications of the brake and grinds the circumference of the wheel until any flat spot is ground out. When the least indication of flatness is observed, a pair of wheel-turning shoes is substituted for the regular brake shoes, and by the time the car has made a trip or two the flats will have disappeared, unless the treatment has been deferred too long. The flat spot must be shorter than the length of the shoe, otherwise the shoe will follow the contour of the flattened area.

57. If the trouble from flat wheels warrants such an outlay, a wheel-grinding machine is installed. These machines are of two types: one type requires that the wheels to be ground should be removed from the car, and the other type does not. The first type is much cheaper in first cost and can do satisfactory work. It is doubtless the better one for roads having but few cars and where grinding the wheels is seldom necessary; but its use is accompanied by so much expense in removing and replacing the wheels each time grinding is necessary that if much work of a like nature is to be done it will be better to use a machine of the second type.

A grinder of the second type is set up over the pit so that its adjustable centers are on opposite sides of the track. The car is run over the pit until the axle of the wheels to be ground is in line with the centers, and is then jacked up bodily. The centers are run into the center holes in the ends of the axle, which is then lowered until its weight, including that of its two wheels that are clear of the track, rests on the grinding centers. Jacks are used to relieve the grinding centers of all weight except that of the axle and its wheels. All the car motors but one on this axle are then cut out of circuit in the controller, and the one remaining motor is driven by line power. An adjustable water resistance is connected in the circuit, so that the axle of the wheels being ground can be rotated very slowly. The grinding wheels, which are mounted on a movable frame and driven by a separate motor, are then started and fed in to take a light cut across the treads of the wheels. If the car has been brought in promptly, a half-dozen light cuts should remove the flats.

As to the relative directions of rotation of the car wheels and the grinding wheels, it probably matters very little whether they are the same or opposed, the most important point being the relative speeds of the two surfaces in contact, that is, the speed of grinding. This depends largely on the quality of the grinding wheel and on that of the car wheel to be ground. The maximum speed at which the grinding wheel should be run is marked on the wheel. The quality of the grinding wheel also depends on that of the car wheel to be ground. A grinding wheel that will grind a chilled-steel car wheel, for example, may be entirely unsuitable for a soft-steel tire. Grinding-wheel manufacturers are prepared to ship wheels adapted to all prominent makes of car wheels.

58. Time can be saved by running the car over the grinder before the flats get deep; also, by installing motor-driven screws or compressed-air jacks to do all lifting. There should be track interferences to stop each length of truck at the point of alinement on the grinder. Both wheels of a pair should be ground to the same size, if practicable; but if the two wheels are of widely different diameters, it will not pay to grind the larger wheel down to the size of the smaller wheel. If the axle of the wheels to be ground cannot be driven by its car motor, one grinding wheel may sometimes be used for turning the axle by friction between the grinding wheel and one car wheel while the other car wheel is being ground.

CAR PAINTING

59. Exterior Painting.—The **primer-filler-and-surfacer method** of painting passenger-car bodies is merely the process of applying ready-mixed preparations according to instructions furnished by the paint manufacturers. Many shop managers prefer this method, asserting that it is just as durable as the older method of lead-and-oil painting and more uniform in result, as well as cleaner and cheaper. The process of painting new car bodies by this method is as follows:

1. Apply a coat of a preparation known as *primer* and allow it to dry 36 hours.
2. Spread, or putty, on with a wide-bladed putty knife a coat of *filler* and allow it to dry 24 hours.
3. Apply three coats of *surfacer*, or *rough stuff*, composed of about one-third coach japan and two-thirds rubbing varnish, allowing each coat about 24 hours to dry.
4. Apply a *guide coat* of colored material, usually coach black, and 1 hour after the application rub it all off with pumice stone and water and finish with No. 0 sandpaper. The colored material merely serves as a guide for the amount of rubbing necessary, as no more rubbing should be done than is necessary to remove the color.
5. When the surface is again dry, usually 5 or 6 hours after the rubbing, apply one or more coats of the final *color* desired. Mix the selected color—Tuscan, Indian red, blue, or green, as the case may be—to a working consistency with turpentine, and to each 25 pounds of the mixture add about 1 quart of rubbing varnish. If colors containing white lead are used, omit the varnish, but add instead 1 pint of coach japan.
6. When the last coat of color has dried, usually in 5 or 6 hours, *letter and stripe* the car and allow it to dry about 24 hours.
7. Apply a coat of *rubbing varnish*, followed within from 24 to 36 hours with another coat of half-rubbing and half-finishing varnish, and allow it to dry 36 hours.

8. Rub thoroughly with pumice stone and water, using curled hair or rubbing felt, and then wash the surface off clean with clear water and wipe dry with chamois skin.

9. When the surface is perfectly dry, apply a coat of outside *finishing varnish;* when this is dry and hard, the car may leave the paint shop.

If the car body is an old one from which the paint has been burned off, the first coat applied should consist of one-third primer and two-thirds filler, instead of being all primer. The primer consists largely of oil, and an old car body will not absorb as much oil as a new one.

60. The process of painting a car body by the **lead-and-oil method** involves practically the same steps as the method just described, although the composition of the various substances applied is somewhat different. The process is as follows:

1. Apply a coat of primer, consisting of lead mixed to a suitable consistency with one-half raw linseed oil and one-half turpentine, and containing 1 pint of coach japan to each gallon of the mixture; allow this coat to dry 36 hours.

2. Apply a second coat of the same mixture, except that turpentine only is used for thinning it; allow this coat to dry for 24 hours and then smooth all uneven and rough places with putty.

3. Apply a third coat of the same kind as the second, and allow it to dry 24 hours.

4. Apply three coats of rough stuff, allowing each to stand 24 hours, or more if necessary, to get thoroughly dry.

5. Apply the guide coat, and after about 1 hour rub it all off with pumice stone and water, finishing with No. 0 sand-paper.

6. When the surface is thoroughly dry, apply a coat of body color, followed, when the first coat is hard, by a second coat, if necessary.

7. Letter and stripe the car and allow 24 hours for drying.

8. Apply a coat of rubbing varnish, followed in 24 hours by a coat of half-rubbing and half-finishing varnish, and allow 36 hours for drying.

9. Rub the surface down smooth with pumice stone and water, applied with curled hair or rubbing felt; wash clean with clear water, and wipe dry with chamois skin.

10. When perfectly dry, apply a coat of finishing varnish, and when this is dry, the process is complete.

61. Interior Painting.—The interior of a new passenger car is painted as follows: After cleaning off all finger marks with No. 0 sandpaper, apply a coat of wood filler of the exact shade of the wood to be finished, or possibly a trifle darker, as the filler may turn a shade lighter in drying. The body of the filler is usually linseed oil and corn starch, mixed to about the consistency of putty. Before applying, thin the mixture with turpentine and add ½ pint of raw oil to 1 gallon of filler. After applying the coat of filler and rubbing off all surplus from the surface, let the car stand, say, 24 hours, and then apply one or two coats of shellac, white shellac being used on inlaid wood. When the shellac is perfectly hard, apply one coat of inside rubbing varnish and allow it to stand from 24 to 36 hours. Rub lightly with No. 0 sandpaper, apply a second coat of inside rubbing varnish, and when this is hard, rub again with sandpaper, as before. If the final surface is to be rubbed, apply a third and last coat of inside rubbing varnish; but if the work is to be left in the gloss, complete by applying a coat of inside finishing varnish instead. For rubbing new work, water and pumice stone are better than oil and pumice stone; but when the rubbing is finished, the surface must be oiled with a mixture of one-half sweet oil and one-half raw oil, and then rubbed off with cheese cloth. For rubbing old work, use crude oil and pumice stone, as it saves the expense of oiling after rubbing. If time is no object, instead of using shellac over the filler, use the same number of coats of rubbing varnish, as the surface thereby produced is much more durable.

RECORD OF WORK

62. In factories, machine shops, etc., workmen are paid by the day or week and are known as time workers or *day workers;* or they are paid only for the amount of work done or the number of pieces completed; in the latter case they are known as *piece workers.* The work of a railway repair shop is usually so varied and so distributed among piece workers and day workers, that it is difficult to keep an accurate account of labor costs. In looking after piece workers, precautions must be taken to prevent the same piece of work being turned in twice, either by mistake or design. On payday, each man should be paid for all work done during the time covered by that pay. If during that time a man has done a considerable amount of work on a certain job, but has not completed it, an estimate of the amount of work done should be made and the workman paid for it. An unmistakable record must be made of this transaction, so that both the man and the company may receive proper credit on the remainder of the job when it is completed. If no piece work is paid for until the pay day following its completion, there is some inducement for an operator to rush his work to completion and possibly to slight it in order to catch an earlier pay.

63. All completed work should, if possible, be placed in a storeroom or in charge of a trustworthy storekeeper, where it will not be accessible to those who worked on it. Dishonest workmen or their foremen frequently seize opportunities to charge the same work more than once, sometimes receiving pay several times for the same job.

64. Among the objections to the employment of day workers is that of getting them to charge to each individual piece of work, the actual time spent on it. Rather than take the trouble to do this, a workman whose time is divided between several different jobs during a day usually guesses the time spent on each as well as he can remember it at the end of the day. Moreover, a day worker is usually ready to help piece workers at every opportunity while charging his time to day work. The remedy for these difficulties is to have all work possible done on the piece-work plan.

65. Each workman, as a rule, in addition to making out his time on the time card, keeps a copy of it in a book of his own. He also keeps a record of the amount of his overtime, as well as the reasons for it. This private record is useful for comparison with the timekeeper's record, should the two records disagree. Besides itemizing the distribution and cost of his time each day on his time card, in many shops it is customary to require each man to write on the back of his card the total amount of money due him. If this does not agree with the timekeeper's total, a consultation is held before any changes are made in either record.

THE STOREROOM

66. The **storeroom** is a very important department of a railway repair shop, and on the storekeeper rests no little responsibility. The most important of his duties are to deliver goods on properly signed shop requisitions and to keep up the stock and provide for its care and orderly arrangement, at the same time avoiding the accumulation of too much stock. When changes in equipment are contemplated, the storekeeper should be notified, so that he may avoid ordering more than is immediately necessary of repair parts for devices that are soon to be discarded.

The demands on the storeroom of a railway repair shop are so erratic that it is very difficult to avoid getting overstocked with some parts. For example, a heavy demand for wire of a certain size or for repair parts of a given kind may suddenly arise and continue for some time. If the storekeeper orders accordingly, and the demand ceases as suddenly as it commenced, there may be left an overstock of material for which there may never be any call and for which the storekeeper must explain to the accounting department. On the other hand, if the stock of repair parts runs out, shop work will be delayed and criticism will again fall on the storekeeper.

Large railway systems employ a method of keeping down stock that involves the least likelihood of delaying work and leaves the least possible amount of responsibility on the storekeeper. By this method, stock is ordered ahead for specified lengths of time and in amounts estimated by the heads of the various departments that use the stock. These heads of departments base their estimates on past experience; but even this, while better than a storekeeper's estimates, often leads to unsatisfactory results. Provision should always be made for contingencies that may arise.

67. Above all things, in a railway repair-shop storeroom everything should be methodically arranged. There should be a place for everything, and everything should be kept in its place. Nothing should leave the storeroom without an authoritative order, to be held as a receipt, and the storekeeper should sign for no delivery until it is ascertained that the various items for which he signs have been received. If the purchasing and delivering branches of the store department are maintained separately, the storekeeper should be provided with copies of all orders, so that he may check off the items as the goods arrive and thereby know when the orders are properly filled. The storekeeper should have a list of the items for which the heads of departments are actually waiting, and should promptly notify each head whenever anything for which he is waiting arrives. Failure to do this systematically results in expensive shop delays, work being held up for several days after the needed parts have arrived in the storeroom.

So far as possible, all persons except storeroom employes should be excluded from the storeroom; storeroom employes can be held responsible for the goods under their charge only when they are the only ones that have access to them. Even with every precaution possible, it is still necessary to take frequent inventories to keep track of the stock; without these, the seemingly unavoidable leakages make it impossible to make stock records agree with the actual stock on hand.

LAVATORIES, CLOSETS, ETC.

68. The appointments necessary to promote order and cleanliness, in regard to both men and tools, should be as complete as practicable, and the men should be offered inducements to keep themselves and their surroundings clean. No single condition more favorably impresses a critical observer than a condition of cleanliness in the men and their surroundings. Suitable wash rooms, provided with hot and cold water and with absorbents for removing grease, should be available; and the practice of removing grease with benzine or gasoline should be discouraged, as it may lead to a fire. An abundance of good soap should be provided, either in solid, liquid, or powdered form; if in solid form, some arrangement should be made to hold each man responsible for his portion, otherwise too much soap will be carried away.

DEPOT SHOPS

OPERATING INSPECTIONS

69. Depot work may be divided into two classes—*operating inspections* and *overhauling*. The work is necessarily the same as some of the work done in the main shop, which has already been described, though there may be differences in the way some of it is done. The term **operating inspection** refers to the daily inspection of equipment, for the purpose of correcting any condition likely to cause trouble. This inspection may be divided into *electrical inspection* and *mechanical inspection*. The two are so closely allied that they are made at the same time and by the same inspector.

70. Inspection is usually made after the car has been run into the house for the night; but to secure the best results it should be made while the car is in service, by inspectors stationed at the terminals.

A fairly good car inspection can be made during a 5-minute wait at a terminal, especially if a pit is provided to permit the inspector to get under the car. The condition of each part should be observed, and any slight changes or repairs necessary should be made at once; if conditions are serious enough, they should be reported for more extensive repairs.

71. The **trolley** should have no loose trunk-wire connections; the pole should not be bent or loose; the wheel should be in good condition, and there should be no connecting parts missing or burnt off; the trolley pole should turn easily on the spring base pivot, so that the wheel will follow the wire when the car is rounding curves; the tension springs holding the wheel against the wire should be in proper adjustment.

72. The **safety devices,** consisting of the circuit-breakers and fuse boxes, should have careful attention. The breakers should open promptly on pressing the hand push button, and should remain closed when closed by hand; the roof-wire connections should be secure; the breaker should not show evidence of excessive burning, and the adjusting spring should be in good condition and free from any indication of having been tampered with. The fuse should be of the proper size and properly installed, with the terminals firm and the trunk connections secure. The area surrounding the fuse should be free from deposits of copper or carbon that will conduct current.

73. Controllers.—Good and frequent controller inspection, with occasional slight repairs, will, as a rule, render it unnecessary to bring the controllers into the repair shop, except in cases of accident. Controllers are subjected to very severe duty, and unless kept in good condition serious trouble is likely to develop at any moment.

It is well to be systematic in making inspections, and therefore the following order is suggested:

1. The drums should turn without unusual effort; the indexing mechanism should act promptly and with precision, and the point on the end of the handle should correctly indicate the notch on which the drum rests. If action is

stiff, oil the drum-shaft bearings, grease the index wheel, and wipe a little vaseline over the drum contact rings, or adjust the finger tension. Failure to correctly indicate the position of the controller cylinder may be caused by wear of the handle or shaft, and may result in operating the drum between notches, which will cause arcing between the fingers and tips and possibly destroy the controller.

2. The surfaces between fingers on both drum finger boards should be very nearly free from carbon or copper deposits, the arc guards between fingers should be clean and free from carbonization, and the asbestos door lining clean and free from holes. All controllers should be thoroughly blown out, at least once a day, with an air blast; deposits between the controller fingers may at any moment start an arc between adjacent fingers and thus burn out the controller.

3. All finger-tension adjusting screws should be properly set, the fingers should have the correct alinement, there should be no bent or buckled fingers, and the contacts between the fingers and the drum tips should be good. With frequent controller inspection, the tension adjusting screws may be set so that each finger will rise $\frac{1}{32}$ inch when it rides up on a drum tip; but if the inspections are not more frequent than once a week, the rise should be made $\frac{3}{32}$ inch. The lesser rise makes lighter contact of the fingers, thus permitting the drum to turn more easily, and the centralizing tendency of the index springs to act more readily. With light contact and a clean drum, all General Electric controllers notch up with a musical click, and it is practically impossible to make the fingers rest between notches.

4. All fingers that are intended to go into or out of action on the same notch, especially those that are active on the first notch, should be so alined as to make and break contact exactly together, otherwise the fingers last to break contact will have unusually heavy duty to perform and will be burned and blistered.

5. Fingers and drum tips must be kept free from blisters, for not only do the blisters cause poor contact to be made, but they may catch when the fingers slide on to the drum

tips and cause the fingers to buckle or bend. Poor contact between fingers and tips causes arcing, which may become so bad as to cause a complete burn-out. The first symptom of poor contacts is a scratched appearance on certain drum tips, caused by the roughness of the finger tips. If this condition is neglected, the contacts will soon become so bad that not only will a sizzling noise be heard in the controller when the defective contacts are operative, but a vibrating effect also will be distinctly felt in the controller handle.

6. It should be seen that the motor cut-out switches are in good working order, and that there are no loose car wires in the controller connecting board. The cut-out switches should work firmly enough to prevent their jarring down when in their upper position, and also freely enough to be thrown by hand without the aid of any tools.

7. The car wires sometimes come loose from the connecting-board posts and thus cause open circuits and arcs. The connections should be made secure and the cause of their working loose ascertained and removed, if possible.

74. Car Motors and Connections.—The most important feature in inspecting car motors in operation is that of seeing that everything about the brushes and brush holders is in good order and that there are no motor terminals loose or likely to become grounded.

1. Feel the brushes to see that all have freedom of movement in the brush holder; try the tension to see that it is sufficient and be certain that the spring hammer rests on the brush. In installing a new brush, both ends should be tried in the holder to make sure that both have the correct thickness; otherwise, a wedge-shaped brush may be unwittingly installed, which will, as soon as it wears down a little, stick in the holder and make trouble. A new brush should not fit the holder snugly, but should have about $\frac{1}{64}$ inch clearance to allow for swelling, running paraffin, etc.

2. See that the brush holders are firmly in place and that no holder is so far from the commutator that the brushes can

change their set when the direction of rotation of the armature reverses, nor so near to the commutator as to rub it. See that the end play of the armature is not sufficient to allow the holders to rub the head of the commutator, or to allow the brushes to play over the outer end.

3. See whether the insulation on any of the motor terminals shows any sign of abrasion; if it does, the interference causing it must be located and removed. In looking for the cause of the abrasion make due allowance for curves and heavy loads that may depress the springs several inches. Motor terminals, especially on double-truck cars, should be encased in armor of some kind, so that any abrasion can be detected and its cause removed before the actual insulation of the wire is touched.

4. See that the ground connections of the lightning arrester, of the heating and lighting circuits, and of every motor in the equipment is in good order; if trouble arises with any of these connections, find and remove the cause. Loose ground connections are generally caused by vibration; to remove the cause make the connection at a place where the vibration is less, or lessen the effect of the vibration by changing the direction of the wire or by introducing a suitable pigtail.

5. See that the armature does not rub the pole pieces. For testing the clearance between the armature and the bottom pole pieces, every inspector should be provided with a piece of fiber of suitable shape, to facilitate getting it into place, and of a thickness equivalent to the minimum air gap permissible for the motors. The lower air gaps of every car motor in active use should be frequently tested, perhaps as often as once every 24 hours. If the testing fiber fails to pass freely through the gap, the car must be held for a thorough investigation, which will probably reveal worn or eccentric bearings. If the pole pieces are detachable, it may be found that one or more of them are not drawn down on to their seats. Some motors are provided with peep holes, protected by lids, at opposite ends of the bottom motor shell and just in line with the bottom air gaps; by looking through

one peep hole while holding a light opposite the other, the clearance can be gauged by the eye. In cases of doubt, however, a mechanical gauge of some kind should be applied.

Modern motors employ such thin air gaps that close inspection of the journals and bearings when assembling the motors, as well as close and frequent inspection of the air gaps while the motors are in use, is absolutely essential to successful operation.

6. See that all bolts and nuts holding the gear-cases, the motor-suspension rigging, etc. are in place and secure. All bolts and nuts likely to work loose, or the loosening of which may result in an accident or serious loss or damage, should be provided with suitable locknuts, lock washers, or cotter pins to keep them in place, and the inspector should see that none of these are missing. No suspension rod or bar should be allowed to remain loose or bent, nor should the rigging as a whole be permitted to stay out of plumb. The suspension springs should be under sufficient compression to prevent rattling. The motor end play must be kept properly adjusted.

75. Trucks.—Test all wheels by striking them with a hammer; the sound will tell whether a spoke, rim, or hub is cracked. A perfect part will give out a clear ring; the sound given out by a cracked part is dull and muffled. Inspect the flanges to see that they are not chipped, and gauge them now and then to see that they are not too deep. A chipped flange is liable to cause the car to jump off the rails at a curve and when running at high speed; a flange that is too deep makes the riding over special work rough.

1. If a car jumps the track without any apparent cause, the wheels should be gauged for distance apart and tested for looseness. The side movement of a wheel that is loose shows on the axle.

2. Notice whether the unloaded car body seems to sag toward one side; if it does, one or more of the springs supporting the body has probably weakened and taken a permanent set. Carrying unusually heavy loads on one side of

a car—for example, a large number of passengers on one running board—may cause the springs to take a set. A competent equipment inspector will not allow a sagging car body to escape his notice, but will ascertain by measuring from a track rail to some part of the car body whether the springs have taken a set, and will report the condition, so that it may be attended to at once. If neglected, the springs will finally break and then repairs will be expensive.

3. See that the journal bearings contain sufficient lubricant and show no evidence of having been excessively worn, and that the side bearings and rollers of double-truck cars are kept well lubricated. These side bearings and rollers are exposed to dust, and their lubricant, if neglected, will soon become gummy and filled with grit; it will then be worse than useless, for it will grind away the metal. Such bearings should be occasionally cleaned out with kerosene and then relubricated. See also that the gears are well lubricated and that the grease is properly distributed. When applying the grease to the gear, it should be spread evenly all around the pinion and not put on in large pieces; the inspector should note any apparent carelessness or neglect in this respect. Notice also whether the pinion is much worn and whether the teeth are wearing evenly over their full length or are wearing more at one end than at the other end, and report the conditions if they seem serious.

76. Brakes.—1. See that all brake shoes are sufficiently thick to last until the next regular inspection, and that none of them either hugs the wheel or has excessive clearance when the brake is released.

2. Renew any of the fulcrum pins that shows wear; worn pins may not only cause the brake to fail to operate, but they cause the lost motion, which increases the time and labor required to set the brakes. See that no rods or levers rub either each other or any part of the car or truck, or any device supported by them, whether the brake is applied or released, making due allowance for the depression of a loaded car and for the position of the various parts when the

car is rounding a sh
porting levers, and al
of motion of rods are
or friction in a brake
increasing the difficul

3. See that all ro
are encased in insulat
exposed area; all m
grounded, and if the
contacts of the brake
cause grounds. The
should be found and

77. The term ov
periodical thorough in
to the making of all n
to be necessary. To
it must be placed c
pletely dismantled.
equipment and a line
that the voltage is a
that the cars receiv
should need overhauli
of continuous service.
depot shop every 30
managements do not
being overhauled onl
much overhauling is
provided for handling
and for removing an

Overhauling is con
when the several jobs
that all parts of the
Experience will teac
found that certain par
attention should be

should receive special attention when overhauling are the current-collecting devices, the circuit-breakers, the fuse boxes, the lightning arresters, the resistance coils, the controllers, the motors, and the trucks.

78. Current-Collecting Devices.—As soon as the car is placed where it is to be jacked up, the removable part of the trolley stand may be taken off and let down into a tub of kerosene to clean off the gummy and dirty grease. The trolley foot, that part of the stand that remains on the car, is likewise cleaned, and then the bearing parts are lubricated and the rough parts painted. When the base is clean, it is replaced on the foot and tried by being rocked sidewise and swung around; if the pivot is sufficiently worn to cause binding, it may be brought up to the standard size by first turning it down below size and then putting a machined sleeve over it. The trunk trolley-wire terminal that is screwed into the base should be renewed, if necessary. Before the car goes out, the stand is adjusted to give standard tension on each end. Where third-rail shoes are used, they must be inspected for excessive wear and for wear in ridges, and renewed when necessary. See that the shoe shunts are in good condition, that the bearing pins are not worn, that the split pins that prevent the bearing pins from working out are all in place, and that the general vertical movement of the shoe is free and positive.

79. Circuit-Breakers.—In the general overhauling of cars, it is probably best to remove all the car circuit-breakers and replace them by others that have been overhauled, tested, and adjusted in the positions they will occupy on the car. Every electric road should have facilities for quickly testing all its car circuit-breakers about once a week without removing them from the car.

80. Fuse Boxes.—The inside of a fuse box that has been long used is likely to be coated with a conducting deposit; this should be scraped off and the inside walls shellacked. See that the terminal blocks are not burned, blistered, or loose, and that the thumbscrews or other devices provided to secure the ends of the pure metal are neither so loose as to become jarred out; nor so tight that they cannot be forced in to bear firmly on the fuse metal.

If a fuse box is in very bad condition, it is best to replace it with a new one. Where cartridge fuses are used, it is customary to dispense with the fuse box entirely. The cartridge fuse-holding terminals should be inspected, and renewed when necessary. If the fuses that the terminals are made to clamp are the only ones used, the terminals will probably never give trouble; but if they are used to clamp substitutes with which they make poor contact, arcs may be formed that will burn out the terminals. All car fuses, whether of the enclosed or ordinary open type, should be protected by a fireproof curtain, so that when a fuse blows the demonstration may not be startling to the passengers.

81. Lightning Arresters.—The lightning arresters, especially in thunderstorm areas, should have thorough and frequent attention. In overhauling a car, the condition of the arrester under the car cannot well be determined; hence it should be replaced by one in which the air gap has been carefully adjusted and secured at standard thickness. The arrester removed, if not already in satisfactory condition, should be repaired and adjusted for future use. Above all, see that arrester, trolley, and ground wires contain no loose connections, because these have the same effect as increasing the air gap across which the lightning must pass on its way to ground; and the lightning, in selecting the easiest path to ground, may go through the controller and motors instead of through the arrester.

82. Resistance Coils.—See that the starting-coil hangers are in good condition and that they are secure; test the starting-coil frame and all supporting parts for grounds, especially if any of the hanger bolts extend above the level of the car floor, where passengers may step on them. If any part of the resistance metal of the starting coil shows deterioration, it should be renewed. The best test of conditions is to try the car and see whether it accelerates smoothly on all notches. If the coil is in good condition, give the frame a coat of japan to prevent rusting. Also, see that the asbestos lining used to protect the car floor immediately above the starting coil is in good condition. Shunts are not used on modern motors, but where they are used they must be tested for both open and short circuits, because either condition will cause one motor to take more than its share of the total load; and in case of a seriously short-circuited shunt, the affected motor may become dangerously overloaded.

83. Controllers.—If the requirements already considered for maintaining controllers are observed under regular operations and in the depot inspections of the car, more thorough inspection and repair will not be required at the time of overhauling. In any case, after a car is overhauled, it should leave the shop with its controllers in practically as good condition as when new. On some roads, to insure this condition, the controllers are given a bench overhauling at least once a year, generally when changing from closed to open cars; this can best be done by having a number of spare controllers in good repair ready to install in place of those taken from cars. Many of the controllers may not need such a thorough overhauling, but the bad results, accidents, damage suits, etc. resulting from the use of defective controllers make it advisable to go over them all systematically, so that no defective ones will be left in service.

84. Motors.—The condition of the motors should, as far as practicable, be made as nearly perfect as when they were first put in service. To do this the motors must be taken apart and the condition of each part carefully inspected. The fields and armatures must be tested, either absolutely or by comparison with standard fields and armatures kept for that purpose, to insure that they contain no open or short circuits, and that their insulation has not begun to roast. A casual inspection of the armature will show whether it has been throwing solder, rubbing the pole pieces or against

foreign objects drav
had excessive end p
of its having throwr
no disorder in the ar
nections, roasted fie
joint in the field f
motor field and allov
armature, resulting
the motors are too s
are continually overl

85. The inner a
are scraped, cleaned
of asphaltum. The
cut out gummy secre
air or steam, and fir
keep out dust and gr
In painting the insid
to leave any paint
the joints between th
it will be impossible

86. If the brus
original perfect cor
replaced by new one
to hold the brushes
tator, permitting no
not radial to the com
it is advisable to c
that the brushes res
also, that the brushe
ence to the poles; or
reference to a verti
shaft, but no general
case being ascertain
from the motor man
case is determined
which is so made a
available for inspect

that purpose. The necessity for counting the bars between brushes may be avoided by using only those brush holders that conform to a standard brush setting jig. All holders, old or new, should be tried by the jig before being put into the motor.

87. All old brush holders, before being replaced, should be thoroughly cleaned, the pivots lubricated, the tension springs and shunts adjusted and renewed if necessary, the yokes scraped and shellacked, and a plug gauge passed through the brush ways to insure a standard dimension and that no burrs or projections of any kind will interfere with the free motion of standard-sized brushes.

In resetting the brushes not only should the correct positions be obtained, but the distance of the holders from the commutator should be made as small as possible without endangering contact of the holders with the commutator. After the motor is reassembled and the brushes are in place, they can be given a proper fit on the commutator surface by drawing a strip of fine sandpaper back and forth between the brushes and the commutator, the rough side being next to the brush.

88. By means of a suitable gauge, the distance from each end shoulder of the armature to the corresponding thrust collar should be adjusted by moving the collar, if necessary, to make the end play correct. Where practicable, the armature should be swung in a lathe and spun to see if the shaft and commutator run true. Be sure that the pinion keyway and thread are in good condition. If axle collars are employed, they must be kept up to standard thickness to minimize the bodily end play of the whole motor. On a straight track, the suspension rigging should exert no tension tending to force the motor to one side or the other; therefore, the axle collars should not be installed until after the suspension rigging is in place.

89. In replacing detachable pole pieces, or in bolting together the halves of the motor frame, see that nothing interferes with making good magnetic joints. It is well to

cover the surfaces to be join
placing them together. The
bolted together should be w
have been put back into the
should be sent through them
the poles alternate in polarit

90. The gear-cases sho
gears and fastenings put in
in place, and the gears cove
The gear-cases must be ad
such a manner that the clear
both sides.

When the armature is in
sure that the bearings are
does not rub a pole piece or
them. See that the air ga
around and then take a pinc
force the armature first to on
as far as it can be forced a
extreme position, to see that
or the brushes run over the

91. Care must be taken
terminals out through the m
tive positions; otherwise, the
ing up. The completed truc
jacked up until the wheels cl
is applied to give the arma
up all moving parts. The
the car, the motors connect
lated and supported, and th
adjusted. Finally, the comp
run on the shop tracks with
after which, if everything is
ened and the car is ready fo

92. Trucks, Brakes,
brakes, etc. has been so w
pages that little need be a

other important parts, it is well to have spare trucks kept in repair and ready to replace disabled trucks, so that delays caused by holding a car while its trucks are being repaired may be avoided.

On heavy elevated equipments, a great deal of apparatus is crowded into a small space, so that there is little working room. Motor, truck, and brake-rigging parts are so dovetailed into each other that considerable experience is needed to properly remove and replace parts needing repairs or renewal. If trucks and motor equipments are sufficiently uniform in dimension, capacity, etc. to permit it, as many repaired trucks should be kept available as will be likely to be needed in a day's car-repair work, the trucks removed from the cars being repaired for future use.

ELECTRI

VOLTM

1. There are
measurement inst
use. The principl
is the same. In
repelling and attra
instrument depend
resistance; in the
connected in para
meter is intended f
with which the c
ammeter shunt. O
tutes an extra devi
of moderate rang
the instrument.
ammeters and the
the amount of ene
conducting parts
that changes but l
moderate changes
of readings. Und
mirror; in making
reflection in the
needle, which is th

2. In Fig. 1 is shown a Weston ammeter. Figs. 2 and 3 show the general interior construction of both voltmeters and ammeters. Permanent magnet *A A*, Fig. 2, has soft-iron pole pieces *P*, *P*, bored out to form a cylindrical opening and secured by screws *S*, *S*. Symmetrically disposed within this opening is the stationary soft-iron cylinder *C*, supported by a screw *M* passing through a lug on the brass plate *B*. Between the cylinder and pole pieces is a uniform air gap across which the permanent magnet projects a strong and uniform magnetic field.

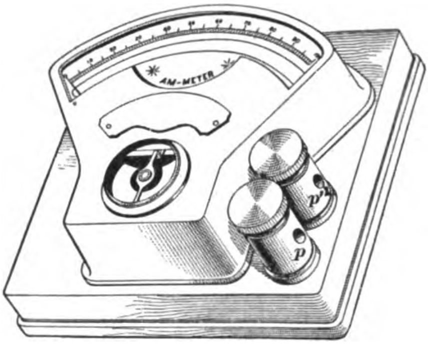


Fig. 1

3. The movable parts of the instrument are shown in Figs. 3 and 4. A rectangular coil *C*, Fig. 4, of fine wire is wound on an aluminum or thin copper bobbin suspended vertically between two delicate jeweled bearings. Two flat horizontal springs *S*, *S* oppose the tendency of the coil to rotate and at the same time conduct the current to and from the suspended coil. On sending current through the meter, interaction between the field of the permanent magnet and the field set up by the current flowing in the coil causes the

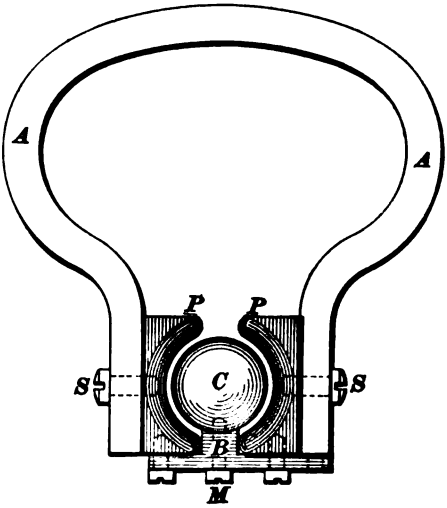


Fig. 2

coil to turn against the restraining action of the springs; the coil moves to a point where the force tending to turn it

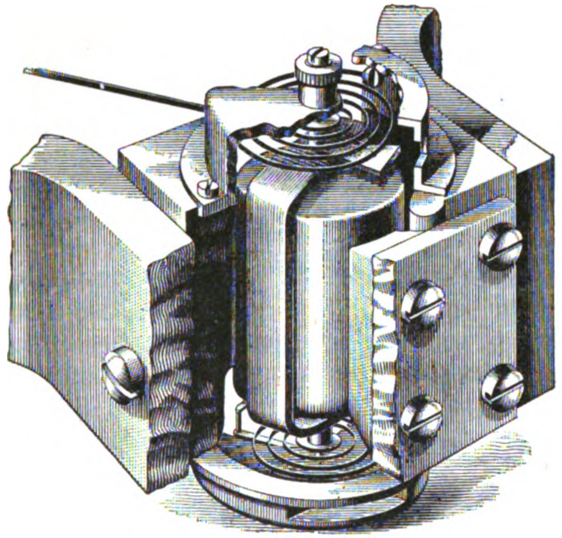


FIG. 3

is balanced by the restraining force of the spring, and then stops. Aluminum pointer *P* attached to the coil indicates on the scale the deflection of the coil from its normal position, shown in Fig. 3. Owing to the field provided by the permanent magnet being so uniform, a given increase of current causes about the same deflection on the lower part of the scale as on the upper part, so that the divisions on the scale are of about the same width. Fig. 5 shows a scale of about three-fourths size.

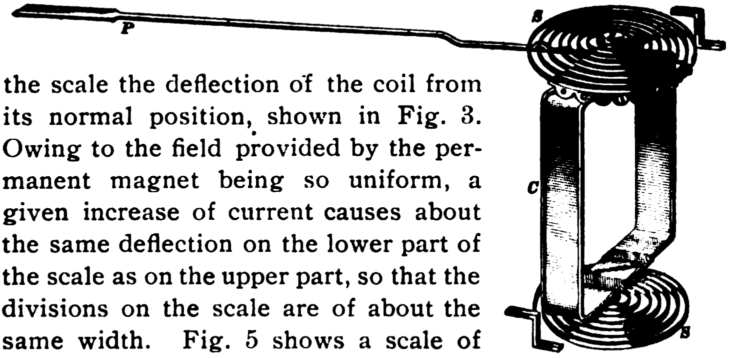


FIG. 4

4. Dead-Beat Instruments.—The copper or aluminum bobbin on which the coil is wound, in moving through the magnetic field, has an electromotive force set up in it that causes a current to circulate around the bobbin as long as the bobbin moves. This current circulates in the opposite direction to the current in the coil; hence it tends to oppose the motion of the coil. As this tendency exists only when the bobbin is moving, it has the effect of preventing the needle from swinging too far over the scale, thus bringing it quickly to rest at the proper point. This *damping effect* is due almost entirely to the currents generated in the bobbin.

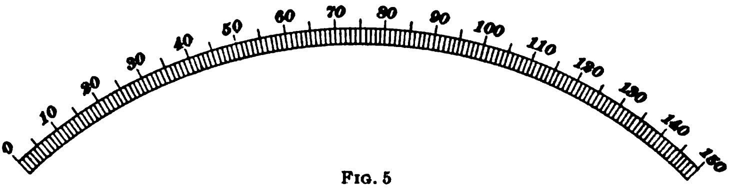


FIG. 5

The friction is so slight that it has practically no effect on the position the needle will take. This is shown by the fact that the needle, having been deflected by a current, will respond to very minute variations in that current; that is, the instruments are very *sensitive*. An instrument that comes to rest quickly at the proper point is known as a **dead-beat instrument**; this is a very important quality, for it contributes very materially to the rapidity with which measurements may be taken.

AMMETERS

5. The interior of a Weston **ammeter** is diagrammatically represented in Fig. 6. Current entering the instrument at post *A* passes to copper plate *a*, thence by way of several parallel paths to copper plate *b*, which is connected directly to the other external connecting post *B*. One of the parallel paths between plates *a* and *b* is the moving coil *c* of the instrument; the other parallel paths consist of wire wrapped around permanent magnet *e* in such a manner as not to magnetize it; that is, the coils are wound non-inductively, and they constitute a low resistance shunt to the moving coil, which, accordingly, gets but a very small part of the total current passing through the instrument. The magnet serves merely as a convenient support for the coils. The resistances of the moving coil and shunt are so proportioned as to allow the necessary amount of current to flow through the moving coil to produce the proper deflection of the coil and pointer *p*.

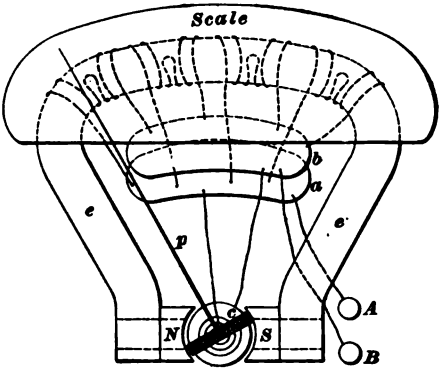


Fig. 6

6. On instruments for measuring large currents, the non-inductive resistance or shunt is not included in the case with other parts of the instrument; if it were the size of the instrument would be objectionable. In such cases, the shunt is a separate device. A standard form of ammeter shunt is shown in Fig. 7. The shunt has a very low resistance, and has much greater current-carrying capacity than the mere matter of safety would require. In addition to these precautions, it has a very large surface, so that heat may radiate as fast as it is generated, thereby keeping the temperature almost constant. The ammeter shunt is connected in series in the circuit in which the current is to be measured. For example, suppose that the total current supplied by dynamo *A*, Fig. 8, is to be measured. The shunt is connected in series with the dynamo and in between the dynamo and all

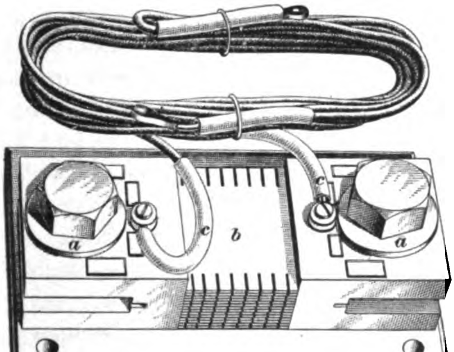


Fig. 7

branching circuits, so that the shunt and ammeter in parallel will get the total current, irrespective of how it may be distributed from the bus-bars *B*, *C*. In Fig. 8, *S* is the shunt, and *M* is the ammeter connected in parallel with it by the two small wires *1*, *2*. The needle may register a large current, while the instrument itself may be carrying but a fraction of an ampere. The resistances of the shunt and ammeter are so related in value, however, that the ammeter carries a known fraction of the total current, whatever its value may be; but the ammeter scale is marked to indicate the total current flowing in the circuit.

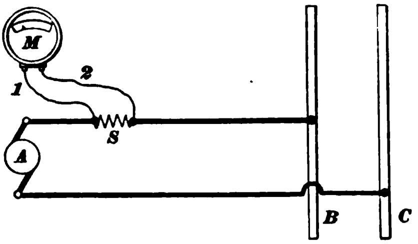


Fig. 8

It can be seen that the small wires *1*, *2* are in series with the ammeter, and therefore constitute a part of the resistance of its circuit; in order to avoid possible errors due to these wires being of the wrong resistance, they are carefully measured at the factory and are shipped with the instrument. The wires are flexible, and if too long they should be coiled up out of the way. If they are too short to reach, under local conditions that cannot be avoided, it will be necessary to get another instrument and shunt to which longer leads have been adjusted. It is equally important that the connections of the small wires to the shunt and ammeter should be securely and unchangeably made, because if the resistance of the connection changes there will be an error in the readings throughout the range of the instrument.

7. In Fig. 7, *a*, *a* are two heavy terminals of large surface area connected by flat strips *b*, which are made of an alloy of practically constant resistance for all ordinary changes of temperature. The small flexible conducting cables used to connect the ammeter to the shunt are shown coiled up at *c*, *c*. The shunts and instruments are always numbered to correspond, and care should be taken to see that these numbers agree before connecting the instruments.

Care must be taken not to mistake an ammeter for a voltmeter and connect it across the line; if such a mistake is made, the excessive current will destroy the ammeter.

VOLTMETERS

8. The action of the Weston **voltmeter** is based on the same principles as that of the ammeter, and the two instruments look very much alike. All ammeters that do not employ an external shunt can be told at a glance because of their heavy connecting posts. On all Weston voltmeters, the connecting posts are light and are rubber covered. The internal resistance of a Weston voltmeter designed to measure voltages up to and including 150 volts is, say, 18,000 ohms, while the resistance of an ammeter for measuring up to 15 amperes is only .0022 ohm. Owing to its great resistance, the current passing through a voltmeter is exceedingly small. All voltmeters have at least two terminals, or binding posts *p*, *p'*, Fig. 9. Conductors called voltmeter leads connect the instrument to the two points between which the difference of potential is to be measured. The connecting wires are in series with the instrument, and therefore constitute a part of its resistance, but the resistance of the voltmeter is so much greater than that of the connecting wires that the latter resistance may be ignored.

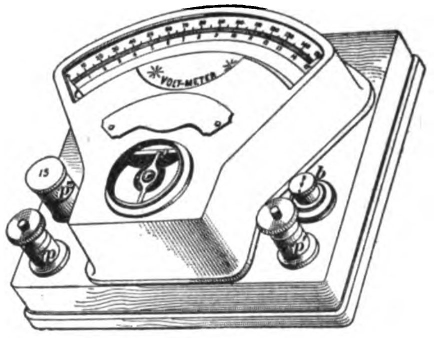


FIG. 9

Weston voltmeters sometimes have a third binding post, *p''*; when *p''* is used with *p'*, the readings must be taken from a second graduated scale situated directly under the upper scale. For example, when using posts *p* and *p'*, the maximum reading to be taken from the upper scale may be 150 volts; but when using the lower scale, corresponding to posts *p'* and *p''*, the maximum reading may be, and generally is, 15 volts. The upper scale is usually some exact multiple of the lower scale. Many of the Weston voltmeters are provided with a push button *b* and the voltmeter does not indicate until this push button is pressed down. On releasing the button, the voltmeter circuit is opened and the needle returns to the zero position. In some cases, the voltmeter can be kept in action by giving the push button a partial turn when pressing it down.

Too much stress cannot be laid on the necessity of carefully distinguishing between the high- and low-voltage posts on a double-scale instrument. If a low voltage is applied to the high-voltage posts, no harm is done; but if a high voltage is applied to the low-voltage posts, the instrument may be damaged. The resistance included between posts *p'* and *p''* is much less than that included between posts *p* and *p'*, so that, in the case last supposed, parts of the instrument would be subjected to excessive current.

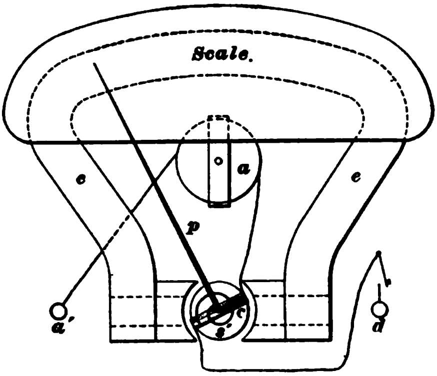


FIG. 10

9. Fig. 10 shows, diagrammatically, the interior of a single-scale Weston voltmeter. Resistance coil *a* is in series with the moving coil *c* and constitutes all but a very small part of the total resistance of the instrument. Coil *a* is wound non-inductively, both to avoid any action that it might otherwise have on the moving coil and so that self-induction will not prevent the needle from sweeping at once to its proper position. One end of the coil is connected to post *a'*, corresponding to post *p* in Fig. 9; and the other end of the coil connects to the moving coil *c*, the remaining end of which connects, when the push button is down, to post *d*, corresponding to post *p'* in Fig. 9.

10. Fig. 11 is a diagrammatic sketch of the connections of a double, or two-scale, voltmeter. In this diagram, the connecting posts are marked the same as in Fig. 9. Stretch of circuit *p*–*a*–*b*–moving coil–key–*p'* includes the total non-inductive resistance coil and the moving coil in series. Assume the total resistance of the two to be 150,000 ohms. Further, assume that the instrument indicates a maximum of 750 volts on one scale, and a maximum of 75 volts on the other, the high-reading scale being divided into 150 divisions and the low-reading scale having 75 long graduations, with ten subdivisions to each. Now the extent of both scales is the same; that is, the same amount of movement of the moving coil is necessary to move the pointer over the full range of both scales. To produce this movement of the coil a certain amount of current will be required, irrespective of which set of binding posts may be used.

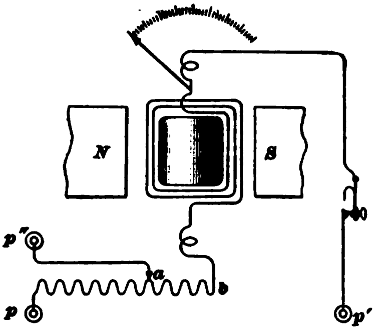


FIG. 11

Since this fixed amount of current must, however, be due in one case to a voltage of 750, and in the other case to a voltage of 75, which is only one-tenth as great, it follows that when the high-reading scale is used, the total resistance of the voltmeter circuit must be ten times as great as when the low-reading scale is used. Accordingly, the tap to post *p''* must be taken off at such a point that when this post is in use the total resistance of the voltmeter circuit will be one-tenth of 150,000 ohms, or 15,000 ohms. An electromotive force of 75 volts will send the same current through

15,000 ohms that 750 volts will send through 150,000 ohms, and this is the condition to be fulfilled. It is now easy to appreciate the danger of applying too high a voltage to the low-reading scale. Where there is some doubt as to the value of the voltage to be measured, connect to posts p and p' first; if the voltage then indicated does not exceed the maximum reading of the lower scale, the lines can be transferred to the posts p' and p''. Current values less than the maximum reading of the lower scale can be read with a greater degree of accuracy on the lower scale because there a division has only one-tenth the value of a division of the same length on the upper scale. In other words, an error of one division on the lower scale would be an error of $\frac{1}{10}$ volt, while an error of a similar division on the upper scale would be an error of 1 volt.

INCREASING CAPACITY OF INSTRUMENTS

11. The maximum current readable on an ammeter can be indefinitely increased by providing the meter with a parallel path or shunt; the maximum reading of a voltmeter can be indefinitely increased by connecting it in series with an extra resistance or *multiplier*. For example, to double the current capacity of an ammeter, it is only necessary to connect in parallel with the meter a resistance equal to its own, and of a carrying capacity liberal enough to avoid error due to heating. In this case the reading of the meter would have to be multiplied by 2 to get the value of the total current flowing. To double the voltage capacity of a voltmeter, it is only necessary to connect in series with the meter a resistance equal to its own, and of a design that will not introduce error as a result of heating. In this case, the reading of the voltmeter would have to be multiplied by 2 to get the total value of the voltage under measurement. The problem of increasing the range of a voltmeter is harder to solve than that of increasing the range of an ammeter, because very high resistances that will not heat appreciably are difficult to obtain.

12. Where several instruments of different capacities are at hand, the idea naturally suggests itself to connect ammeters in parallel to measure currents that exceed the capacity of any single ammeter, and to connect voltmeters in series to measure voltages that exceed the capacity of any single voltmeter.

This may be done to a certain extent, but in applying the idea certain limitations must be observed. Suppose, for example, that it is desired to measure a current of approximately 150 amperes and that there are two 75-ampere ammeters available. At first sight, it would be supposed that the two meters connected in parallel ought to satisfactorily measure any current not exceeding 150 amperes; but whether they will do so or not depends on their relative resistances. If the resistances of the two meters are exactly the same, which is not very likely to be the case, any current applied to them connected in parallel will divide equally between them, and it will be practicable to measure a current of 150 amperes; but if the resistances of the two meters are not exactly the same, the current may divide between them in such a manner that, even when considerably less than 150 amperes is flowing, the needle of one instrument will be nowhere near its maximum reading, and the needle of the other instrument will be entirely off the scale. In such cases, unless the difference is too great, the practice is to loosen the connections at the binding screws of the high-reading instrument until the current equalizes, but this practice is not recommended. In any case, where readings can be made, the total current is the sum of the two readings. Whether or not two voltmeters can be used to measure a voltage that exceeds the range of either depends on their relative resistances. If there is too much difference in the resistances of the meters, the voltage on being applied will divide between them in such a manner that one needle will be off the scale, while the other needle will indicate nowhere near the maximum capacity of the instrument.

VOLTMETER AND AMMETER MEASUREMENTS

AMMETER MEASUREMENT

13. To measure the total current flowing in a circuit, the ammeter must be connected in series with a conductor through which the total current flows. To assure this condition, the instrument should be connected as near as practicable to the source of current. If the ammeter is some distance from the source and there are leakage paths for the current between the two sides of the line, the ammeter will not measure the total current, but simply the current supplied to the part of the system beyond it. In measuring current with an ammeter three conditions should be considered:

1. Care should be taken not to connect in circuit an ammeter of smaller current capacity than the value of current that is flowing in the circuit. An approximate estimate of the current can usually be made from the known load conditions. Excessive currents through ammeters are to be avoided because they injure the instrument.

2. One of the connecting posts of all ammeters is marked +, and the other −; the post marked + should receive the wire from the + side of the circuit in which the instrument is connected, and the − post should receive the wire going to the − side of the circuit; otherwise the needle will deflect to the wrong side of the zero mark with possibly sufficient force to bend it or strain its bearings. If possible, always be certain that the needle is going to deflect in the proper direction before switching on the current.

3. If important calculations are to be based on the current measurements, be certain that the ammeter is correct. This condition can be insured by connecting the instrument in series with another instrument that is known to be correct, passing current through both and comparing their readings. Many errors and discrepancies are due to instruments that have been abused until they have become unreliable.

VOLTMETER MEASUREMENTS

14. In measuring differences of potential with a voltmeter, three precautions must be observed: (1) The difference of potential to be measured must be within the range of the voltmeter; otherwise the instrument will be liable to injury. (2) The + side of the voltmeter should be connected to the + side of the circuit, so that the needle will not be thrown to the wrong side of the zero mark and possibly injured. (3) The indications of the instrument must be correct; otherwise the results of calculations based on them will be useless. It must be borne in mind that while the drop of potential across the terminals of an ammeter is very small, that across the terminals of a voltmeter may be the total voltage of the line; accordingly, it is not permissible to short-circuit the terminals of a voltmeter under any circumstances. The voltmeter itself would not necessarily be injured by so doing, because it would be cut out, but the other parts of the circuit, as well as the eyes of the operator, would be liable to injury.

Since the drop of potential between two points depends on the resistance between those points and the value of the current, it might be supposed that connecting the voltmeter in parallel with the resistance reduces the resistance between the points and therefore reduces the drop between them. This is correct to a certain extent, depending on the relative resistances of the voltmeter and the device across which the drop is to be taken. In most practical work, however, the resistance of the voltmeter is so great compared with that with which it is connected in parallel that the change produced in the drop may be neglected.

VOLTMETER-AMMETER METHOD OF MEASURING RESISTANCES

15. The voltmeter-ammeter method of measuring resistances is the method most used in practical work, because it is convenient and the results given are satisfactory. Fig. 12 shows the connections for measuring an unknown resistance. The ammeter is connected in series with the resistance to be measured, and the voltmeter is connected in parallel with the resistance.

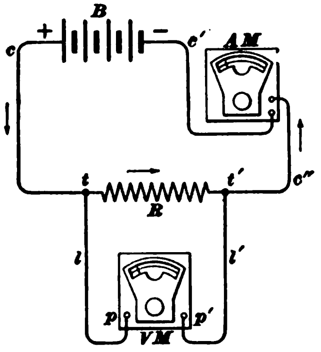


FIG. 12

To find the resistance of a circuit, when the electromotive force and current are known, use the following rule:

Rule.—*Divide the number of volts by the number of amperes.*

EXAMPLE 1.—A current of 40 amperes is sent through an ammeter in series with four field coils of a railway motor. A voltmeter is applied across the outside terminals of the motor fields. On pressing the voltmeter button, the needle indicates the drop across the field coils to be 10 volts. What is the resistance of the motor field coils?

SOLUTION.—Here the reading of the ammeter is 40 and the reading of the voltmeter is 10. Therefore, according to the rule,

$$10 \div 40 = \frac{1}{4} = .25 \text{ ohm. Ans.}$$

EXAMPLE 2.—The field coils referred to in example 1 were placed in a motor, the motor installed on a car, and the car run a round trip. On its return to the barn the field coils were disconnected from the car wiring, a current of 40 amperes was again sent through them, and the drop across them was again taken with the voltmeter. Owing to the increase in resistance caused by heating, the voltmeter now indicated the drop across the coils to be 12 volts. What was the resistance of the coils?

SOLUTION.—Here the reading of the ammeter is 40 amperes, as before, and the reading of the voltmeter is 12 volts. According to the rule, then,

$$12 \div 40 = \frac{3}{10} = .3 \text{ ohm. Ans.}$$

16. By using instruments of the proper range very low or very high resistances can be measured. Fig. 13 shows a way of measuring a very low resistance. Here *R* is a section of heavy copper rod connected in series with ammeter *A* and battery *B*. The drop between points *C* and *D* is to be measured by voltmeter *V*. As the drop across such a low resistance will be very small, unless the current used is very large, a millivoltmeter, which is capable of measuring a very small difference of potential, must be used.

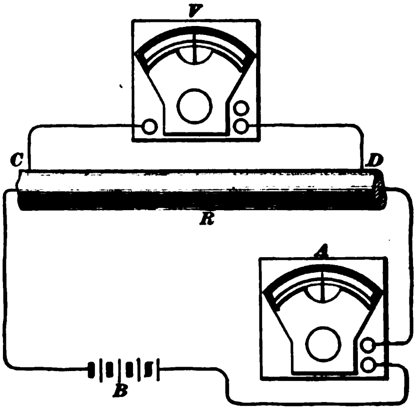


FIG. 13

EXAMPLE 1.—In Fig. 13, suppose that rod *CD* is a piece of copper 3 feet long, that it is desired to use for a bus-bar. Further, suppose that when the ammeter indicates a current of 35.4 amperes to be flowing through the rod, the millivoltmeter indicates a drop across it of .008 volt. What is the resistance of the rod?

SOLUTION.—Here the ammeter reading is 35.4 and the millivoltmeter reading is .008. Applying the rule of Art. **15**,

$$.008 \div 35.4 = .00023 \text{ ohm. Ans.}$$

EXAMPLE 2.—On passing a current of 10 amperes through an ammeter of 15-ampere capacity, and taking the drop across its terminals with a millivoltmeter, the drop is found to be .022 volt; what is the resistance of the ammeter?

SOLUTION.—Here the ammeter reading is 10 and the millivoltmeter reading is .022. Applying the rule of Art. **15**,

$$.022 \div 10 = .0022 \text{ ohm. Ans.}$$

RESISTANCE MEASUREMENTS WITH VOLTMETER AND KNOWN RESISTANCE

17. A portable voltmeter is available in many instances where a portable ammeter is not. In such a case the value of an unknown resistance can be measured with the voltmeter, provided that there is available a suitable resistance of known value. Fig. 14 shows the connections for this method of measuring resistances. In Fig. 14, *B* is a battery, *R* is the resistance to be measured, and *R′* is the resistance of known value. The measurement is conducted as follows: Send through the two resistances in series a current sufficiently heavy to give a readable deflection, but not sufficiently heavy to cause excessive heating of either coil. Take the drop across the known resistance, then take the drop across the unknown resistance. Repeat these readings until it is certain that the current has not changed during the time required to transfer the voltmeter lines from one resistance to the other; in other words, be certain that both drops are taken with the same current. The drop having been obtained across both resistances, the value of the unknown resistance can be obtained.

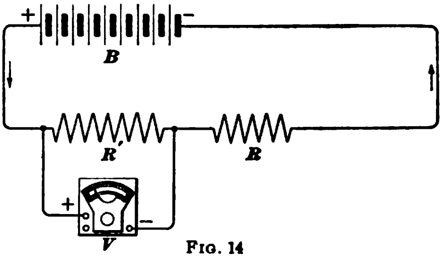


FIG. 14

To find the value of an unknown resistance when the drop of potential across its terminals is known, as well as the drop of potential across the terminals of a known resistance through which the same current is flowing, use the following rule:

Rule.—*Multiply the value of the known resistance, in ohms, by the drop across the unknown resistance, and divide the result by the drop across the known resistance.*

EXAMPLE.—It is desired to measure the resistance of a set of railway-motor field coils; there is no ammeter available, so the measurement must be made by means of a double-scale voltmeter and a street-car starting coil known to have a resistance of 4 ohms. One scale of the voltmeter reads as high as 150 volts, and the maximum reading of the other scale is 15 volts. On maintaining through the field coils and starting coil, connected in series, a steady current for a few seconds, and taking the drops across the two resistances, the drop across the starting coil was found to be 40 volts, and that across the field coils, 2.5 volts. What was the resistance of the field coils?

doubled, provided, of course, that the line voltage has remained constant. In effecting this change, it is immaterial whether the resistance has been doubled by doubling the resistance of R' itself or by putting in series with it a resistance equal in value to its own. It follows, then, that if insertion of a resistance at R causes the reading of the ammeter to become one-half of what it was previous to inserting the resistance, the resistance must equal that of R'.

EXAMPLE.—Suppose that there are on hand a lot of street-car starting coils that have been laid away in the storeroom for some time: each coil is supposed to have a resistance of 5 ohms, but as all record of them has been lost, their condition is uncertain. For measuring them, there are available an ammeter of 150-ampere capacity and a starting coil known to have a resistance of 5 ohms. How can the resistances of the coils be found?

SOLUTION.—Connect the starting coil of known value across the line in series with the ammeter, close the switch, and take a quick reading; then insert in series with the starting coil the coil to be checked and take a second reading. If the second reading is approximately one-half the first reading, it may be assumed that the coil under test is in good condition and of the same resistance as that with which it has been compared.

19. This method can be used to measure resistances that are not of the same value as that of the coil that is used as a standard. To do this conveniently, a simple rule must be applied. Before the rule is applicable, however, the resistance must be inserted and the effect on the ammeter noted. For example, suppose that a 25-ohm standard coil is available, to be used with an ammeter of 150-ampere capacity for measuring a lot of starting coils of unknown resistance. The circuit is first closed on the standard coil and ammeter in series, and a reading taken. The circuit is then opened, the unknown resistance inserted in series, the circuit closed, and a second reading taken. As the resistance of the circuit is always greater at the time the second reading is taken than at the time of taking the first reading, the second reading will always be less than the first reading.

To find the value of an unknown resistance by means of a known resistance and an ammeter, use the following rule:

Rule.—*Keep the voltage constant and take ammeter readings, first with the known resistance alone in circuit and then with the known and the unknown resistance in series in the circuit: divide the difference between the two readings by the second reading and multiply the quotient thus obtained by the resistance of the known resistance coil.*

EXAMPLE 1.—An ammeter of 150-ampere capacity and a 25-ohm coil are connected in series across a 500-volt line, the circuit closed, and a reading taken: the reading is 20 amperes. The circuit is then opened, an unknown resistance inserted, and a second reading taken; the second reading is 5 amperes. What is the value of the unknown resistance?

SOLUTION.—Here the first reading is 20 and the second is 5; according to the rule,

$$20 - 5 = 15;\ 15 \div 5 = 3;\ 3 \times 25 = 75 \text{ ohms. Ans}$$

EXAMPLE 2.—It was desired to ascertain the resistance of an incandescent-lamp bank composed of ten 16-candlepower lamps in series in each row, and ten of these rows in parallel. The facilities available for making the test were an ammeter of 50-ampere capacity and a 20-ohm resistance. (*a*) How was the measurement conducted? (*b*) What was the resistance of the lamp bank?

SOLUTION.—(*a*) The 20-ohm coil, the lamp bank, and the ammeter were connected in series across a 500-volt line; in parallel with the lamp bank was a heavy wire that included a switch to be used in short-circuiting or cutting out the lamp bank. A second switch, called the line switch, was connected in the main circuit, so that all current flow could be conveniently interrupted. The lamp-bank switch and line switch were successively closed and a reading taken: the reading was 25 amperes. The lamp-bank switch was then opened and a second reading taken: this reading was 2 amperes. The line switch was then opened.

(*b*) In this case the value of the known resistance was 20 ohms, and the current through it, constituting the first deflection, was 25 amperes; the second deflection was 2 amperes. According to the rule,

$$25 - 2 = 23;\ 23 \div 2 = 11\tfrac{1}{2};\ 20 \times 11\tfrac{1}{2} = 230 \text{ ohms. Ans.}$$

HIGH-RESISTANCE MEASUREMENTS WITH A VOLTMETER

20. High-reading voltmeters may be used to measure very high resistances, such as the resistances of insulation. The connections to be used in order to measure a high resistance are indicated in Fig. 16, where *R* is the high resistance to be measured, *B C* is a battery or other source of electromotive force, which should be the maximum value readable on voltmeter *VM*, and *K* is a switch for short-circuiting the resistance *R*. As the resistance of switch *K* is negligible, when the switch is closed the voltmeter is directly across the line and indicates line potential. When *K* is open, however, resistance *R* is in series with the voltmeter. The test consists in first closing the switch and reading the deflection caused by the line voltage; this deflection may be called the first deflection. The switch is then opened and a second deflection taken. Since the voltmeter circuit contains more resistance at the time the second deflection is taken than when the first deflection was taken, the first deflection will always be greater than the second. For example, should the resistance of *R* happen to equal that of the voltmeter, the result of inserting *R* will be to double the resistance of the voltmeter circuit, thereby halving the voltmeter current and halving the deflection. If *R* is three times the resistance of *VM* the current will be one-fourth the original value. In any case, the relation between the resistances of the voltmeter and the unknown resistance determines the relation between the resulting deflections. This relation is embodied in the accompanying rule, from which the unknown resistance can be determined.

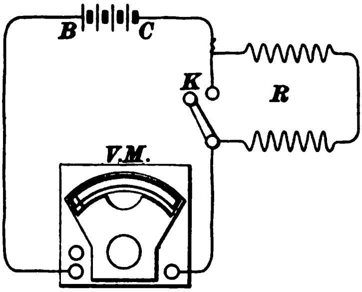


FIG. 16

To measure a high resistance with a voltmeter, use the following rule:

Rule.—*Take two deflections, one with the voltmeter across the line and the other with the voltmeter and unknown resistance in series across the line. Divide the difference between the two readings by the second reading and multiply the resulting quotient by the resistance of the voltmeter.*

Note.—The resistance of the voltmeter is always marked on the label pasted on the inner side of the sliding cover of the voltmeter box.

Example.—It is desired to measure a high-resistance coil. There is available a 500-volt voltmeter having a resistance of $66{,}666\frac{2}{3}$ ohms. The electromotive force of the line is exactly 500 volts. Required: (*a*) The method of conducting the test; (*b*) the resistance of the coil.

Solution.—(*a*) The voltmeter and the unknown resistance were connected in series, the unknown resistance being provided with a switch by means of which it could be short-circuited. With the short-circuiting switch closed, a 500-volt reading was taken. This switch was then opened and a second reading of 200 volts taken.

(*b*) The resistance of the voltmeter is $66{,}666\frac{2}{3}$ ohms; the value of the first deflection is 500, and that of the second deflection is 200 volts; according to the rule,

$500 - 200 = 300$; $300 \div 200 = 1.5$; $1.5 \times 66{,}666\frac{2}{3} = 100{,}000$ ohms. Ans.

VOLTMETER-AMMETER METHOD OF MEASURING POWER

21. To ascertain the power or rate at which electrical work is being expended in any part of a circuit when a voltmeter reading is taken of the electromotive force across that part of the circuit, and a simultaneous ammeter reading is taken of the current flowing through the circuit, use the following rule:

Rule.—*Multiply the drop, in volts, across that part of the circuit by the current, in amperes, flowing through it; the result will be expressed in watts. To express the result in foot-pounds per second, multiply the number of watts by .7373.*

Example 1.—The drop of potential across a certain length of circuit is 100 volts and the current is 7.46 amperes; what is the rate at which energy is expended, expressed in watts and also in foot-pounds per second?

Solution.—Applying the rule,

$100 \times 7.46 = 746$ watts. Ans.

$746 \times .7373 = 550$ ft.-lb. per sec. Ans.

Since 746 watts is exactly 1 H. P., and 1 H. P. is 550 ft.-lb. per sec., it is evident, without calculation, that energy is being expended at the rate of 550 ft.-lb. per sec.

Example 2.—The current in a certain circuit is 15 amperes and the drop of potential across a certain resistance coil in that circuit is 46 volts; at what rate is energy being expended in the coil?

Solution.—Applying the rule,

$$15 \times 46 = 690 \text{ watts. Ans.}$$

Example 3.—A certain heater circuit takes a current of 20 amperes at a voltage of 500; how many watts are expended in the heater circuit?

Solution.—Applying the rule,

$$20 \times 500 = 10{,}000 \text{ watts. Ans.}$$

HINTS ON INSTRUMENTS AND CONNECTIONS

22. Care must be taken in the handling of electrical instruments on which dependence is to be placed. Preferably, testing instruments should be handled only by one responsible person who knows the conditions of the instruments, that is, whether or not they indicate accurately. To minimize the liability of errors due to abuse unknown to the tester, every instrument used in an important test should be calibrated immediately before the test; that is, its readings should be compared with those of an instrument known to be correct. If it is not convenient to calibrate the instrument just before the test, mark its number on the test sheets so that it can be unmistakably identified for calibration after the test. Slight jars and exposure to magnetic fields or to conductors carrying currents are apt to affect the accuracy of readings. It is well, then, to keep the instruments at a safe distance from electrical machines. Too much reliance must not be placed on a single reading or set of readings; repeat all readings, and where practicable it is well to have a second operator repeat the readings to check them.

23. Where corresponding readings are to be taken on several instruments at once, it is important that they should be taken simultaneously, for should any of the quantities under measurement change, the error will affect the results. Simultaneous readings are most reliable when they are taken by several operators at a given signal from the tester.

24. Before making the connections for a practical test, it is well to make a diagram of the connections and then make the actual connections conform to the diagram. Always include in the trunk wire from the source of current a fuse or breaker to interrupt the circuit in case of a short circuit, and also a switch for conveniently interrupting the circuit by hand should occasion require it. In making connections to the instruments, avoid bringing live wires against the metal cases of the instruments. When returning instruments to their boxes do not replace them upside down, because that subjects the needle to unnatural stresses. In taking readings on an instrument the scale of which has a mirror, be careful that the needle just hides its reflection in the mirror; otherwise there will be an error.

In making tests that call for accuracy, it is well to so select the instruments that the maximum current or voltage, as the case may be, to be read includes almost the whole range of the scale. For example, if the maximum current to be read is 20 amperes, use a 25-ampere ammeter, if one is available, because a given change in the current will produce more movement in the needle than the same change would produce on a 100- or a 150-ampere ammeter. On a 150-ampere ammeter having 150 scale divisions, a variation of 1 ampere would cause the needle to move only the width of a division of the scale, and a reading error of one-fifth of a division would be an error of $\frac{1}{5}$ ampere. On a 25-ampere ammeter, however, having 150 divisions, a variation of 1 ampere would cause the needle to move six times as far, and a reading error of one-fifth of a small division would be an error of only $\frac{1}{30}$ ampere. The same advantage applies to voltmeters.

WATTMETERS

INDICATING WATTMETERS

25. Fig. 17 shows a form of portable **wattmeter.** This instrument includes a voltmeter and ammeter coil in the same case, and they are so disposed that the effect of the interaction of the magnetic fields set up by the currents in the two coils brings about movement of the indicating needle. The advantage of this device is that if the ammeter coil is inserted in series in the circuit by means of terminals *a* and *b*, and the voltmeter coil is connected across a given stretch of circuit by means of terminals *c* and *d*, the needle of the instrument will show, at a glance, the rate at which energy is being expended in that part of the circuit included between the voltmeter terminals.

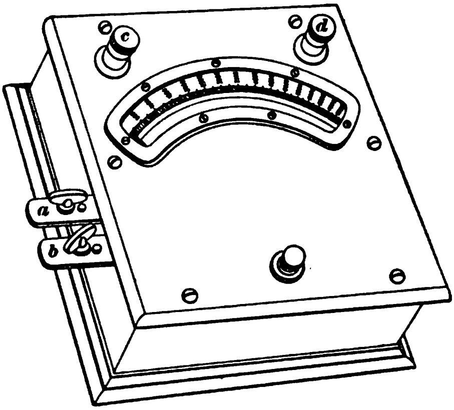


FIG. 17

RECORDING WATTMETERS

26. Indicating wattmeters show the rate at which energy is being expended in a circuit or stretch of circuit at the instant the reading is taken. In practical work, it is far more important to know the amount of energy that has been expended during a given period of time. For such indications, **recording wattmeters** are used. Fig. 18 (*a*) shows the motion of the armature and make its speed proportional to the load on the circuit. On the lower end of the armature shaft, in (*a*), and rotating with it is an aluminum disk *k*. At *e*, *e*, *e* are indicated permanent magnets, between the poles of which the aluminum disk rotates. As the disk rotates, it is cut by the lines of force of the permanent magnets and has set up in it eddy currents that retard its motion and thereby put a drag on the armature. The higher the speed of the armature, the greater is the drag or retarding force acting on it. This retarding force prevents the momentum of the armature from introducing error and makes the speed of the armature proportional to the energy that it is measuring.

27. The amount of energy expended in the circuit to which the meter is connected is measured by the rotation of the armature. The worm on the upper end of the shaft engages a set of gears that operate a dial similar to that seen on a gas meter, so that the energy expended in a certain time can be read from the dial by noting the reading at the beginning and end of the interval of time and taking the difference between the two. In the earlier types of meter the reading had to be multiplied by a constant in order to get the true result; the later types are direct-reading, except in the larger sizes, where the dial reading must be multiplied by 10 or 100, according to the number marked on the dial, in order to get the true reading.

28. The distinguishing difference between an indicating wattmeter and a recording wattmeter can be seen from the following: Simultaneous readings of the voltage across a circuit, and of the current flowing in it, when multiplied together, give the rate at which energy is being expended in the circuit at that instant; if it could be assumed that the load would remain absolutely constant for a given time, it would be a simple matter to get the amount of energy consumed in that time by multiplying the rate, in watts, by the time, in hours, the result being, in watt-hours, the unit used in such measurements; but no load ever remains sufficiently constant to make any such assumption. The result is that if the amount of energy expended in a circuit in a stated time is to be measured on a voltmeter and an ammeter, it must be done as follows:

Take a large number of successive and simultaneous readings on the voltmeter and ammeter; suppose, for example, that 120 pairs of such readings are taken in 1 hour. Add all the voltage readings together and divide their sum by 120; the result is the average voltage. Then add all the current readings together and divide their sum by 120; the result is the average current. If the average voltage and average current are multiplied together, the result is the average watts expended during the given period of time; and to get the amount of energy expended during the time, expressed in watt-hours, multiply this average rate of expenditure by the number of hours during which the readings were taken; in this case, 1 hour.

29. The indicating wattmeter gives, at a glance, the result of multiplying a voltmeter reading and its corresponding ammeter reading together to give the rate at which energy is being expended at the time of taking the reading. The recording wattmeter, however, in effect, since it is in action continuously, gives the result of multiplying the average voltage, the average current, and the time together. It has also the advantage that, since its action is continuous, the average values are obtained from voltmeter and ammeter readings that are infinite in number and therefore infinitely close together.

WHEATSTONE BRIDGE

30. The **Wheatstone bridge** and its modified forms are very useful devices in electric testing; for measuring resistances that are neither very high nor very low, the results obtained are satisfactory. The bridge is not well adapted to measure exceedingly low resistances, because in such measurements the resistance of the bridge parts have an appreciable effect; and it is not adapted to the measurement of very high resistances because, to secure accuracy, higher voltages than those ordinarily employed in bridge work must be used. In very particular work, considerable care, judgment, and experience are necessary to obtain satisfactory results. On this account, in some work, other measuring devices are to be preferred to the bridge. There are times and places, however, where the bridge can be used to great advantage in practical work, and for such occasions simple, convenient, portable forms of bridge are provided by the instrument makers. The theory and application of the Wheatstone bridge, the slide-wire bridge, and the ohmmeter have been treated at considerable length in *Electricity and Magnetism*, Part 2.

MISCELLANEOUS TESTS

TEST AND ADJUSTMENT OF CAR CIRCUIT-BREAKERS

31. The accurate adjustment of the circuit-breakers used on electric-car equipments is an important matter for two reasons: (1) It is necessary in order that the expensive operating and controlling devices on the car may be effectively protected. (2) In the testimonies incident to the damage suits instituted against the railway company, it is important that counsel for the company shall be able to show that all safety devices have been periodically and systematically inspected and adjusted, and that, therefore, reasonable care of the safety devices must have preceded the accident in question. Irrespective of whether inspection and adjustment could have prevented the conditions responsible for the accident, if it can be shown that reasonable precautions were taken to avoid the conditions, one of the strongest points usually put forth by counsel for the prosecution is much weakened in effect.

32. In modern railway practice, it is considered well to use both a fuse and a circuit-breaker: A circuit-breaker, if in good order, will promptly interrupt the circuit whenever the current for any reason reaches a value likely to injure the electrical devices on the car; and after operation, due, perhaps, simply to momentary overload, the breaker can be closed and the car sped on its way with minimum delay to the service. The function of the fuse is to finally open the circuit with certainty, should the circuit-breaker fail to act owing to its sticking or being otherwise out of order. The size of fuse selected is one that will not blow until the current considerably exceeds the rated blowing current of the breaker.

33. Inspection and adjustment, to be most effective, should be conducted with the breaker in the position in which it is to operate; otherwise, gravity is apt to affect the adjustment.

AMMETER METHOD

34. The **ammeter method** of testing car breakers consists in connecting in series an ammeter, a variable resistance, and the circuit-breaker to be tested; the current through the test circuit is gradually increased until the ammeter indicates the current value at which the breaker is intended to operate. If the breaker fails to operate within 5 or 10 amperes of the desired value, its adjustment is changed by means of the nut provided for that purpose. Fig. 19 indicates the connections used for testing car breakers by the ammeter method on a ground-return system. *T* is the overhead-trolley wire, *A*, an ammeter, and *G*, the rail or ground; *a*, a fuse box; *b*, a switch, and *c*, a wire connecting *b* and *A*; at *d* is a pigtail connecting the ammeter to an adjustable, suspended iron stem terminating in an iron plate *e*; *f* is a second iron plate provided with a terminal *g* that extends through the bottom of the barrel containing water, to which a little salt has been added to improve its conductivity. Flexible test leads *h* and *i*, which are 20 to 30 feet long, are provided with suitable hooks, clamps, or plug terminals, and are of sufficient size to safely carry the maximum current to be used in the test. Test lead *h* connects to the lower plate in the barrel, and test lead *i* to the ground. If the two test terminals are held in contact with

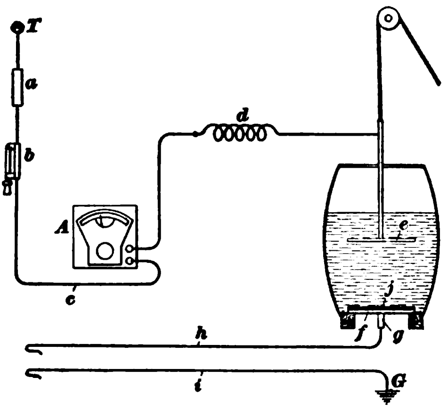


FIG. 19

each other, switch *b* closed, and plate *e* lowered into the water, current will flow. The amount of current-flow will depend on the distance apart of plates *e* and *f* and on the amount of salt in the water: the line voltage is assumed to remain constant.

35. Assuming that the car to be tested has two circuit-breakers connected in series, the test is conducted as follows: Run the car up within easy reach of the test lines and tie down the trolley pole. Next, connect the two test leads to opposite sides of the breaker to be tested first; if switch *b* is closed, plate *e* lowered into the water, and the breaker to be tested is open, no current can flow through the test circuit, because the open breaker prevents it; but on closing the breaker to be tested, current will flow through the test circuit, including the breaker, and the ammeter will indicate the value of the current flowing. The current is gradually increased by lowering plate *e* farther into the water, until the ammeter indicates the value at which it is designed that the breaker shall operate. If the breaker operates before this value is attained, the current must be interrupted by pulling the plate out of the water, and the adjustment nut on the breaker should be turned so as to increase the tension of the regulating spring. The current is then introduced to try the new adjustment; if the breaker does not operate until the ammeter reading exceeds the value at which the breaker should operate, the breaker adjusting nut must be turned so as to decrease the tension of the regulating spring. In either case, the routine of gradually increasing the current and noting the value at which the breaker operates, and then changing the adjusting nut accordingly, must be repeated until the breaker is so adjusted that it will operate every time within 5 or 10 amperes of the desired adjustment.

36. It is well to permanently fix a fiber plate *j* on top of the lower water-barrel plate, so that should the rope break and thereby let *e* down toward *f* there will be no resulting short circuit. Before finally closing the circuit, be certain that the ammeter is connected properly, so that its needle will not be thrown to the wrong side of the scale. It is customary to use common salt to decrease the resistance of the water; very little salt is generally required, and when using it each little bit added must be given time to have its full effect before adding more, otherwise the current will increase beyond control, making it necessary to draw off some of the salt water and add fresh water to bring the resistance back to a safe value. For convenience in such cases, the barrel should have a faucet at the bottom and a rubber supply pipe at the top. In making the test just described, care must be taken that the test current does not pass through the motor circuit.

AUXILIARY CIRCUIT-BREAKER METHOD

37. Fig. 20 indicates the connections used in the **auxiliary circuit-breaker method** of testing and adjusting car circuit-breakers. This method should be used where the question of time is important. In Fig. 20, the parts are lettered as in Fig. 19, so far as the devices are the same. In addition, *c* and *c'* are two auxiliary circuit-breakers, called test breakers, conveniently mounted on a board and connected in series to take the place of the ammeter *A* and connecting wire *c* in the test of Fig. 19. There is nothing peculiar about the test breakers, except that one of them is so arranged that when it operates, extra contacts carried on the handle immediately close the circuit that it has just opened. The object of this special feature will be seen from the description following.

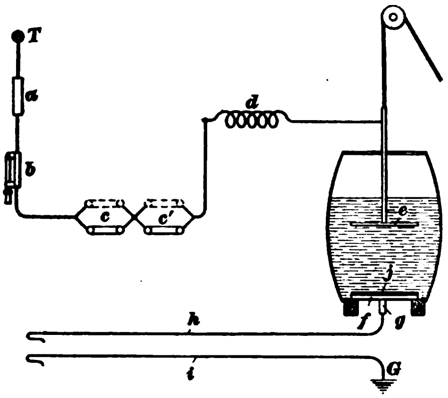


FIG. 20

Assume that the car breake
are all designed to operate at a
in such a case, test breaker *c* w
operate at a current value of 19
at 210 amperes. The test is c
is run up to the test lines, whic
car breaker to be tested, aft
pulled down. Switch *b* is the
into the barrel; no particular
ating the current, provided t
to prevent the two plates from
even if such means have not
circuit cannot well occur, bec
to act one of the test breakers
plate down into the water, the
either of the test breakers ca
adjustment of the car breaker
than 190 amperes is required
breaker *c*, set to operate at 19
Should both test breakers op
operates, it proves that the ad
such that it requires a curre
operate it. Operation of the c
circuit, which remains interru
closed by hand. Operation o
however, does not interrupt th
because the secondary contacts
diately reclose the circuit. If
its adjusting nut must be turne
of the spring and the test mu
breakers operate first, howeve
breaker must be turned so as t
spring, and then the test sho
ment of the car breaker sho
operates between the two test
adjustment of the car breake
and 210 amperes, breaker *c*,
immediately reclose the test

operate next. If the adjustment of the *c'* breaker is known to be correct, its operation every time will be unnecessary, because if the car breaker operates right after the *c* breaker, its adjustment must be more than 190 and less than 210 amperes; also, the car breaker opens the circuit.

38. The reliability of the test depends on the accuracy of the adjustment of the two test breakers: the operating values of these two breakers should be periodically tested by means of a reliable ammeter. If it is certain that *c* will operate at 190 amperes and that *c'* will operate at 210 amperes, then the adjustment of any breaker that operates between them must be within 10 amperes of the desired value, which in this case is 200 amperes. Where the breakers on a road have all been inspected and put in good operating condition, the test becomes simply a rapid method of checking their condition, and should not take more than a couple of minutes for each device. All breakers can then be checked each day as the cars run out of the house in the morning or back into the house at night. The test is conducted to best advantage where special plug terminals are provided for quickly connecting the test leads on to the two sides of the circuit-breaker to be tested.

39. A single test circuit can be adapted to test breakers of several capacities simply by adding test breakers in series. For example, suppose that a certain road operates both single-truck and double-truck cars: the breakers on the single-truck cars are supposed to operate at 175 amperes, and those on the double-truck cars at 250 amperes. There is no predicting in what order the cars will come in to have their breakers tested, so the testing outfit must be qualified to test without notice any capacity of breaker that may happen to come along. In this case, the test circuit would include four test breakers connected in series and set, respectively, at 165, 185, 240, and 260 amperes. Ordinarily, the four test breakers are in their normal closed position. Suppose that a small car comes along first; its breaker, if in good order. will operate between the 165- and 185-ampere test breakers, and the heavier breakers will not be disturbed. Next comes a large car; its breakers, if in order, will operate between the 240- and 260-ampere test breakers. In order to do this, however, the 165- and 185-ampere test breakers will be operated first; but this will in no way interfere with the test of the larger breaker, because as each low-value breaker goes off it immediately recloses the circuit.

40. It is not necessary that the test breaker that is set at the highest operating value shall have the auxiliarly contacts for reclosing the circuit after operation, because if it is the last breaker to go off, it is generally time to open the test circuit. In making a test, care must be taken that all test breakers are in their operating positions; otherwise, they will keep the circuit closed through their auxiliary contacts, so that abnormal current can flow; for, with the exception of the higher-value breaker, they will not be able to respond to the abnormal current and open the circuit before some expensive devices are injured.

BRUSH-HOLDER TESTS

41. One of the most important and probably the most neglected feature of successful railway-motor operation is inspection of the brush holders to see that the brushes are being held in their proper positions. New holders from the factory will usually give the correct set of the brushes, but home-made holders must be watched carefully, or they will cause much trouble of a kind difficult to locate. The brushes of most railway motors are radial—that is, they point to the center of the commutator. If they do not, wear in the commutator will introduce error in the set and sparking will result. In many cases, the brushes are not rightly set at any stage, because the brush holder is untrue when it leaves the shop. The only way to keep brushes set right is to inspect them at regular intervals and provide for testing every holder on a jig before allowing it to leave the shop.

42. The requirements of such a jig are as follows: The radial guides in which the brush holders are slid toward or from the commutator must be at right angles to each other and be so arranged that, when in position for service, radial lines passing through the centers of the holders will meet at the center of the armature shaft. Thus, in Fig. 21, *c* represents the center of the armature shaft, and *a* and *b* the two brush holders or brushes. Radial lines *ac* and *bc* are at right angles to each other and they meet at the center of the armature shaft. Such requirements realized in a brush holder will maintain the proper set of the brushes permanently, provided that the holder is made of non-shrinkable material, because, irrespective of wear in the commutator, the brushes will always point toward the center of the shaft, and will therefore always include one-fourth the total number of bars in the commutator. Now consider the dotted lines in Fig. 21; they represent a condition in which the holders are at right angles to each other, as they should be; but the mounting of the brush-holder yoke is such that the point of intersection of the radial lines extending from the holders is above the center of the armature shaft. The direct result of this displacement is to throw the brushes too close together. Were the yoke mounted too low, the point of intersection would be below the center of the armature shaft and the brushes would be thrown too far apart.

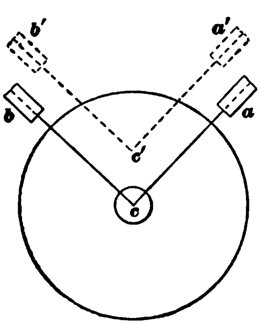


Fig. 21

43. The practical method of securing with certainty the proper position of the holder, to insure that the brushes shall always be set properly, is to reproduce as nearly as possible, by means of a jig or model, the conditions under which the holder is to set in the motor, and to make all holders satisfy this condition. In Fig. 22, *a* and *b* represent the holes by means of which the yoke is secured to the motor frame; c represents the center of the armature shaft. These distances will be found constant on every motor of the same designation, and they must be transferred to the jig with great precision. At d is a round cylinder of wood turned to two sizes, corresponding in diameter to the diameters of the new and old commutators. At p, p are two marks representing one-fourth of a circle, equidistant from a vertical line passing through the center c. Points p', p' represent similar marks on the smaller part of the cylinder. A finished brush holder is mounted on the jig just as it would be in a motor; a set of snugly fitting brushes is inserted; the centers of the brushes should coincide with marks p, p; assuming that they do, the holders are slid in radially until they are the proper distance from the smaller cylinder, when the centers of the brushes will coincide with marks p', p'. Assuming that the coincidence is perfect in both positions, the brush holder can be passed as satisfactory; otherwise, it cannot be passed.

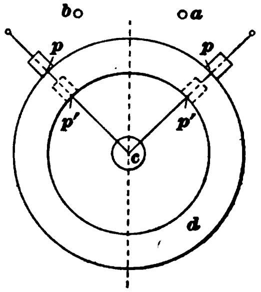


FIG. 22

DETERMINING THE AVERAGE POWER TO OPERATE A CAR

44. In modern practice, the rate at which a car in regular operation takes energy from the line and the total energy taken from the line in a given time are ascertained by means of wattmeters. On small roads, where such conveniences are not always available, satisfactory results can be obtained by means of a voltmeter and ammeter. The ammeter is connected in series with one of the overhead switches, so that the total motor current must pass through it, and the voltmeter is connected directly across the line. The instruments are preferably put in boxes filled with waste, placed a foot or two apart, so that the meters cannot influence each other. Simultaneous readings of the voltage and current are taken at regular intervals and noted on a book or record sheet. The two instruments may be so disposed that one tester can see them both without effort at the same time; in this way simultaneous readings are assured. The best way to get readings at regular intervals is to take them continuously; that is, as soon as one pair of readings is taken, take another pair; in this way, if the tester starts off at a rate that he can maintain without fatigue, a great number of readings can be taken during a round trip of the car, and the readings will be sufficiently close together to give accurate results. Since the line is alive all the time, while the car takes current only part of the time, there will be pairs of readings in which the voltage is, say, 500 or 550, while the corresponding current is zero. Whenever the line voltage is zero, the current also will be zero; in such cases, and in cases of delay, an accurate record of the time passing must be kept and noted on the test sheet, because in estimating the amount of energy transformed, the time is multiplied by the average rate of transformation, or the power, and it would not be fair to an equipment to charge against it time in which, owing to circumstances that cannot be avoided, it was drawing no energy from the line.

45. Suppose that the actual running time consumed by a round trip is 1 hour and 15 minutes; further, suppose that in this time 750 voltage and current readings were taken. The first step toward summing up the results is to add all the voltage readings together, and then add all the current readings together. If the sum of the voltage readings is divided by 750, the result will be the average voltage on the line during the test; and if the sum of the current readings is divided by 750, the result will be the average current flowing during the test. If the average current is now multiplied by the average voltage, the result will be the average rate at which energy was transformed during the round trip; this result is expressed in watts.

To calculate the work expended on the trip, expressed in watt-hours, multiply the rate in watts by the number of hours, which in this case is 1¼.

46. Suppose that the average of all the current readings is 20 amperes, and that the average of all the voltage readings is 500 volts. The average rate at which electrical energy is being expended is,

500 volts × 20 amperes = 10,000 watts

Now, since there are 746 watts to the horsepower, the average rate at which work has been done during the test, expressed in horsepower, is

10,000 ÷ 746 = 13½ horsepower, approximately

Also, since the work has been done at the rate of 10,000 watts, the total amount of work done is

10,000 watts × 1¼ hours = 12,500 watt-hours

47. The current taken by a car in operation varies between wide limits. When the controller is at the off-position, the current is zero; when starting or throwing from series to parallel on a grade, the current in some cases may jump to several hundred amperes, the maximum value depending a great deal on the weight of the car and on the judgment with which the controller is handled. In many cases, the ammeter available for making a power test is not of sufficient range to stand the test without injury. In such cases, the capacity of the meter can be increased by means of a shunt to be adjusted by experiment.

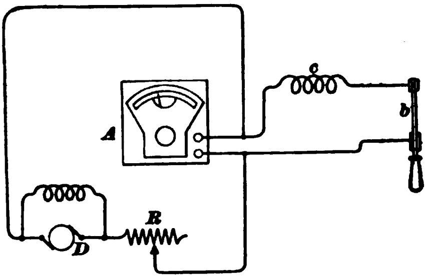


FIG. 23

Suppose that it is desired to double the capacity of a 100-ampere ammeter and thereby enable it to be used in a current test. Fig. 23 indicates the connections for a rough but very satisfactory method of doing this. Here *A* is the ammeter connected in parallel with a switch *b*, which is used as follows: With the switch open, send a current of about 20 amperes through the ammeter by adjusting the variable resistance *R*, which is in circuit with dynamo *D*; then close the switch and note carefully how much the ammeter reading is reduced. One of the stout wires *c* that place the switch in parallel with the ammeter must be so arranged that its length can be conveniently varied. The adjustment of the capacity of the meter consists in varying the length, and therefore the resistance, of one of these connecting wires until the value of the deflection when the switch is closed is exactly one-half the value of the deflection when the switch is open. Assuming that the capacity of the meter is to be doubled, this adjustment by trial is continued until closing the switch halves the deflection, whatever it may be. It must be borne in mind, however, that when using the meter adjusted in this manner, the deflection of the meter must be multiplied by 2 in order to get the true value of the total current flowing, because the meter carries only one-half the total current.

TESTING THE ELECTRICAL BALANCE OF CAR MOTORS

48. In order that the two or more motors composing a car equipment may share the load equally, it is necessary that they be electrically balanced. When an equipment has two motors that are electrically balanced operating in series, the line voltage will divide equally between them; when the two motors are operating in parallel, the line current will divide equally between them. When two motors are in series the current flow through both is the same, so that if the voltage drop across them is equal, the two must be absorbing equal amounts of electrical energy. When the two motors are in parallel, the voltage applied to each is the same; so that if the current flow through each is the same, they must be absorbing equal amounts of electrical energy.

VOLTMETER METHOD

49. Fig. 24 shows, diagrammatically, the connections for testing the condition of electrical balance with a voltmeter. *T* is the trolley and *G* is the ground (or the negative conductor rail, in the case of a conduit system). The two motors are connected in series between the line and ground. *V* is a voltmeter provided with flexible testing leads *a* or *a'* and *b* or *b'*. If the test leads are applied to the stretch of circuit indicated by *c*, the voltmeter reading will be the drop of potential across the No. *1* motor; if the test leads are applied to the stretch of circuit indicated by *d*, the voltmeter reading will be the drop of potential across the No. *2* motor. In either case, the magnitude of the reading will depend on the effective resistance included between the terminals of the motor on which the drop is being taken and the current flowing. If the effective resistance of the two motors with a given current flow is the same, the drop across the two will be the same, and the indications are that the two motors are electrically balanced and will share the total load equally.

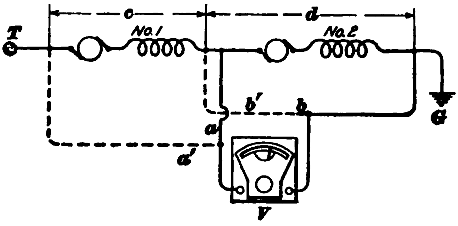


FIG. 24

50. The test, as conducted on a car, consists simply in running the car on the last series-notch and taking the drop across the two motors. If the two drops thus taken are equal, or approximately so, the motors are considered to be balanced; if the two drops are widely different, however, the motors must be thoroughly tested and inspected to find the cause. The test is preferably conducted by means of two voltmeters, a meter being placed across each of the two motors and simultaneous readings taken. Where a single voltmeter is used, care must be taken that the positive terminal of the voltmeter is connected to the positive terminals of the motor in each case. In practice, instead of taking the reading across the whole motor, it is customary to take the two drops across the armatures only; the difference in the results is not much, and the test can be made more conveniently.

AMMETER METHOD

51. Fig. 25 shows, diagrammatically, the connections for the ammeter method of testing the balance of the motors. Here an ammeter is connected in series with each motor armature, so that when the motors are operating in parallel the current flowing in each is correctly indicated. If the two motors are exactly the same in all respects, the two ammeters *A* and *A'* will indicate the same on all parallel notches of the controller. It is very seldom that two motors will be sufficiently well balanced for the meters to indicate exactly the same current, but the difference should not be allowed to exceed 20 per cent. of the full load current of one motor. If more than this, a careful investigation should be made as to the cause. In practice, it is customary to set the ammeters in a box of waste on the car seat and to cut them into series with the motor brush-holder terminals.

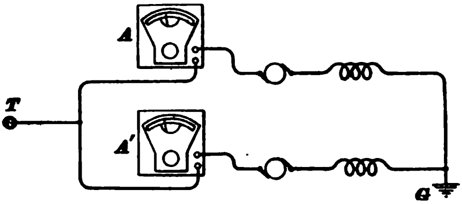


Fig. 25

UNBALANCING EFFECTS

52. Any condition that tends to affect the counter electromotive force of either motor tends likewise to affect the division of the load between them. The effective resistance included between the terminals of a motor in operation is composed of the ohmic resistance of the field coils and armature and of the opposition offered by the counter electromotive force of the armature. Under operating conditions, considered. Slight differences may also be due to a difference in the diameters of the car wheels to which the motors are geared. In such a case, one armature will turn faster than the other and will consequently generate a higher counter electromotive force. This effect, too, can in most cases be ignored, although for other reasons it is desirable to have the diameters of all motor-driven wheels as nearly as possible the same. One other unbalancing condition not likely to occur, though it has been known to occur, is a difference in the gearing of two motors on the same car, due, perhaps, to a green pitman mating the wrong pinion with a gear already installed. The effect of a difference in the gearing is that the armatures will rotate at different rates, so that one will generate a higher counter electromotive force than the other.

TESTING A HEATER CIRCUIT

53. The thorough test of the condition of a heater circuit consists in testing its insulation to ground and in comparing the resistances of the several heaters to see if any of them have become short-circuited or open-circuited. The insulation to ground can be satisfactorily tested with a voltmeter; but before applying the test, the regular heater-circuit ground must be disconnected; otherwise, the meter will indicate a ground whether a fault ground exists or not. A dead ground on the circuit will cut out some of the heaters, but whether it will cause sufficient demonstration to be noticed at the time depends on the location of the fault in regard to the positive side of the circuit. A good ground, such as that caused by a screw passing through a grounded part into a heater wire, may be effective in permanently cutting out a heater, and it may cut it out without any demonstration if the heater happens to be the last heater on the ground end.

To compare the resistances of the heaters and thereby determine if any of them are open-circuited or short-circuited, the connecting wires between heaters may be bared. The heater switch is then put on the first notch, and the drop in volts across the individual coils operative on that notch is taken with a voltmeter; the heater switch is then put on the second notch, and the drop, in volts, across the second set of individual coils taken. If all values of drops, in volts, taken on the first notch are about the same, the upper sections may be considered sound; if all values of drops, in volts, on the second notch are about the same, the lower sections may be passed. If, in taking the drop, in volts, on any given set of sections, one drop is found to be considerably higher than the others, the heater that gives the irregular drop must be investigated; there may be confusion of connections between the two sections. If one section reads lower than its fellow sections, the low-reading section may contain a short circuit. Men familiar with the work can tell the condition of the heater circuit by the length of spark caused by opening and closing it.

BOND TESTING

54. No matter how well a track may be bonded, tests should be made frequently to see that the bonds are in good condition. This is especially necessary around railroad crossings, special work, or wherever low joints are noticed. It is not necessary to measure the actual resistance of each joint; comparative readings are all that is required. For a given class of bonding, the resistance of a joint in good condition as compared with a certain length of rail is known, and it is only necessary to measure the resistance of the joint in terms of rail length; any joints showing an abnormally high resistance can then be investigated. Usually, 3 feet of rail is taken as the standard, and the resistance, measured between two points 18 inches on either side of the joint, is compared with that of 3 feet of rail. For example, the bonding may be such that a joint in good condition has a resistance perhaps slightly over that of 3 feet of rail, and if a test showed that the resistance were over twice that of the standard rail length, the bonding would be considered poor.

DROP-OF-POTENTIAL TEST

55. The simplest method of testing for poor bonds is by measuring the drop across the joint by means of a millivoltmeter and comparing this with the drop across 3 feet of rail. Fig. 26 shows a method of doing this very rapidly and accurately by means of a test car especially fitted up for the purpose. A wooden beam *a* is suspended underneath the rear car platform, so that it will be a few inches above the rail. A spring is arranged to press down on the beam, and means are also provided for raising it when not in use. To the under side of the beam are attached two stiff copper brushes *b*, *b'*; these are made of several leaves of sheet copper and are set on a slant, as shown, so that they will slide easily along the rail and make a good running contact. They should have at least 1 square inch contact surface with the rail; high-contact resistance will have a marked effect on the accuracy of the millivoltmeter readings. A resistance *c* is carried on the car, so that a large steady current can be made to flow through the track; resistance wire wound on a frame and submerged in a barrel of water is capable of carrying a large current and furnishes a resistance that is fairly constant.

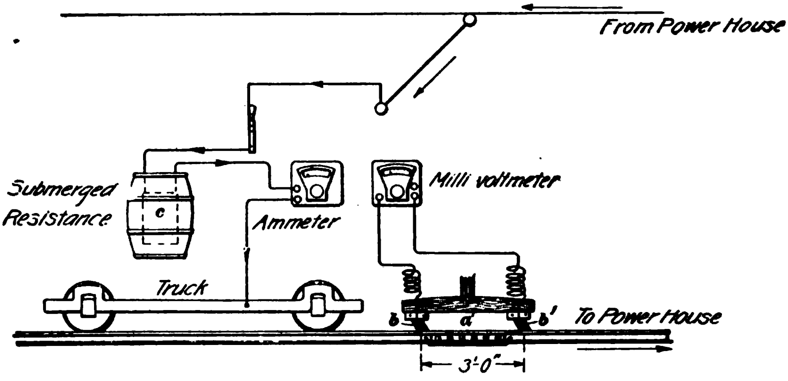


FIG. 26

In making bond tests, it is best to pass sufficient current through the joints to give good readable deflections on the millivoltmeter; the current used to propel the test car, or that taken by other cars on the line, is not usually large enough or steady enough for the purpose. The current flows from the trolley, through the resistance and ammeter to the truck and rails, thence back through the track to the power house. The brushes *b*, *b'* are placed 3 feet apart, and as the car moves slowly over the track the brushes span the joints in succession. A millivoltmeter is connected to the brushes, and when the brushes are as shown in Fig. 26, it indicates the drop across the joint. When the brushes are not across a joint, the voltmeter reading is the drop across 3 feet of solid rail. Since the current in the rail is the same as that in the joint, the voltmeter readings are proportional to the resistances of 3 feet of rail and 3 feet of rail including the joint. The car can also be fitted with another set of brushes over the other rail, this set being connected to a second voltmeter; test of the bonds on both sides of the track can thus be made at the same time. The rheostat is adjusted so that a normal joint will give a good readable deflection, and the car is then run slowly over the line; any joints that give abnormally high readings can thus be quickly located, their position being marked by a splash of whitewash ejected on to the track. The test should preferably be carried out at some time when traffic is light, so as not to interfere with the regular operation of the cars.

CONANT BOND TESTER

56. The method of testing devised by R. W. Conant, while it is not so rapid as the one just described, is very useful where a moderate number of joints are to be gone over. Fig. 27 shows the method of using the instrument. A **T**-shaped support for three hardened-steel knife-edge contacts *a*, *b*, *c* is provided, and when the pole is placed on the rail as shown, contacts *b*, *c* span the rail joint and *a*, *b* span 3 feet of solid rail, plate *p* being placed over the joint. The pole is made of tough wood that has considerable spring to it, and when the two end contacts rest on the rail, the center contact is 1 or 2 inches above the rail and is pressed down by placing a foot on the pole, as shown; this forces the end contacts out sidewise slightly, and the hardened chisel-like contacts cut through any scale or dirt that may be on the rail, thus making a good connection. Move the center pole to and fro a little, as indicated by the dotted lines, to make sure that the contact is good. The contacts must be sharpened occasionally by means of a small oilstone.

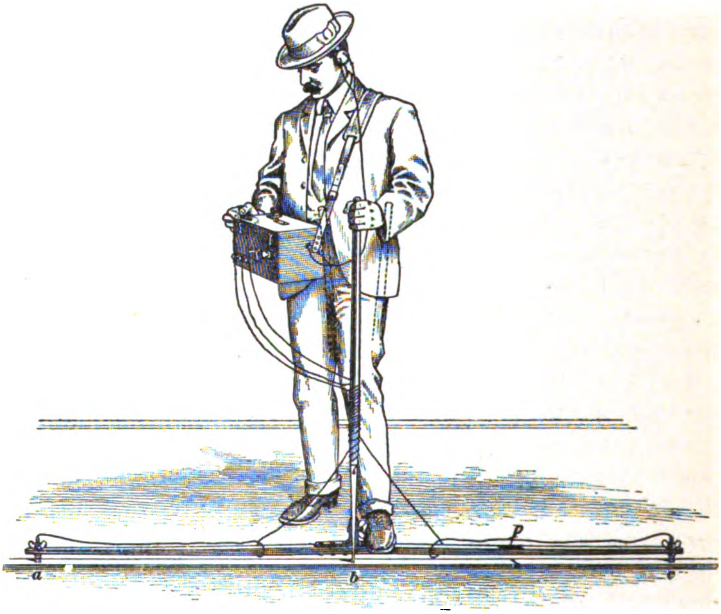


FIG. 27

57. The operation of the instrument will be understood from Fig. 28, where a, b, c represent the three contacts on the rail; d is a resistance to which the central contact can be connected at various points by means of a multipoint switch s. In series with the middle wire is included a telephone receiver e and an interrupter f, consisting of a clockwork mechanism that drives a toothed contact wheel on which presses a small contact spring. The instrument works on equal to 1.5 × 3 = 4.5 feet of rail; if a balance is obtained on 2, the joint resistance is equal to 6 feet of rail. Readings from 1 to 2 are considered as indicating good bonding; readings on points 3 or 4 indicate poor bonding; all readings above 4 indicate bad bonding. For any given class of bonding, the point at which the switch should give a balance for a good joint is known, and bad joints can be easily located. Good bonding will never have a resistance greater than twice the same length of rail, and in the better quality of work it will not exceed 1 to 1.5 times the length of rail; in fact, if proper care is taken, there is no reason why the joint resistance should not be less than that of a 3-foot rail, particularly if solid rail joints are used.

58. Table I shows the results of some tests on different bonds made* by the method shown in Fig. 26. They were made in September, 1903, so that the bonds had been in use for periods ranging from 2 to 7 years.

TESTING RESISTANCE OF TRACK-RETURN CIRCUIT

59. After a road has been in operation some time it is often found that the drop on certain sections is larger than it should be and the question naturally arises as to whether the track return is at fault or whether more copper is required in the overhead feeders. To find this out, it is necessary to know the comparative resistances of the two; if the track resistance is high compared with that of the overhead line, additional return feeders should be run.

Fig. 29 shows one method of measuring the resistance of a railway circuit; FF is the feeder, running out to the section under consideration, and RR is the rail return. The time selected is at night, when traffic can be kept off the section for a short time, and a water rheostat W is connected in series with the feeder F and the regular feeder ammeter A. The feeding-in point x is connected to the track, as shown at $x\,y$, and a steady current sent through the circuit $G+$

---

* W. E. Harrington, Journal of the Franklin Institute, Vol. CLVII

TABLE I

RESULTS OF RAIL-BOND TESTS

No.	Trade Name of Bond	Trade Name of Rail Section	Line Voltage	Amperes Used	Drop Across 3-Foot Section of Rail (Millivolts)	Drop Across 3-Foot Section Including Bond (Millivolts)	Ratio Resistance of Bond to Rail	Date Placed	Style of Joint
1	C. & S. No. 1	9-inch girder, Pennsylvania Steel Co., Sec. 200	550	200	28	12	.43	1899	Regulation fish-plate
2	C. & S. No. 2	9-inch girder, Pennsylvania	545	220	27	15	.55	1900	Regulation

$-W-A-c-F-F-x-y-R-G-$. The drop through the entire feeder and rail circuit is measured by a voltmeter V connected to c and b. From the readings of A and V, the total resistance of the feeder and rail circuit is at once determined. The resistance of the feeder FF can be calculated from its known length and cross-section, and its resistance subtracted from the total resistance of the circuit will give the resistance of the track return.

The above method of finding the resistance of the track return assumes that there are no bad joints and that there is no unusually poor conductivity in any part of the feeder FF; but such is not always the case. If the trolley wire runs back to the power house, or if there is another feeder near by that can be used as a pressure wire, the drops in the feeder and track may be measured separately and an accurate idea gained as to just how the drop is distributed. For example, if the upper voltmeter terminal is connected to the end a of the trolley wire instead of to c, the reading obtained will be the drop through the track alone, because the voltmeter takes such a small current that there will be practically no drop through Tx. If one terminal of the voltmeter is connected to c and the other to a, the reading obtained will be the drop in the feeder FF. This method is the one to be preferred, because it at once gives an accurate comparison between the loss in the overhead work and the loss in the track, and shows what part of the system requires attention in order to bring about better working conditions.

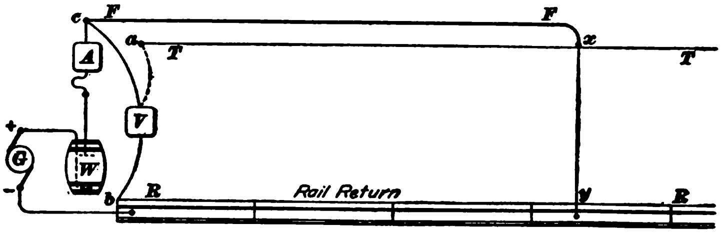


FIG. 29

TEMPERATURE TEST OF RAILWAY MOTORS

60. Many managements think that the most satisfactory test for an armature that has been rewound or repaired is to give it an actual running test at full load current and voltage. The running test has the advantage not only of testing the motor electrically, but of showing up mechanical defects, such as a bent shaft, a commutator on too far or not far enough, loose commutator bars, or an eccentric commutator. In other words, this single test accomplishes what otherwise would be accomplished by a number of individual tests. By careful adjustment of the current and voltage to correct value, a measurement of the speed will tell if the armature is standard electrically. In factories, the resistance of the fields and armature is measured cold, and then the motor is run under full load a while, then under overload a while, and the resistances again measured; any abnormal increase in the resistances of the windings will indicate abnormal heating, the cause of which is at once investigated. In repair shops, however, only the armatures, as a rule, are subjected to the running test, the same set of fields serving for all armatures of the same type. The brush holders and fields of the test motor are kept up to standard, so that any discrepancy in the speed observed at full load can at once be laid to the motor armature. As the main idea of the running test is to ascertain whether the armature will run a specified length of time without excessive rise of temperature in any of its parts, the test is usually referred to as a **temperature test.** Another great advantage of the temperature test is that the armature winders have more confidence in its results than they have in the more modern stationary tests. In the larger repair shops, rewinding is all done on piece work, and piece workers seem more willing to accept the outcome of a temperature test than of any other kind. It is to the advantage of the management and men, however, to subject the work to preliminary tests, such as the puncture test and bar-to-bar test, to determine whether there are any faults that the temperature test is likely to develop in a violent and destructive manner.

61. Fig. 30 indicates the connections for subjecting repair armatures to the temperature test. Other connections just as good are in use, but the diagram of connection given is selected as one of the simplest. In Fig. 30: *T*, is the overhead trolley wire; *s*, a switch; *CB*, a circuit-breaker; *f*, a water rheostat; *A*, an ammeter, and *R S*, an ordinary reverse switch. Two motors are lined up on the testing floor so that when they both contain armatures the pinion ends of these armatures can be coupled in some quick and simple manner. The armature to be tested is put in one of the frames to be operated as a motor; the field coils and brush holder of this motor remain permanently in place. The second machine is kept intact all the time and is used as a generator for putting a load on the armature to be tested. In Fig. 30, A_1 is the armature to be tested, and F_1 is the field in which it is tested. A_2 is the armature and F_2, the field of the motor that is permanently used as a generator. The armature of the generator is connected across the terminals of a water resistance *g*. By following the current path from the trolley wire to ground, it will be seen that the field and armature of the motor to be tested and the field of the generator are in series; whenever current is applied to the motor circuit, the field of the generator becomes separately excited. The object of this connection is to facilitate getting a load on the generator.

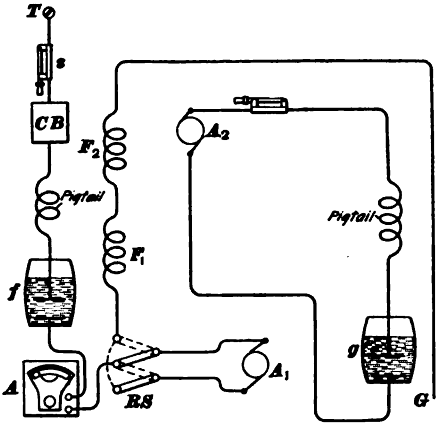


FIG. 30

62. On closing the circuit-breaker, the main-circuit switch, and the water rheostat *f*, the motor starts up. The direction in which the motor turns depends on the position of the reverse switch *R S*. A special switch can be so arranged that after the water barrel has been used to bring the motor up to speed, it can be transferred to the terminals of the generator armature, thereby avoiding the use of the second water rheostat *g*. Another advantage of separately exciting the generator field is that generation is made independent of the direction of rotation. If a series-connected generator is running in a certain direction and is generating current, when the direction of rotation is reversed it will be necessary to reverse either the field or the armature connection, otherwise the machine will not be able to generate in the new direction of rotation.

63. An armature test is conducted as follows: After subjecting the armature to preliminary tests that will detect slight and perhaps easily removed faults, it is installed in the test motor and fitted with brushes with as much care as if it were going into regular operation. The resistance of the armature is measured when it is cold. The test then begins and the water barrel *g* is adjusted until the load on the motor is correct; assuming that the voltage is normal, the speed is taken, after which the armature is allowed to run at constant load for about ½ hour; the test is then shut down, the reverse switch thrown, and the motor run at full load for ½ hour in the opposite direction. The resistance of the armature may then be measured to ascertain whether or not the temperature rise is excessive, as indicated by the relation between the hot and cold resistance measurements. If the armature operates without sparking and no other irregularities develop during the test, its insulation is tested, and if it is found to be sound, the armature is removed and another one put in. In some shops it is customary to subject the armature to a puncture test by applying a high electromotive force between the core and the windings while it is heated. Where the facilities for making the puncture test are available it is a good idea to make it. During operation, the machine is inspected for mechanical defects, such as a sprung armature shaft, etc.

RESISTANCE MEASUREMENT OF A CAR CONTROLLER

64. By the resistance of a car controller is meant the resistance of controller wires and contacts that must carry current when the controller is operated. Looked at from the point of view of energy transformed, excessive resistance in a controller would be no objection on the resistance notches, where resistance is wanted; but since excessive resistance at a contact generates heat likely to result in burning or scoring the contacts, and since this burning or scoring will further increase the resistance and invite flashing, contact resistance in a controller must be kept at the minimum.

65. The resistance of a car controller can be measured as follows: Set the controller in a convenient position, after removing all car wires, if it has any in it. In all connecting-board and cut-out switch posts to which car wires were connected, place short-circuiting jumpers instead; that is, instead of the armature or field posts being connected together by an armature or a field, connect them together with a short piece of wire. For connecting the resistance posts together in the proper relation a sort of metal crab must be used. If it is desired to include the car wires in the measurement, simply remove the wires from their respective devices under the car and connect them together. For example, each pair of armature or field wires, instead of being connected to an armature or field, are connected together. In any case, connect the trolley wire through a resistance, circuit-breaker, and ammeter to the controller trolley post, and connect the controller ground post to the ground. Place the controller on the first notch, adjust the current to a safe and steady value, and take the drop, in volts, across the trolley and ground posts; this drop divided by the current gives the resistance of the controller and connecting wires.

ARMATURE-RESISTANCE MEASUREMENTS WITH VOLTMETER AND AMMETER

66. Fig. 31 shows the connections for measuring the resistance of an armature with a voltmeter and ammeter by what is called the **fall-of-potential method.** The test current may be supplied by a storage battery or by power or lighting mains. In any case, unless the electromotive force of the source is very low, a variable resistance must be provided for limiting the test current to a safe value. In Fig. 31, the test current is applied to the armature through contacts placed at diametrically opposite points on the commutator, because the armature in question operates in a motor that has only two poles. On street-railway motors and other motors having four poles, the current must be introduced at points including between them one-fourth of the total number of bars in the commutator. In any case, the current contacts are applied in the same places as are the motor brushes when the armature is in regular operation.

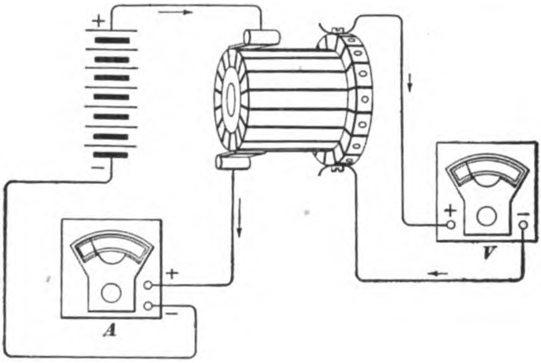


FIG. 31

Placing the ammeter and voltmeter at a safe distance, so that they will not be affected by the magnetism of the armature, about the full load current of the armature is sent through it. The voltmeter test points are scratched clean with a file and the commutator bars immediately under the test-current contacts are sandpapered. With the current perfectly steady, as indicated by the stationary ammeter needle, the voltmeter test points are applied to the cleaned bars on the commutator or to the tops of the commutator ears, thereby enabling the voltmeter to indicate the fall of potential through the armature. The reading of the voltmeter divided by that of the ammeter gives the resistance of the armature.

67. The same method carried out with a low-reading voltmeter can be used for measuring the resistance of ammeter shunts, heavy conductors, and bad contacts occurring in switches, cut-outs, safety devices, joints, etc. on switchboard wiring and leads. In any case, the drop of potential across a contact should not be greater than the drop of potential across an equivalent length of the conductor of which the contact forms a part. Great care must be taken that the test lines make perfect contact.

ADJUSTING STARTING-COIL RESISTANCE

68. A starting coil may have the proper total resistance to start a car smoothly on the first notch, and still have its sections so proportioned as to cause jumping on the accelerating notches. The general rule observed in proportioning the sections of a starting coil is to have each notch cut out, one-half of the resistance remaining in the coil up to the time that the notch becomes effective. Thus the first notch includes the whole coil; the second notch cuts out one-half of the coil; the third notch cuts out one-half of what remains; and so on until the coil is entirely cut out. Whether this condition exists or not can be readily ascertained with a voltmeter. Fig. 32 shows, diagrammatically, a four-sectioned starting coil connected to the five resistance fingers of a series-parallel controller. Under the assumed adjustment, the resistance between fingers R_1 and R_2 should be one-half of the total resistance of the coil; the resistance between fingers R_2 and R_3 should be one-half of the resistance between fingers R_2 and R_5; the resistance between fingers R_3 and R_4

70. Fig. 33 shows the connections for testing the resistance of the insulation that separates the copper parts of an armature from the iron parts. Here *T* is the trolley wire and *V* is a voltmeter, the maximum reading of which must at least equal the voltage to be used in the test, so as to avoid liability of injuring the instrument. Voltmeter test line *a* connects the commutator of the armature under test to the negative side of the meter, and test line *b* connects the shaft to the ground. The test is conducted as follows: The two lines are first touched together, thereby placing the voltmeter between the trolley and the ground, so that it indicates full line voltage. Next, test line *a* is held on the commutator and test line *b* on the armature shaft, so that the voltmeter has, in series with it, the insulation to be tested. Assuming that the insulation is so good that the line voltage is unable to send through it sufficient current to affect the voltmeter perceptibly, the resistance of the insulation would, under the conditions of the test, be called infinite. As a matter of fact, however, it would not be infinite, as could be demonstrated by the use of a higher test voltage or of a more sensitive instrument; but the insulation would have to be good to prevent any deflection of the meter from a 500-volt service.

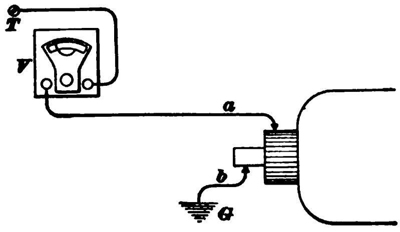


FIG. 33

Suppose that the line voltage is exactly 500, as indicated when touching the test lines together, and that including the insulation in circuit reduces the deflection to 250 volts; in this case, since the deflection of the voltmeter has been halved, the effect of introducing the insulation into circuit must have been to double the resistance of the circuit; therefore, if the resistance of the voltmeter is 70,000 ohms, the resistance of the insulation also must be 70,000 ohms. Now suppose that the deflection with the insulation in circuit is 125 volts; in this case the effect of introducing the insulation if the resistance of a certain line insulator is 1,000,000 ohms, the resistance of 1,000,000 similar insulators in parallel would be only 1 ohm, and a line voltage of 500 would cause a leakage current of 500 amperes.

LAMP-CIRCUIT PUNCTURE TEST

72. A satisfactory puncture test can be conducted by means of a high-potential circuit. Fig. 34 indicates connections that can be used in such a test. Here *a*, *b* are high-tension alternating-current lines. A bank of incandescent lamps is provided, consisting of ten lamps for a 1,000-volt circuit and twenty lamps for a 2,000-volt circuit. Test points are provided with long wooden or hard rubber handles, so that the high voltage can be applied without danger to the operator. Both sides of the test circuit are connected to a double-pole switch *c*; when this switch is open, test points *d* and *e* are dead. Switch *c* is preferably provided with a long wooden or fiber handle, so that the operator can open and close it without coming in contact with the high-tension lines.

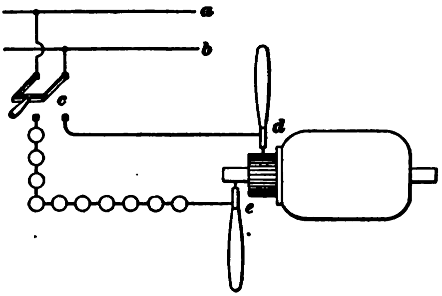


FIG. 34

73. The test is conducted as follows: The armature or field coil, as the case may be, is wheeled up within convenient reach of the test lines. The tester then looks to see that no spectator is in a position in which he may get hurt, and warns all of his assistants. Switch *c* is closed; then, taking the test lines up by their insulated handles, the two test points are held together so that the lighting of the lamps will show that the test circuit is in order; one of the test points is then placed on the armature shaft, or field shell in case a field coil is being tested, and the other on the commutator or line on the armature shaft and the other tapped along the surface of the commutator, the telephone will give no positive indication because, owing to the high resistance of the insulation that is included in its circuit, it can get no current.

Suppose, however, that a coil or commutator bar is grounded to the shaft or core by an insulation defect represented in the figure by a dot near *x*. In this case, the *b* test line is virtually in contact with the battery circuit at the point where the ground fault exists, and the *a* test line makes contact with the same circuit wherever the test point happens to rest on the commutator. With one test line resting on the shaft and the other test line resting on a grounded commutator bar, the telephone can get no current, because both of its terminals practically touch the shaft or core. Both ends of the receiver are at the same potential and current cannot flow between points that are at the same potential. Accordingly, on tapping the *a* test point on the commutator at the place shown in Fig. 35, the telephone will emit no clicking noise. At all other points on the commutator, however, the telephone circuit will shunt the stretch of battery circuit included between the ground fault and the point of contact of *a* on the commutator, and will therefore take a current, the value of which depends on how much of the armature circuit is shunted by the telephone circuit. The actual test consists in repeatedly tapping the *a* test line along the surface of the commutator until the point is found where the clicking sound emitted by the telephone ceases or becomes almost inaudible. The ground fault will be on the bar or coil corresponding to this point of least sound. The diaphragm of a telephone receiver will emit its characteristic clicking noise only when the current sent through the receiver coil is an intermittent or an alternating current. A steady current will draw the diaphragm up once, thereby causing it

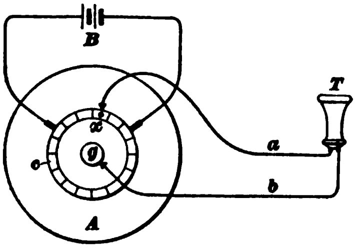


FIG. 35

to give out a single click, and will hold it in that position until the current is broken and made again. The idea of repeatedly tapping the test point on the commutator is to repeatedly make and break the circuit through the receiver coil, so that the receiver will click continuously as long as the proper conditions exist for causing it to do so. The same result can be obtained with much less labor by inserting in series with the battery circuit a current interrupter of some familiar kind, such as a buzzer or an electric bell.

BAR-TO-BAR TEST

76. Armatures may be tested for short-circuits by holding a nail near the revolving armature and noting whether or not the nail is strongly vibrated. If a coil is short-circuited, the nail will vibrate as the sides of the coil pass near it. Fig. 36 shows the connections used in making what is called the **bar-to-bar test** for short circuits in an armature. The bar-to-bar test will locate short circuits and open circuits and at the same time show the condition of the soldered connections between the coil and commutator ears to which it connects. In a two-circuit winding, there are two coils connected in series between adjacent commutator bars. Current from a dynamo, storage battery, or other controllable source of electromotive force is passed through the armature by means of contacts applied in the same manner and relation as are the motor brushes when the armature is in operation. *V* is a millivoltmeter, provided with flexible test lines terminating in spring contacts, rigidly held by hand so as to span the distance between commutator bars, but insulated from each other. The value of the current is adjusted by trial until the deflection obtained on applying the contact

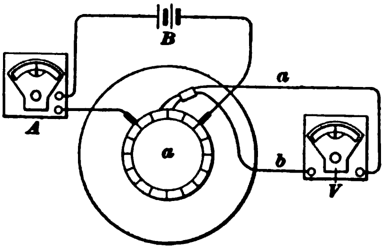


FIG. 36

points to adjacent bars is readable. The voltmeter deflection represents the potential difference required to force the current (one-half of the total current through the armature) through the resistance of the two coils spanned and their adjacent connections to the commutator.

In testing for short circuits, it is generally assumed that the resistance of properly soldered connections is negligible. Since the amount of deflection depends on the resistance of the two coils that are spanned and on the strength of the current flowing, any variation of the drop obtained on sets of coils successively tested will be due to variations in the resistance of those sets of coils, provided the current is kept constant throughout the test. Very slight variations in deflection will be unavoidable, because no two sets of coils are likely to be exactly alike, nor is it usually practicable to keep the current absolutely constant with the facilities generally available in a shop. Any serious variation in the resistance of a coil, such as that caused by a short circuit of some or all the turns of a coil, or set of coils, or by a short circuit between two or more coils, or by poorly soldered lead connections, will be indicated by an unmistakable discrepancy in the voltmeter readings. Attention is called to the fact that the accuracy secured by using a delicate millivoltmeter can be easily offset by using with it a high-range ammeter to indicate currents of a very low range. The error in reading the current and in keeping it at a constant value when an ammeter unadapted to the work is used will give rise to misleading results.

77. The test is conducted as follows: The armature is supported in bearings or on trunnions, so that it can be turned easily; the main current contacts are held in a frame that prevents their turning with the armature; the voltmeter is preferably supported several feet from the armature, so that its indications will not be affected by the magnetism of the armature. The armature is then slowly turned by hand, the test points being held stationary on the commutator and the voltmeter readings being observed as the successive pairs of bars pass under the test points. If any reading is strikingly low or high, the bars between which it was obtained are marked so as to be easily identified for thorough investigation afterwards. The low readings indicate short circuits and the high readings indicate poor lead connections.

78. Preliminary to conducting the bar-to-bar test, the test points should be applied to a few pairs of bars in the upper half of the armature, and then to a few pairs of bars in the lower half of the armature, in order to determine if either half of the winding contains an open circuit. One open circuit will not open the main circuit, because the armature has two paths through which current can flow from one contact to the other. Should the two test points happen to be placed across the two bars between which an open circuit existed, the low-reading voltmeter would be liable to injury as a result of being subjected to the drop of potential across a single armature path, and this drop of potential is much greater than the drop across a set of two coils. If, on applying the test lines to adjacent bars on one side of the armature, the deflection is uniformly too great, and the deflection is zero when the test lines are applied to adjacent bars on the other side of the armature, indications point to an open circuit in the winding, which must be removed, even if only temporarily and by means of a jumper, before the low-reading voltmeter can be used without liability to injury.

TELEPHONE TESTS FOR ARMATURE FAULTS

79. Fig. 37 indicates the connections for a very simple telephone test used for locating short circuits in completed armatures. Here a direct current, from a battery or its equivalent, is allowed to flow through the armature, by means of contacts, at the points occupied by the motor brushes in regular operation. *T* is a telephone receiver, provided with test lines and points *a* and *b*. When the test points are placed on two adjacent bars of the commutator of an armature in good condition and one of the points tapped on the bar near it, a humming sound will be emitted by the receiver; the intensity of the sound will be uniform when any two adjacent bars on the commutator are tested. As soon, however, as a test is made on a faulty armature and the test points include two bars between which a short circuit exists, the noise emitted by the receiver ceases or becomes almost inaudible. When the spanned armature coil, or the set of two coils, is short-circuited, the drop across the adjacent bars to which it is connected becomes almost or quite zero, according to the completeness of the short circuit, and the receiver either ceases to hum altogether or the humming becomes weaker. On the other hand, assuming that an open circuit exists between two commutator bars, when the two test points touch these bars the noise emitted by the telephone receiver is almost unbearable to the ear, because, when the receiver coil spans the two bars between which the open circuit exists, the receiver coil closes the open circuit and a larger than normal current is sent through the receiver. The receiver takes the place of the millivoltmeter in Fig. 36. The condition of the coils connected between two adjacent bars is indicated by the relative intensity of the noise made by the receiver.

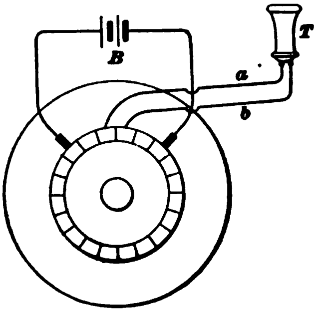


Fig. 37

TRANSFORMER TEST

80. Where there are a large number of armatures to be tested, an arrangement similar to that shown in Fig. 38 is very convenient for locating short-circuited coils. *A* is a laminated iron core with the polar faces *b*, *b* (in this case arranged for four-pole armatures). This core is wound with a coil *c* that is connected to a source of alternating current. The core is built up to a length *d*, about the same as the length of the armature core. The core *A* is lowered on to

I

NOTE.—All items in this index refer
section. Thus, "Adjusting starting-coil r
coil resistance will be found on page 58 of s