PAIGE FOUR-PASSENGER CAR

Courtesy of Paige-Detroit Motor Car Company, Detroit, Michigan

Automobile Engineering

A General Reference Work

FOR REPAIR MEN, CHAUFFEURS, AND OWNERS; COVERING THE CONSTRUCTION, CARE, AND REPAIR OF PLEASURE CARS, COMMERCIAL CARS, AND MOTORCYCLES, WITH ESPECIAL ATTENTION TO IGNITION, STARTING, AND LIGHTING SYSTEMS, GARAGE DESIGN AND EQUIPMENT, WELDING, AND OTHER REPAIR METHODS

Prepared by a Staff of

AUTOMOBILE EXPERTS, CONSULTING ENGINEERS, AND DESIGNERS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Fifteen Hundred Engravings

SIX VOLUMES

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost Automobile Firms and Manufacturers in making these volumes thoroughly representative of the very latest and best practice in the design, construction, and operation of Automobiles, Commercial Vehicles, Motorcycles, Motor Boats, etc.; also for the valuable drawings, data, illustrations, suggestions, criticisms, and other courtesies.

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WINTON SEVEN-PASSENGER TOURING CAR
Courtesy of The Winton Company, Cleveland, Ohio

EIGHT-CYLINDER COLE SEDAN
Courtesy of Cole Motor Car Company, Indianapolis, Indiana

Foreword

THE period of evolution of the automobile does not span many years, but the evolution has been none the less spectacular and complete. From a creature of sudden caprices and uncertain behavior, it has become today a well-behaved thoroughbred of known habits and perfect reliability. The driver no longer needs to carry war clothes in momentary expectation of a call to the front. He sits in his seat, starts his motor by pressing a button with his hand or foot, and probably for weeks on end will not need to do anything more serious than feed his animal gasoline or oil, screw up a few grease cups, and pump up a tire or two.

¶ And yet, the traveling along this road of reliability and mechanical perfection has not been easy, and the grades have not been negotiated or the heights reached without many trials and failures. The application of the internal-combustion motor, the electric motor, the storage battery, and the steam engine to the development of the modern types of mechanically propelled road carriages, has been a far-reaching engineering problem of great difficulty. Nevertheless, through the aid of the best scientific and mechanical minds in this and other countries, every detail has received the amount of attention necessary to make it as perfect as possible. Road troubles, except in connection with tires, have become almost negligible and even the inexperienced driver, who knows barely enough to keep to the road and shift gears properly, can venture on long touring trips without fear of getting stranded. The refinements in the ignition, starting, and lighting systems have added greatly to the pleasure in running the car. Altogether, the automobile as a whole has become standardized, and unless some unforeseen developments are brought about, future changes in either the gasoline or the electric automobile will be merely along the line of greater refinement of the mechanical and electrical devices used.

¶ Notwithstanding the high degree of reliability already spoken of, the cars, as they get older, will need the attention of the repair man. This is particularly true of the cars two and three seasons old. A special effort, therefore, has been made to furnish information which will be of value to the men whose duty it is to revive the faltering action of the motor and to take care of the other internal troubles in the machine.

¶ Special effort has been made to emphasize the treatment of the Electrical Equipment of Gasoline Cars, not only because it is in this direction that most of the improvements have lately taken place, but also because this department of automobile construction is least familiar to the repair men and others interested in the details of the automobile. A multitude of diagrams have been supplied showing the constructive features and wiring circuits of the principal systems. In addition to this instructive section, particular attention is called to the articles on Welding, Shop Information, and Garage Design and Equipment.

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SIDE VIEW OF PEERLESS EIGHT-CYLINDER MOTOR
Courtesy of The Peerless Motor Car Company, Cleveland, Ohio

GASOLINE AUTOMOBILES

PART IV

CLUTCH GROUP

TYPES OF CLUTCHES

Classification. Principal among the indispensable parts intervening between engine and road wheels, and one which may be a source of great joy or correspondingly great wrath, according to whether it be well or poorly designed and fitted, is the clutch. There are six forms into which clutches may be divided, although not all of them are in general use in the automobile. Only the first four are widely used on automobiles. These different forms are:

(1) Cone clutches
(2) Contracting-band, or drum, clutches
(3) Expanding-band, ring, clutches
(4) Disc and friction clutches
(5) Hydraulic, or fluid, clutches
(6) Magnetic, or electric, clutches

The necessity for a clutch lies in the fact that the best results are obtained in an automobile engine when run at constant speed. In as much as the speed of the car cannot, from the nature of its use, be constant, it requires some form of speed variator. This is the usual gear box, or transmission, but, in addition, there is the necessity of disconnecting it from the motor upon starting, since the engine cannot start under a load. There is also the necessity for disconnecting the two when it is desired to change from one speed to another either by way of an increase or a decrease. So, also, when one wishes to stop the car, there must be some form of disconnection. There are, then, three real and weighty reasons for having a clutch.

Requirements Applying to All Clutches. In a serviceable clutch there are two general requirements which are applicable to all forms. These are gradual engagement and large contact surfaces, although the latter requirement may be made to lose much of its force by making the surfaces very efficient. In the cone clutch, gradual engaging qualities are secured by placing a series of flat springs under the leather or clutch lining. By means of these springs, acting against the main clutch spring, the clutch does not grab, since the large spring must have time in which to overcome the numerous small springs. In this way, the engagement is gradual and the progress of the car is easy as well as continuous.

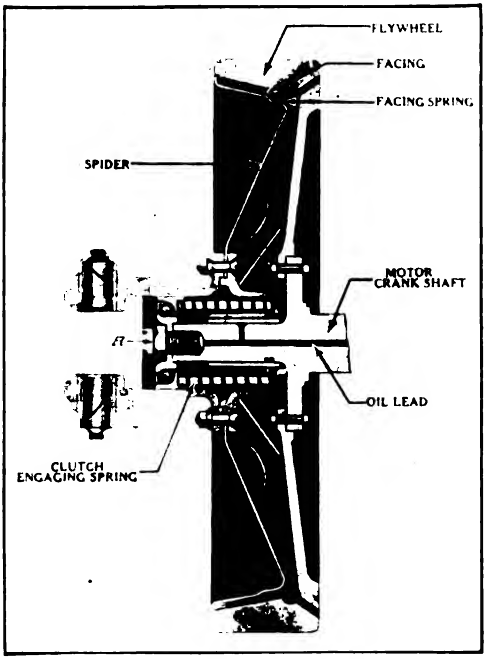


Fig. 246. Section through Studebaker Direct Cone Clutch
Courtesy of Studebaker Corporation, Detroit, Michigan

The specific necessity in a cone clutch, whether it be direct or inverted, is a twofold one—sufficient friction surface and proper angularity. The latter, in a way, affects the former, as will be discussed more in detail later. The angularity varies in practice from 8 to 18 degrees.

Cone Clutch. The cone clutch consists of two members, one fixed on the flywheel or other rotating part of the engine and the other fixed to the transmission shaft. The latter usually slides upon the shaft so as to allow engagement and disengagement. A spring holds the two together or apart, according to the type of clutch used. When the smaller-diameter member is spoken of, it is usually called the male member, while the part of larger size is spoken of as the female member.

The cone type is made in two different varieties: one in which the male member enters the female naturally at the open end is called the direct cone type; in the other, the male member is set within the structure of the female and is pressed outward toward the open end to engage it. This is called the inverted, or sometimes the reversed, cone clutch.

A great disadvantage of the inverted form is that the spring must be carried between the two cones, which means that it is inside where it cannot be reached for adjustment. This form causes trouble in assembling because the male cone must be put in place with the spring between it and the flywheel before the female can be set into its place and bolted up. These two big sources of trouble have caused designers to turn to the direct type more freely, as it lends itself readily to an external adjustment. If the spring is outside, it is easily put into place and as easily taken out.

An excellent example of the direct cone clutch is seen in Fig. 246, which shows the Studebaker clutch in section. The noticeable point about this clutch is its simplicity. It will be noted that the spring is entirely enclosed, so that when it needs adjusting the repair man must open the universal joint and operate the bolt *A* which regulates the tension of the spring.

Fig. 247. Direct Cone Clutch with Cork Inserts

Another good example of the simplicity of the cone clutch is seen in Fig. 247, which is an aluminum member with bosses cast for cork inserts. Between the inserts may be seen the flat heads of the copper rivets which hold the clutch facing in place. Obviously, this has the same disadvantage of internal, and thus inaccessible, spring.

In the cone type of clutch, shown in Fig. 248, the inaccessible spring is avoided. In addition, a number of small springs are used in place of one very large and very stiff one. The ease of adjustment and the greater ease in handling the springs make this clutch a much better design for average use from the repair man's point of view.

An example of the inverted-cone type is shown in Fig. 249, which shows the clutch on the four-cylinder Stearns-Knight. This type has an odd number of small springs equally spaced around the clutch, but these cannot be adjusted from the outside.

Contracting-Band Clutch. A short consideration of the band style of clutch shows that this does not differ radically from the ordinary band brake, either in construction, application, or actual working. The difference in the two lies in the fact that the band, as a clutch, is designed to transmit power with as little loss as possible, while the band as a brake is designed to absorb the forward energy of a moving vehicle in the shortest possible space of time, i.e., to waste as much power as possible.

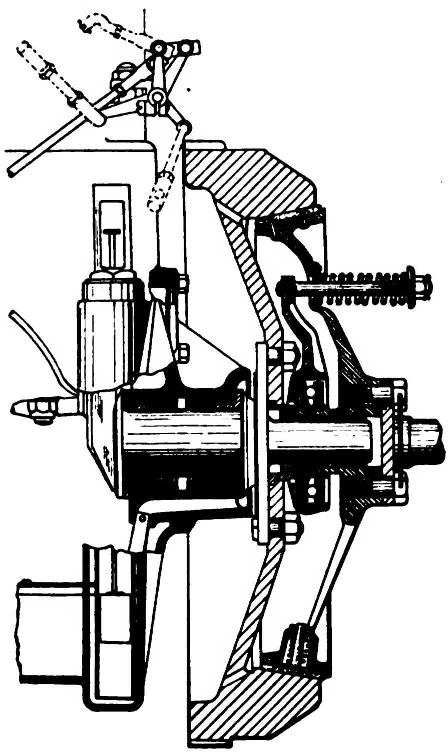


Fig. 248. Direct Cone Clutch with Small Springs and External Adjustment
Courtesy of Willys-Overland Company, Toledo, Ohio

Fig. 250 shows a typical contracting-band clutch. It will be noted that this clutch has the two parts, or sections, of the band united at the bottom and two operating levers pivoted at the top, where a single conical-shaped cam moves both outward and tightens the bands on the drum.

The usual place in which the band clutch is found is in connection with a planetary transmission. There the band is always used, and there it reaches its simplest form, that of the plain band wrapped around the drum. One end is fixed and the other attached to the braking, or more correctly, the clutching, lever. A plain pull on this effects the clutching action. A more modern and more efficient form has one end of the band attached to one extremity of the clutching lever, while the other end of the band is fastened to the middle of this lever. The clutching pull comes upon the upper extremity of the lever. Then the band acts to aid in clutching itself, i.e., a scissors action is obtained, and the required pull is lessened.

This construction can be seen quite plainly in Fig. 287, which shows the planetary transmission and bands used on Ford cars. In this, the low- and reverse-speed bands are shown in full. This is of particular interest as Mr. Ford is now the only American maker using the planetary form of transmission, all other makers, even of very low-priced machines—some below the Ford price—having gone to the selective sliding-gear form.

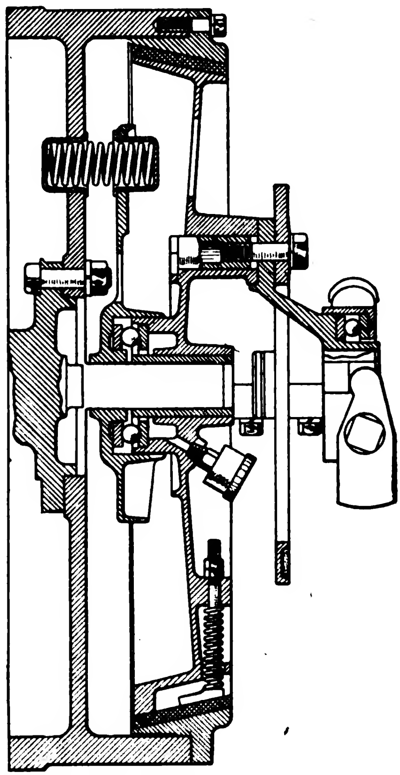


Fig. 249. Inverted Cone Clutch Used on Stearns-Knight Four-Cylinder Cars
Courtesy of F. B. Stearns Company, Cleveland, Ohio

Expanding-Band, or Ring, Clutch. The expanding-band clutch finds favor among few. Like the contracting band, which is very similar to the band form of brake, the expanding band is much like the expanding type of brake, except that the clutch is used to form the connection between two rotating parts. Viewed from the standpoint of pure engineering, the expanding band is little different from the cone type of clutch, granting that the angularity of the operating cam is the same as that of the cone.

Much depends upon how the band is expanded. This expansion is usually accomplished by means of screws, which may be either right-handed or left-handed or both.

Another form is expanded by a right-and-left screw operated by a lever. The lever, in turn, is moved by a pair of sliding collars on the main-clutch shaft, the clutch foot pedal moving these forward.

Disc Clutch. With its advent in 1904, the multiple-disc clutch has steadily grown in popularity, until today it is looked upon as the most satisfactory solution of the difficult clutch problem. Designers who have once adopted it, seldom, if ever, go back to another form, while of the new cars coming out from time to time nearly three-fourths are equipped with some form of disc clutch.

Popularity Compared with Other Forms. Statistics for 1914 showed that the disc form of clutch was easily the most popular type. Of 230 different chassis for 1914, 119 were equipped with disc clutches, 97 with the cone, 9 with a contracting-band type, and but 5 with an expanding-band form. The relative figures for 1916 were about 94

Fig. 250. Typical Contracting-Band Clutch

disc, 81 cone, no contracting band, no expanding band, and 1 electric. This would give the first-named approximately 54 per cent of the total.

Two Forms of Same Make. Reference to the types of clutch brings to mind the relative advantages of the two leaders, the cone and the disc. These are presented in a very striking manner in Figs. 251 and 252, which show the cone and disc clutches used interchangeably by the Warner Gear Company, Toledo. These clutches are designed to be interchangeable, consequently the general layout is the same. It will be noted that the cone is somewhat simpler than the disc, as it has fewer parts which take up room. The design is such that the internal spring of the cone can be adjusted from the outside as can the outside spring of the disc. An interesting point in this connection is that the transmissions also are interchangeable, although the type, Fig. 252, with roller bearings is intended for a moderately heavy passenger car, while that in Fig. 251 is for lighter work.

Simple Types. The simple types differ in number and shape of discs, method of clutching, material, and lubrication; but in principle all are alike. This clutch is one in which the flat surfaces properly pressed together will transmit more power with less trouble than any

Fig. 251. Typical Three-Speed Gearset with Cone Clutch for Unit Power Plant
Courtesy of Warner Gear Company, Toledo, Ohio

other form. By multiplying the number of surfaces and making them infinitely thin, the power transmitted may be increased indefinitely. That this is not idle fancy is shown by a number of very successful installations of 1000 horsepower and over in marine service.

The minimum number of plates in use is said to be three, but very often the construction of a three-plate clutch is such that one or two surfaces of other parts are utilized, making it a two- or even one-plate clutch in reality. In the Warner clutch, shown in Fig. 252, there are really but two clutching surfaces, the face of the inner plate against the flywheel and the outer face against the engaging disc. Both plates are faced with suitable friction surface but it really is a one-disc clutch.

Multiple-Disc Clutches. The modern tendency in disc clutches, however, is away from those of few plates requiring a very high spring pressure—since the friction area is necessarily limited—toward the multiple-disc variety, in which a very large area is obtained. The large area needs a very light spring pressure, and

Fig. 252. Typical Three-Speed Warner Gear Box Shown in Fig. 251, but with Disc Clutch

consequently it is easier to engage and disengage the clutch. For this reason, the multiple disc is becoming more popular with owners and drivers than the variety requiring the extra-heavy effort. The construction of the three-plate disc clutch does not differ radically from one maker to another. Three fingers are used to clutch and declutch generally, the amount of movement being adjustable. A single spring of large diameter and large-size wire is generally used, and sheet steel is used for one-half the clutch plates. Between the three-plate and multiple-disc are many gradations.

In the true multiple-plate clutch, there are three general varieties met with in practice: the metal-to-metal with straight faces; the metal-to-metal with angular or other shaped faces designed to increase the holding power; and the straight-face kind in which metal does not contact with metal, one member either being lined with a removable lining or fitted with cork inserts.

Metal-to-Metal Dry-Disc Type. The metal-to-metal method has the additional advantage of having the central part within which the clutch is housed very small in diameter, so that the portion of the flywheel between the rim and the clutch housing may be made in the

Fig. 253. Multiple-Disc Clutch and Transmission of Winton Cars
Courtesy of Winton Motor Car Company, Cleveland, Ohio

form of fan spokes that convert it into a fan which serves to cool the motor better.

As the various examples of disc clutch shown would indicate, the designer has had his choice between a few large discs and a large number of small ones. If he chose the former, the clutch could be housed within the flywheel, but that would make it inaccessible. If he chose the latter, the clutch could not be kept within the flywheel length. A separate clutch housing would be a necessity, but the clutch could be made accessible and flywheel fan blades could be used.

Another example of the plain metal-to-metal disc clutch is shown in Fig. 253. In this case also the clutch is not housed in the flywheel, as in most of the preceding examples of this form of clutch, but in the forward end of the transmission case, that is, instead of motor and clutch forming a unit, the clutch is a unit with the transmission. It is claimed that this position makes it more accessible, since it brings the clutch directly under the floor boards of the driver's compartment where it can be lubricated better. The lubrication is effected through communication with the gear part of the case, which is always filled with lubricant.

In the figure it will be noted that there are 13 driven discs, with keyways, which hold them to the driven drum. Note that the drum is held to its shaft by means of a pair of large set screws. The clutching springs are of small diameter and size, spaced equally around the periphery of the discs; each disc is enclosed in a small and thin metal casing. Attention is called also to the universal joint shown. This joint forms the rear end of the driving connection with the flywheel, which will be referred to later. These discs are flat-stamped out of sheet steel with the proper keyways for internal or external holdings.

Use of Facings. The more modern disc clutch has two sets of sheet metal discs, one of which is faced on one or both sides with a special material. Without a single exception, all the disc clutches shown have had plain discs against plain discs. This makes a simple and fairly inexpensive construction, but one that is not very efficient. The most recent tests have shown that metal against metal gives a coefficient of friction of but .15, which is reduced to .07 when the surfaces become oily or greasy. With one of these contacting faces lined with leather, the coefficient rises to .23 when dry and to .15 when oiled. Again if fiber is used for the facing, the coefficient becomes, respectively, .27 and .10, while with cork or with cork and leather, it becomes, respectively, .35 and .32. Here is a very apparent reason for (1) facing the clutch discs, and (2) running them dry.

By going over these figures, it will be noted that discs with almost any form of facing will show an increase in efficiency over the same discs without facing, varying from 60 up to almost 300 per cent. Again, any form of disc clutch, faced or otherwise, will show a much higher coefficient when dry than when oiled and thus a greater efficiency. These two facts point out the obvious reasons for the modern tendency toward the multiple-disc clutch, faced and running dry.

To present an example of the faced type, Fig. 254 shows the multiple-disc clutch of the eight-cylinder V-type Cadillac. In this illustration the eight driving discs can be seen with the facing on each side of each one. This facing is of wire-mesh asbestos, and between each pair of discs comes a plain driven disc, so that it has a facing of the asbestos against each side of the metal which it grips. The keys holding the inner discs to the shaft can be seen on the

Fig. 254. 1917 Cadillac Clutch and Transmission, Showing New Clutch Drive
Courtesy of Cadillac Motor Car Company, Detroit, Michigan

end of the housing, while the slots into which the keys project can be seen on the discs. By examining the group closely, the driven plain discs can be seen between each pair of the drivers. The method of driving these discs through a multiplicity of keys and grooves is unusual, but it is a good example of Cadillac thoroughness. Fig. 254 also shows the pedals and the exterior of the clutch case where it bolts up to the engine. This indicates how a unit power plant simplifies the control group and eliminates parts.

Floating Discs a Novelty. The clutch on Locomobile cars, shown in section in Fig. 255, is very much like the Cadillac just shown, except for the novel feature that the fabric facings are not attached either to the driving or to the driven discs but float between them. This fabric, usually a woven asbestos material with a central core of interwoven metal wires, instead of being attached to both sides of every other disc or to one side of every disc, is not attached at all. The rings for the fabric discs are made up in the form of annular rings. They have the same inner diameter as the inside of the

Fig. 255. Floating Dry-Disc Clutch Used on Locomobile Cars

driving discs and the same outside size as the driven discs; consequently, assembling one of these clutches is simply a question of piling first a driven disc, then a fabric, then a driving disc, and so on.

The fact that the fabric rings are not united to either of the metal discs allows them to free themselves with remarkable rapidity so that either on engagement or on declutching the action is very quick.

Greater Power Transmitted by Surfaces Not Plane. To increase the power transmitted by a clutch of given size, either the number of plates must be increased or the form of the surface changed. The latter method was followed on the clutch of the French car "Ours."

The discs of this unusual clutch had a perfectly flat outer portion and a conical inner portion, only the latter taking part in the transmission of power. In this disc form, then, we have the advantage of the disc economy of space, together with the advantages of the cone clutch and the additive gain of running in a bath of oil.

Another form utilizing this principle, and one that is more widely used, is that known as the "Hele-Shaw" so named from its inventor, the famous English scientist, Dr. H. S. Hele-Shaw. This is essentially a flat disc, as shown at *A*, Fig. 256, with a ridge *B* at about the middle of the friction surface; this ridge consists of a portion

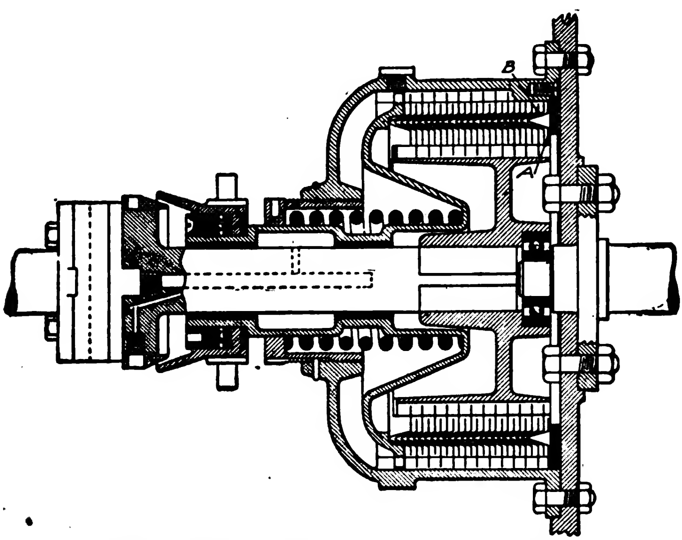


Fig. 256. Hele-Shaw Disc Clutch, Showing Cone Surfaces

of the surface, which has been obtruded during the stamping process in such a way as to leave the surface of the ridge in the form of an angle of small height. The angle used is 35 degrees, and this value has been determined upon experimentally as the best. Fig. 256 shows a cross-section through an assembled clutch, which reveals the clutch angle very plainly. In use, the ridges nest one on top of the other; and in the extreme act of clutching, not only the flat surfaces but both sides of the ridge are in contact with the next plate. Thus, not only is the surface for a given diameter increased, but the wedge shape is also taken advantage of.

Hydraulic Clutches. All the methods of engaging and disengaging the engine at will, as discussed before, have been of a mechanical nature. The hydraulic clutch, on the other hand, partakes more of the fluid nature, although it is operated by mechanical means. Ordinarily, it is in the nature of a pump with a by-pass, the pump working at ordinary speeds to force the heavy liquid, usually glycerine, through the by-pass. To clutch up tightly, however, the by-pass is closed and, the liquid being unable to circulate while the pump continues to operate, the whole device is rotated as a unit. In this case it operates just as any other clutch, but, due to the sluggish action of the fluid, it is slower to respond. Then, too, the grave question of leakage is always present, and the smallest leak puts the clutch entirely out of use. These disadvantages, together with the necessary complications, have retarded the development of the hydraulic form so that there are few of that type in use today.

Magnetic Clutch. All the foregoing clutches present in one form or another very complicated devices for freeing the transmission shaft from the engine shaft, but the magnetic clutch is a device which has simplicity for its foremost argument. The magnetic clutch consists primarily of three parts: the field, usually in the form of a ring; the armature, always of ring shape; and the oil casing shaped to accommodate the other parts, its function being that of a cover. The armature is a simple cast-iron plate of rectangular section, adapted to be drawn into engagement with the field when the latter is energized.

The field, on the other hand, is made up of the back plate, the inner and outer field rings, the magnetizing coil, and the contact rings. In operation, the accelerator is energized by closing the electrical circuit, which sends a current through the field. This magnetism attracts the armature, which then moves laterally, closing the very small gap between the two. The oil in which the whole clutch works prevents it from taking hold suddenly, or gripping, but as this oil film on the two surfaces is gradually squeezed out, the clutch as gradually takes hold.

New Electric Generating Clutch. So great has been the interest in the various electrical mechanisms in the automobile, and so quickly has the public taken up with all these that this has stimulated an entirely new invention, called by its maker, the Vesta

Accumulator Company, Chicago, a centrifugal electric-generating clutch. This name gives a little clue to its action, which is that of a combination of the usual friction clutch and that of the electric-magnetic drag between armature and fields of any electric machine.

In addition to its clutching feature, its ability to drive when partially clutched makes it, in effect, a transmission, so that it is designed to replace the usual clutch, gearset, flywheel, electric generator, and starting motor. It is composed of two parts: an armature, which becomes the flywheel; and a field mounted on the propeller shaft. The former carries an internal commutator, and the

Fig. 257. Field Unit of the Vesta Centrifugal Electric Clutch
Courtesy of Vesta Accumulator Company, Chicago, Illinois

latter carries brush holders which hold brushes against the commutator. These brushes are mounted so that the centrifugal force of rotation increases the force with which they press against the commutator. Thus there is a variation from practically no contact up to the maximum, at which point the centrifugal force is so great that field and armature revolve as a solid unit.

This construction is well indicated in the two illustrations of this device, Figs. 257 and 258. Fig. 257 shows the field unit mounted on the propeller shaft in which *F* is one of six field poles, *B* a brush, and *C* one of the collector rings. Fig. 258 is an external view which shows the clutch assembled. In this illustration the brushes *B* are shown pressed out against the commutator by the centrifugal force.

An automobile built in France—the Ampere—uses the electric-generating clutch construction exclusively, the master clutch being dispensed with in favor of an individual-clutch transmission. The differential is dispensed with, and in its place a pair of magnetic clutches—one for each wheel—are used. The differential action is

Fig. 258. Assembled Vesta Electric Clutch
Courtesy of Vesta Accumulator Company, Chicago, Illinois

obtained on curves by decreasing the current to the clutch on the inner wheel up to a certain point, at which it is cut off entirely. This gradual reduction and cutting off of the current is accomplished automatically by the movement of the steering wheel.

DETAILS OF CLUTCH OPERATION

Methods of Operation. Practically all modern clutches are operated by means of a special pedal moved by the left foot. The pedal is connected to the internal member by means of rods and levers, which compresses the clutch spring or springs and allows the clutch members to separate. This throws the clutch out. To throw it back in, remove the foot pressure from the pedal, and the springs again exert pressure and force the parts together. This action causes them to take hold. There was a time when a considerable number of cars had the clutch so constructed that the pedal held it in and the springs threw it out, just the reverse of the present plan. This method is no longer used, as it necessitated a constant pressure on the pedal while driving—a very fatiguing process.

Gradual Clutch Release. The Dorris clutch, made by the Dorris Motor Car Company, St. Louis, Missouri, Fig. 259, is a new arrangement of the clutch pedal, and its operation is such that the clutch is released or thrown out with very light pressure on the pedal. Pressure on the pedal *A* is transmitted by the shorter lever arm *B*, thus greatly increasing the leverage. This pressure is transmitted to lever *C* and through it to lever *D*, these two being hung on the frame cross member *E*. As *C* is much longer than *D*, there is another multiplying action here. This does not act directly upon the clutch but upon the upper end of the clutch shifter *F*, which is attached to the clutch at *G* and pivoted at its lower end *H*—here again in a multiplying action. The net result of these three multiplications is a combination which will release the strongest and stiffest clutch with a very slight pressure of the foot.

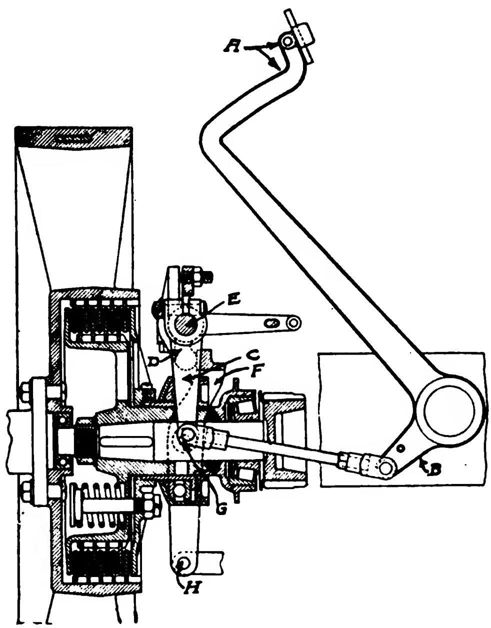


Fig. 259. Multiplying Lever of Dorris Clutch to Make Pedal Pressure Light
Courtesy of Dorris Motor Car Company, St. Louis, Missouri

Clutch Pedals. It has been the general practice in the past to have the clutch pedals separate and distinct, with the service-brake pedal on a concentric shaft occasionally. Now, however, the rapidly growing practice of simplification and elimination, combined with the wide use of the unit power plant, is eliminating the so-called clutch shaft with its bearings and fastenings to the frame, to the clutch operating yoke, and to many other parts. As the Cadillac illustration, Fig. 254, shows and as the Buick drawing, Fig. 260, shows even better, all these shafts, rods, and fastenings can be eliminated and the pedals and levers mounted directly on or in the power unit. In the Buick illustration, the foot brake has a simple rod connection from the ear *A* on the pedal to the brake-operating system, while the

Fig. 260. Unit Power Plant of New Small Buick Four
Courtesy of Buick Motor Company, Flint, Michigan

hand brake has a similar connection from the extended lower end of the rod *B* to that brake-operating system. In this simple way, perhaps 40 or more pieces are eliminated and their weight saved.

Clutch Lubrication. As has been previously pointed out, some clutches run in oil, while others run dry. The former type must be kept filled with lubricant at all times. The general plan in such a case is to provide a lead from the engine oiler when the clutch case is separated from the engine case or a connecting means when the two are in one case. In addition to the actual clutching members, there is practically always a sliding member, which must have lubricant of some form, while the thrust bearings to take the thrust of the clutch springs must be cared for. Generally, these two cases are cared for by a pair of grease cups, which are visible in Figs. 247 and 249. The operating rods are lubricated usually by means of small oil holes, either drilled directly into the part or covered with a small oil cup. In those cases in which the clutch runs in oil, it will be noted that a filling plug is provided, by means of which additional lubricant can be poured into the casing, Fig. 256.

Clutch-bearing lubrication is highly important, particularly with clutches like the cone which must be kept free from lubricant and the dry disc in which lubricant is not used. Where the clutch itself runs in oil, it is a simple matter to lubricate the bearings, but in the other cases, oil or grease must be provided from one of three places: from a prolongation of the engine oiling system, as shown in Figs. 246 and 251; from the outside—generally by means of grease cups—as just discussed; or from the transmission end. The last form is used only in unit power plants; combinations of clutch and transmission, as shown in Fig. 253; and in cases, Fig. 256, where the construction allows a grease or an oil cup attachment at the transmission end, the transmission itself being some distance away.

Clutch Bearings. The need for bearings in a clutch depends somewhat upon its nature and location, but regardless of these a thrust bearing is needed for the clutch spring. To explain this briefly, it is known that action and reaction are equal, and opposite in direction. For this reason, when a clutch spring presses the discs or parts together with a force of, say, 100 pounds, there is exerted in the opposite direction this same force of 100 pounds. In order to have something for this to work against, a bearing is used, and since it takes up this spring thrust, it is called a thrust bearing. Not all bearings are fitted to take thrust, as the majority are designed for radial loads only. For this reason a special design is needed.

When the clutch is incorporated in the flywheel, two additional bearings — one for the end of the crankshaft and another for the transmission or driven shaft—are generally needed. The bearings will be noted in Figs. 246, 248, and 249, although the transmission-shaft bearing does not have the clutch combined with the engine but rather with the transmission. In the majority of cases, it will be found that a means of fastening the end of one shaft has been worked out so as to eliminate one bearing. This accounts for the large number which show but two—the thrust and one other. In looking back over the clutches, it will be noticed also that nearly all the bearings are of the plain ball form. This is due in large part to the fact that the plain ball bearings take up the least room for the load carried, both in diameter and width—a contributing reason being the fact that in many cases one of the shafts or parts can be formed to take the place of either the inner or outer ball race.

Clutch Adjustment. Adjusting a clutch, as a rule, is not a difficult task as there are but two possible sources of adjustment—the throw or movement of the operating pedal or lever and the tension of the spring. An adjustment is generally provided for each. When the fullest possible throw of the pedal does not disengage the clutch, an adjustment is required to give a greater throw. If the throw is correct, but the clutch takes hold too quickly and vigorously, the spring pressure can be lessened somewhat to soften down this action. On the other hand, when dropped in quickly, if it takes hold slowly, more spring pressure is needed, and it should be tightened.

Clutch Accessibility. Clutches are made accessible in two ways: by their location on the car and by the relative ease with which they can be removed. Accessibility as to location is less in the various combinations, such as in the unit power plant, housed within the flywheel, or combined with the transmission. Ease of removal is determined by the number and location of the joints (usually universal) used with the clutch.

CLUTCH TROUBLES AND REMEDIES

The very fact that the clutch is a more or less flexible, or rather, variable, connection between engine and road wheels makes it necessary that it be kept in the best of shape. It is rather surprising to the novice with his first clutch trouble to have his motor racing at the highest possible speed and to find his car barely moving, but to the experienced driver it is humiliating.

Slipping Clutch. Slipping is the most common of clutch troubles. This is brought about in a cone clutch by oil, grease, or other slippery matter on the surface of the clutch and can often be cured temporarily by throwing sand, dirt, or other matter on the clutch surface, although this is not recommended. Many times, the clutch leather, or facing, becomes so glazed that it slips without any oil or grease on it. In that case it is desirable to roughen the surface. This may be done by taking the clutch out, cleaning the surface with kerosene and gasoline, and then roughing-up the surface with a file or other similar tool.

In case it is not desired to take the clutch out, or when it is very inaccessible, the clutch surface may be roughened by fastening the clutch pedal in its extreme out position with some kind of a stick, cord, or wire, and then roughing the surface, as far in as it can be reached, with the end of a small saw, preferably of the keyhole type, as shown in Fig. 261. Before starting this repair, it is well to soak the leather with neat's-foot oil. This softens the leather and makes the roughening task lighter.

Many drivers make the mistake of driving with the foot constantly on the clutch pedal. This wears the leather surface and helps it to glaze quickly. The constant rubbing from frequent slipping makes the leather hard and dry.

When a metal-to-metal oiled clutch slips, the trouble usually is in the clutch spring, which is too weak to hold the plates together. To remedy slipping with this type, it is necessary to tighten up the clutch-spring adjustment.

Clutch troubles are not always so obvious. In one instance, the clutch slipped on a new car. In the shop, the clutch spider seemed perfect and properly adjusted, also the spring, but to make sure, a new clutch was put in. Still the clutch slipped. To test it out still farther, the linkage was disconnected right at the clutch and then it held perfectly, showing that the trouble was in the linkage. On examination one bushing was found to be such a tight fit that it would not allow the pedal to move freely enough to release the clutch fully. When this was relieved a little, the clutch acted all right.

Replacing Clutch Leathers. Clutches offer many chances for trouble. The most frequent causes are the wear of leather facings with the attendant loss of power, and weak springs. Weak springs may be cured by screwing up on the adjusting nut or bolt provided.

Slippery leather may also be corrected by washing first with gasoline and then with water, finally roughing the surface with a coarse rasp and replacing only after the leather is thoroughly clean. Dry leather is fixed by soaking in water or neat's-foot oil. It should be replaced while still moist, and copious lubrication will keep it soft.

The greatest problem in replacing a worn, charred, or otherwise defective leather lies in getting the right layout for the form of the new leather the first time. It must be remembered that the surface is a portion of a cone and, therefore, its development is not easy. It is attacked in this manner: Prepare the cone by removing the old leather and all rivets, cleaning out the rivet holes, and providing new rivets. Measure the cone, taking the diameters at both the large and small ends and also the width. Take a large sheet of paper and lay off upon it a figure similar to $ABCD$, Fig. 262, drawn to exact scale and having for its dimensions the three measurements just obtained, viz, the large and small diameters and the width of the cone. This figure represents the projection of the cone in a flat plane. Bisect the line AD and draw the center line EF at right angles to AD. Prolong the two tapered lines AB and DC until they meet the center line as at G.

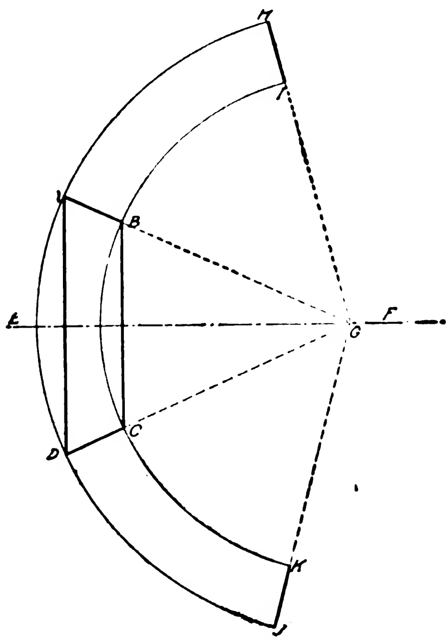


Fig. 262. Diagram Showing How to Cut Clutch Leathers

The point G represents the apex of the cone if it were complete, and hence any circular arc with the correct radius, drawn from this point as a center, will be a correct projection of the development of that portion of the conical surface. With GA and GB as radii, draw the two circular arcs $HADJ$ and $IBCK$, also draw the radial lines HI and JK to pass through G. The enclosed figure

HIBCKJDAH may then be cut out and used as a pattern from which to cut out clutch leathers. If the distances *AH* and *DJ* be made approximately equal to or slightly more than *AD*, the pattern will a little more than encircle the cone clutch.

After the leather has been cut out, it should be prepared by soaking in water or oil, according as its surface is fairly soft or rather harsh. In either case, it must be well soaked, so as to stretch easily. In putting it on the cone, one end is cut to a diagonal, laid down on the cone, and riveted in place. Next, the leather is drawn down tightly past the next pair of rivet holes, which are then driven into place. This is continued until the strip is secured. The leather is now wetted again, for, if allowed to dry off immediately, the shrinking action will break it out at most of the rivet holes and render it useless. By drying it out gradually, a taut condition may be arrived at without this danger.

Handling Clutch Springs. Clutch springs, like the valve springs mentioned previously, are mean to handle and compress. The best way is to compress and hold them compressed until needed. For this purpose, a rig similar to that described for valve springs should be made but of stiffer stronger stock. A very good one can be made from two round plates, one small, and the other of larger diameter with a pair of L-shaped bolts through it. The spring is placed between the two, with the ends of the L's looped over the smaller plate, and then, by tightening the nuts on the bolts, the spring is gradually compressed.

Courtesy of "Motor World"

An excellent device for holding clutch springs consists of a simple pair of metal clamps which are joined together by three or more short metal bars, as Fig. 263 shows. If one particular clutch spring is handled continuously, the length can be made to fit this best, otherwise it will have to be made of any convenient length. The inside diameter of the clamps when fully open is greater than the outside diameter of the spring. The clamp is set in a vise or on a drill press and the spring set inside of it. Then the spring is compressed by working the vise handle or by lowering the drill-press spindle. When compressed down to the length used in the car, the ends of the clamp are tightened and the spring is held by friction. Then the spring can be handled readily, using one of the metal bars as a handle. It is put into place, and then the retaining screws can be loosened and the clamp removed.

Fierce Clutch. A fierce clutch is one that does not take hold gradually but grabs the moment the clutch pedal is released. In a metal-disc clutch, this is caused by roughened plate surfaces and insufficient lubricant, so that. instead of the plates twisting gradually across each other as the lubricant is squeezed out from between them, they catch at once and the car starts with a jerk. On a cone clutch, this fierceness is produced by too strong a spring, too large a clutching surface in combination with a very strong spring, or a hard or burned clutch surface or both.

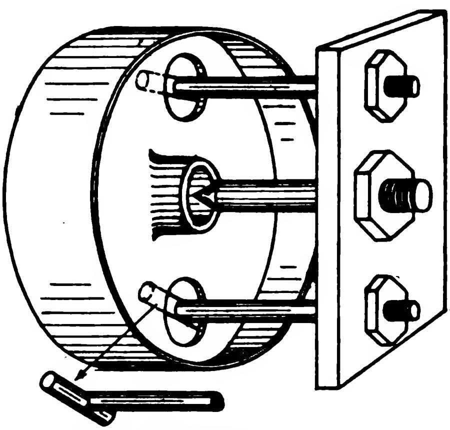


Fig. 264. Simple Rigging for Removing Ford Clutch Disc

Ford Clutch Troubles. There are now so many Fords in use that the average repair man feels justified in making special apparatus or tools to save time or work in Ford repairs. For one thing, the clutch-disc drum frequently needs removal and this is a difficult job. By means of a simple rigging, however, consisting of a plate and a few bolts, it can be taken off in a few moments and with little trouble. It will be noted from Fig. 264 that the rigging is but a modified form of wheel puller. It consists of a $\frac{1}{4}$-inch plate of steel with three holes drilled in it for three bolts. The two outside ones have T-head ends and have to be specially made, and made carefully, as this T-head must slip through either one of the oval holes in the web of the drum. When this is done, it is straightened up so as to stand at right angles to the drum and is thus in a position to press firmly against the drum from the inside. There are nuts on the center bolt on both sides of the plate, but the drawing shows only that on the outer end. When the T-bolts are in place, the center bolt, which is slightly pointed and preferably hardened on the end, is screwed down so as to come into contact with the end of the clutch shaft. After tightening the center bolt, the T-head bolts are tightened until they pull the drum off the shaft.

Clutch Spinning. A trouble which is bothersome but not dangerous is clutch spinning. This is the name applied to the action of the male clutch member when it continues to rotate, or spin, after the clutch spring pressure has been released. With the male member connected up to the principal transmission shaft and gear, as is often the case, these members continue to rotate with it. This gives trouble mainly in gear shifting, for the member which is out of engagement is considered to be at rest or rapidly approaching that condition. When at rest, it is an easy matter to mesh another gear with this one; but when this one is rotating or spinning, it is not so easy, particularly for the novice.

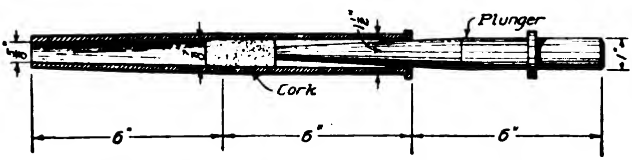


Fig. 265. Simple Device for Inserting Corks in Clutches

Clutch spinning may be caused (1) by a defect in the design, in which case little can be done with it; (2) by a defect in construction, as in balancing, for instance, which can be corrected; or (3) it may be due to external causes, as, for instance, in a bearing which has seized, owing to a lack of lubricant, etc.

In any case, the best and quickest remedy is a form of clutch spinning brake. This may consist simply of a small pad of leather or of metal covered with leather so located on the frame members that the male drum touches against it when fully released. Or it may be something more elaborate as to size or construction or both. On many modern cars, in fact on practically all good cars, some form of clutch spinning brake is fitted. Thus, the Hele-Shaw design provides at the left end, Fig. 256, a metal cone of small diameter, while Fig. 255 shows flat concentric discs *19* of the Locomobile clutch.

Cork Inserts. When cork inserts are used in a clutch, the insertion of new corks is not an easy job. A cork is a difficult and unhandy thing to work with, and above all to hold straight and true while applying longitudinal force to it. By making up a special tool with a tubular member having an inner taper, into which the corks are forced by means of a special plunger which forms the other part of the tool, this is simplified considerably. This tool is shown in Fig. 265, with such dimensions as would be needed for a ⅞-inch cork. It is advisable to make the small end of the tube ⅛ inch smaller than the cork, as this amount provides the proper compression. After being soaked in water for 10 or 15 minutes, the cork is dropped into the large end of the tube, and, with the small end in place against the cork opening in the clutch, a single stroke of the plunger will force the cork through the tool, incidentally compressing it into the hole in the clutch. With a few handlings any clever mechanic can soon become expert in the use of this tool.

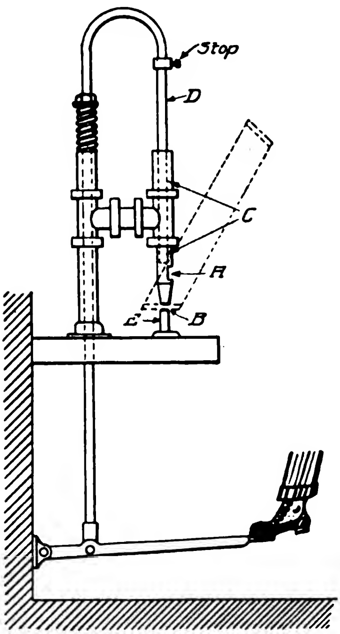


Fig. 266. Machine for Handling Cork Inserts Quickly
Courtesy of "Motor World"

A more elaborate device, but one which works more quickly where there is a great deal of this work, is shown in Fig. 266. This is not an expensive machine — the original of this sketch was home made. The framework is made of standard pipe fittings, the spring is a valve spring, and the rods are cold rolled steel. Only a few pieces such as the working member *C* were specially made. The working member is made with a slot at *A* into which the corks are inserted. When the pedal attached to the rod *D* is pressed, it brings the rod down and forces out the cork at *B*. At point *B*, the clutch resting on the anvil *E* is held ready. The stop limits the downward movement, so a strong stroke of the foot will just push the cork into the hole flush and no more. The lower end of the working member is made with a taper so as to compress the corks about ⅛ inch, as mentioned before. They should be soaked in water just the same as when using the hand tool.

In Fig. 267, several other common clutch troubles and their remedies are suggested; the parts shown in the illustration, however, are in excellent condition, in fact, new.

When the right kind of clutch discs for a multiple-disc form are not on hand, new discs can be cut from leather to answer the purpose by means of the gasket cutter, shown in Fig. 268. This cutter consists of a pair of steel L-shaped arms, preferably forged, with points sharpened enough to cut the leather or the gasket material. The clamp has a point for the center of the circle on its under side, while

Fig. 267. Clutch Troubles Illustrated

the actual clamping is done by the bolt or screw with wing head. To use for clutch discs, set the inner, or shorter, member to the radius of the inside of the outer discs and the outer, or longer, arm to the radius of the outside of the inner discs. By pressing down hard on the arms and rotating them at the same time, an annular ring will be cut out which will fit exactly. One hand should be held on or near the center, while the other hand supplies the pressure and rotating motion on the cutting ends. It should not be expected that the points will cut through in one revolution; on the contrary, the first time around will just mark out the section and it will need from

6 to 10 revolutions, with heavy pressure, to cut a leather disc. In time, the workman will become skilled in the use of this cutter and

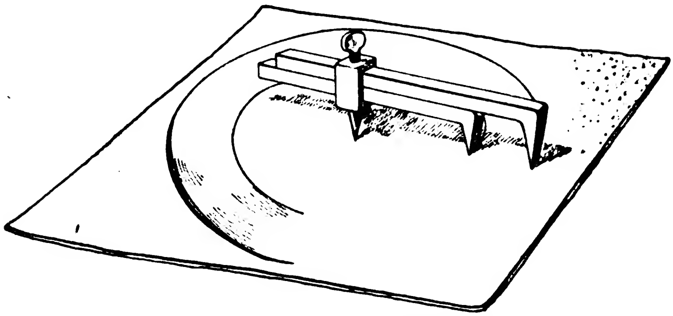


Fig. 268. Method of Cutting Facing for Disc Clutches in an Emergency
Courtesy of "Motor World"

have a knowledge of its limits, as well as of the method of keeping it in good cutting order.

Adjusting Clutch Pedals. Some cars are made with adjustable clutch pedals so the long- or short-legged driver can set the length of these to suit, but when no adjustment is provided and it is desired to change the length, some figuring must be done. To shorten a non-adjustable pedal, the best way is to take it out of the car and bend it somewhat on the order of the dotted lines in Fig. 269. The idea is to make the same amount of metal take a roundabout and longer path. In doing this, the workman must be governed largely by what the floor boards and the other parts of the mechanism in the immediate vicinity will allow. The bend must be made so as to allow the pedal to work in the same slot. If necessary, cut the slot a little longer, but first consider the result before bending the pedal.

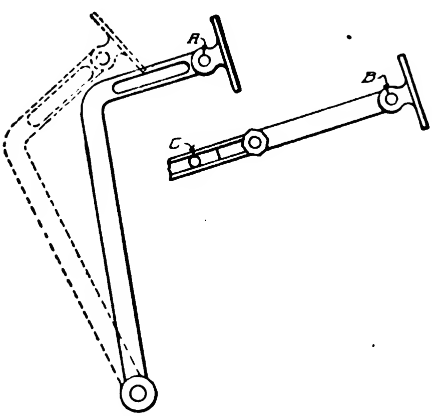


Fig. 269. Schemes for Shortening or Lengthening Clutch Pedals to Fit Driver

On the other hand, when the pedal is too short, the pad can be removed from where it is bolted on at *A* and a pair of steel strips cut so as to fit into the two sides of the pedal shank and brought together at the other end. These are bolted in at A, where the pad was formerly, and the pad moved out to the new end at B. In some such cases, where the sides of the pedal shank offer no groove to help hold the steel strips, it is necessary to put another bolt through them, as at C, to prevent the whole addition swinging about A as a center.

Clutch Troubles Outside of Clutch. Frequently, there is trouble in the clutch when the basic reason for it is outside of the clutch entirely. Thus, failure of a clutch to engage or disengage properly is often the fault of the connecting rods and levers; wear in the clutch collar or in other parts; or the emergency-brake interlock may have been fitted so close that as soon as the rods are shortened once or twice to compensate for wear, it stands in such a position as to throw the clutch out slightly although the latter appears to be fully engaged.

Another clutch trouble outside of the clutch is apparent slipping at corners, especially at turns on grades. On a turn—the road being cambered—the frame is distorted, especially with the combination of curve and grade. This may be sufficient to throw the clutch and driving shaft out of alignment just enough so the clutch face will not make full contact. This is most noticeable on cars with a single universal joint, in which case the distortion of the frame has more effect on the driving shaft. Similarly, a car with an unusually light or flexible frame will show this trouble very often, as the combination of curve and grade is too much for the light frame.

Summary of Clutch Troubles

Throwing in Clutch. Do not throw clutch in suddenly and cause rear wheels to spin. Such action is destructive to tires and throws great stress on the entire mechanism of the car.

Lubricating Multiple-Disc Clutches. These are best lubricated by injecting oil into the opening for that purpose by means of an oil gun. A very light lubricating oil should be used.

Multiple-Disc Clutches Failing to Hold. Inject three or four gunfuls of kerosene into the clutch housing and run the engine a little, thereby washing out the plates of the clutch. This will cut the gum caused by the oil. If, after this treatment, the clutch squeaks or takes hold too suddenly, lubricating oil may be added.

Loss of Power. This is noticeable in changing from intermediate to high gear, in climbing hills, or in running through muddy or sandy roads. The trouble is often the result of the clutch slipping. The remedy is to clean the clutch with gasoline and, if the clutch is leather-faced, to apply castor oil after cleaning. Castor oil should never be used on the multiple-disc clutch.

Failure of Clutch to Take Hold. This may be owing to a broken or weakened clutch spring, the clutch leather may be damaged, clutch shaft may be out of line or bent, leather may be gummed, or bearing may be seizing.

TRANSMISSION GROUP

Primarily, the clutch is used to allow the use of change-speed gearing; or, stated in the reverse way, the form of the transmission determines whether a clutch must be used or not, there being cases in which it is not used. Thus, where the frictional form of transmission is used, no clutch is necessary; the frictional discs act as a clutch and render another one superfluous. So, too, with the form of transmission known as the *planetary gear*, no master clutch is needed.

On the other hand, the reverse of this does not always hold. Any form of clutch may be used with the various other forms of transmission, as the sliding gear; in fact, in actual practice every known kind of a clutch will be found coupled with the sliding-gear transmission.

Classification. Broadly considered, there are five classes of transmissions used. In cases where the use of any one of these forms eliminates the final drive, this from its very nature does not alter the facts but simply calls for a different and more detailed treatment. The five classes are:

(1) Sliding gear $\left\{\begin{array}{l}\text{Operated in various ways}\\ \text{but usually selective}\end{array}\right.$

(2) Individual clutch

(3) Planetary, or epicyclic

(4) Friction disc (various arrangements)

(5) Miscellaneous

The features of the 1917 transmissions which stand out from previous years are: reduced sizes; simpler, lighter construction; greater compactness and greater accessibility. Perhaps the most noticeable trend has been toward the unit power plant which has helped materially to make transmissions smaller, lighter in weight, and more simple, with unusual compactness. This very compactness has brought with it a stiffness which has rendered less repairs and adjustments necessary, despite lighter weight. The smaller sizes have brought about the simplification and lighter weight, and in turn have been produced in answer to the popular demand for lighter weight cars. In part, simplification has been produced by unit power plants, now so popular.

SLIDING GEARS

General Method of Operation. Of the different types of sliding gears, the first two subdivisions are not very closely marked, but blend somewhat into one another. The only real difference between them is the method of operation, the names serving to indicate the distinctive characteristics. Thus, in a selective gearset, it is possible to "select" any one speed and change directly into it without going through any other. So, too, in the progressive form of transmission, the act of changing gears is a "progressive" one, from the lowest up to the highest, and *vice versa*.

Selective Type. With the selective method of changing gears, it is possible to make the change at once from any particular gear to the desired gear without passing through any other. Of course, the car will not start on the high gear any more than in the other case, but shifting into low for starting purposes is but a single action, accomplished quicker than it can be told. So, too, when the car has been started, it can be allowed to attain quite a fair speed and the change to high made at once without going through the intermediate gears.

Progressive Type. Progressive gears, which are now little used, operate progressively: from first, or low, to second and from second to third, or high; in slowing down, from third to second to first and in this way only. This leads to a number of troublesome occurrences; thus, in stopping, it is necessary to gear down through all the higher speeds into low. If this is not done, when it is next desired to start the car, it will be necessary to start the engine, throw in the clutch, drop from the gear in mesh to the next lower, from that to the next, and so on down to low, throwing the clutch out and in for each change of speed. When first is reached, the car may be started. After starting, it is then necessary, in order to obtain any measurable speed with the car, to change back up the list, from low to second, from second to third, and so forth. In this way the progressive gear is disadvantageous, since its use means much gear shifting; but, on the other hand, the shifting is very easy for the novice to learn, as it is a continuous process, all in one direction.

Modern Selective Types. To present some modern selective types of gear boxes and point out their various differences, advantages, and disadvantages, refer to Fig. 270. This type shows the three-speed selective gear used on the Cadillac cars, which is but slightly modified from the type which has been used by this concern for three years. This change should be noted, however; the lay-

Fig. 270. Cadillac Transmission and Housing

shaft, which formerly was on the same horizontal level as the main shaft, is now placed directly below it. This makes a higher but narrower gear box, that is, instead of being wide and fairly flat, it is now high and narrow. The placing of the shifting levers on the cover, directly over the center, has aided in making the gearset more compact than formerly. In it there are two shifting gears, one gear carrying a set of dogs cut into its face, which mesh with a similar set on the main driving gear to give the direct drive. The gear portion of this member meshes with another gear for second. The second shifting member meshes with one gear on the layshaft for low speed and with another on the third shaft for reverse. The reverse gear is at all times in mesh with the fourth layshaft gear, so that on reverse the drive is through five gears instead of four. On high gear the drive is through the dogs, the layshaft being driven, of course, but silently, as it transmits no power.

Four-Speed Type with Direct Drive on High. One of the tendencies of recent years has been the gradual change toward more speeds, as shown by the increasing use of four-speed gear boxes.

Fig. 271. Sectional Plan Drawing of the Locomobile Four-Speed Transmission
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

Other indications of this change have been the two-speed axle, which gave double the number of gear-box speeds, with the ordinary three-speed and reverse transmission; and the electric transmission, which affords seven forward and two reverse speeds.

Following this increase of speeds, the multi-cylinder motors and downward price revisions of the early part of 1916 brought about a combination which almost eliminated the four-speed gear box or at least removed it from all but the most expensive of cars and from many of those. It is claimed that the eight- and twelve-cylinder motors have so much power and flexibility that a fourth speed is rendered unnecessary. The four-speed gear box is more expensive than the three-speed box, and the lowered prices of cars have been instrumental in preventing its continued use. At the same time, there was considerable lightening of weight all over the chassis, and the four-speed gear box had to go out of all but the biggest cars on account of its greater weight.

Fig. 271 is a sectional plan of one of the few four-speed gear boxes left. In this drawing it will be noted that the two-gear shafts, as well as the operating shafts, lie in the same horizontal plane. The halftone reproduction of the photograph of this drawing, Fig. 272,

Fig. 272. Photographic Reproduction of Locomobile Gear Box Shown in Section in Fig. 271

shows the location of the shafts even more plainly and will, perhaps, be of more use to the average reader. Both forms show the arms which project up to attach this unit to the frame. The cover, which is a light easily removed aluminum member, is taken off from above after the floor boards are lifted out. This arrangement makes for accessibility and eliminates any need for lying on the ground while working on the transmission gears or shafts, should such work be necessary.

The form of final drive alters the construction of the transmission very materially. Formerly, when all final drives were of the double-chain form, it was customary to include the differential, bevel gears, and driving shafts in the gear box. Now that the chain has gone out, this construction is found only when the gear box is a unit with the rear axle.

Four-Speed Type with Direct Drive on Third. In all the transmissions shown and described thus far, the direct drive has been the highest speed. By referring back to Fig. 253, which show the Winton four-speed gear box, as well as the clutch, a point of difference will be seen. This has the direct drive on third speed, fourth being a geared-up speed for use only in emergencies, when the very highest rate of travel is required, and when a little noise more or less would make no difference. This arrangement of the direct drive and silent speed has long been a debated point, some designers favoring the direct-drive type with an over-geared speed for occasional use, while the opponents of this method say that this construction practically reduces the transmission to a three-speed basis, the fourth being so seldom used that it is practically negligible. They say, also, that the modern motor can attain a high enough speed, on the one hand, and is flexible enough, on the other, to permit its being used with the high-gear direct drive upon almost all occasions.

Transmission Location. There are but four recognized positions for the transmission in the modern car. These are: (1) unit with the engine (unit power plant), (2) amidships in unit with clutch or alone in a forward position, (3) amidships in unit with forward end driving shaft or in a rear position, and (4) at the rear in unit with rear axle.

Unit with Engine. The unit with the engine type is illustrated in an excellent manner in Fig. 273, which shows the eight-cylinder Northway motor, cone clutch, and three-speed transmission. Some idea of the compactness of this outfit, which is shown exactly as used on the Oakland car, can be gained from comparison with cylinder bore and crankshaft size, the motor being $3\frac{1}{2}$ by $4\frac{1}{2}$ inches. The noticeable features of the transmission, aside from its compactness, are the use of double row ball bearings on the splined main shaft, with a Hyatt roller form for the spigot bearing (free end of main shaft) and very long plain bronze bushing for the countershaft unit, the latter being made as a single piece rotating on a single bearing around a straight fixed shaft. The countershaft, or layshaft, as it is sometimes called, is placed below the main shaft.

Another example of the unit with engine type is seen in the Grant-Lee three-speed gear box, Fig. 274, as utilized in the Hackett car. This is unusually small and compact, as will be noted by comparing the size of the unit with the operating levers and pedal. While

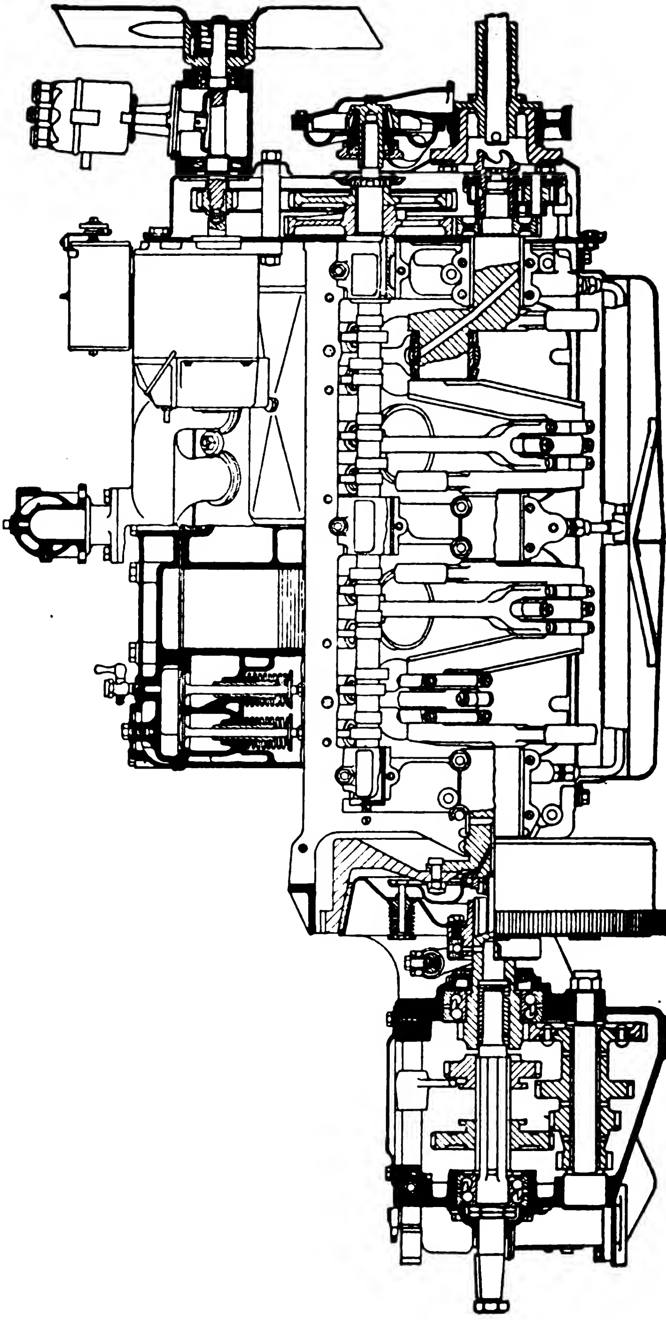


Fig. 273. Unit Power Plant of Oakland Eight-Cylinder Car
Courtesy of Oakland Motor Car Company, Pontiac, Michigan

the clutch is not shown, its housing is, also the flange which attaches it to the flywheel housing to complete the power unit. A third example of the engine-unit power group is shown in Fig. 275, which shows the flywheel, clutch, and transmission of the Peerless eight. This unit transmits many times the power of the Hackett unit and is therefore much larger. In this unit the bearing arrangement is rather unusual, as roller bearings of the taper form are used on the main shaft, a straight roller for the spigot bearing, and plain ball bearings for the lay-shaft. The shortness and large diameter of the shafts should be noted.

Additional transmissions in a unit with clutch and motor will be seen under Clutches, in Figs. 251, 252, and 254.

Amidships Alone or with Clutch. The amidships unit joined with the clutch, shown in Fig. 253, represents the Winton transmission and clutch. This is not a common construction on pleasure cars, although it is used on quite a number of trucks. On the amidships-clutch unit type, however, the combination is not quite so intimate as the one in which the two units are enclosed in a common case.

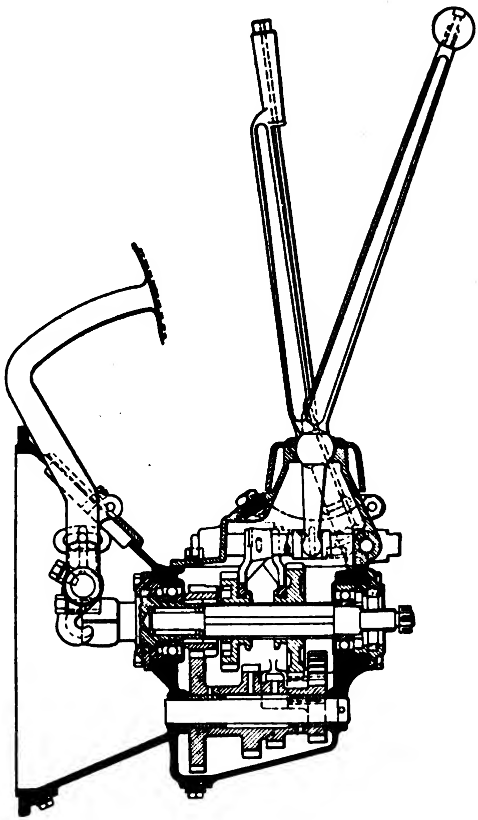


Fig. 274. Gear Box Used in Hackett Cars Is Very Small and Compact
Courtesy of Hackett Motor Car Company, Jackson, Michigan

Amidships Joined with Driving Shaft. The amidships unit joined with the forward end of the driving shaft is well shown by the Locomobile, Figs. 271 and 272. The universal joint with the driving-shaft pivots is seen at the left side of both these views. In this construction, which is more widely used than the other amidships arrangement, there is usually a frame cross-member at the point on which the rear end of the transmission is supported. This same arrangement is used on the Stearns-Knight four-cylinder chassis, the transmission of which is shown in Fig. 276. In this transmission the stiffness of the cross-member at the rear end of the transmission is also utilized to support the brake drum of the foot-brake system.

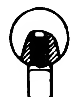


Fig. 275. Gear Box and Clutch of Peerless Eight
Courtesy of Peerless Motor Car Company, Cleveland

The short stiff shafts on the transmission will be noted, also the many splines on the main shaft and the use of double row ball bearings on the main shaft, with a flexible roller on the spigot, and the same type of bearings on either end of the layshaft, which is alongside of the main shaft. Note also the means provided for adjusting the countershaft longitudinally by the two steel screws projecting through the bearing caps so that this adjustment can be made from the outside.

Rear Unit with Rear Axle. The position at the rear axle is not as widely used as a couple of years ago, but those manufacturers using it have large outputs, so that a considerable number of these cars are in use and considerably more are being added each year. One of these, the Studebaker, is shown in Fig. 277. This is a shadow drawing of the rear axle and transmission, showing the upper, or main, shaft of the transmission in full and the layshaft which is below

Fig. 276. Three-Speed Transmission and Brake of Stearns Four-Cylinder Car
Courtesy of F. B. Stearns Company, Cleveland, Ohio

it, partially. As will be noted, this position of the transmission calls for two operating rods, each the full length from the operating levers to the rear axle. The rod on the left operates the reverse and first speeds and that on the right second and third, or high, speeds.

To make this shifting of gears and connection of levers with the actual position of the gears plain, Fig. 278 is also shown. In this figure the gear-shifting lever is placed in the center and is shown solid in the neutral position and lighter in the other four positions.

Just below it, the transmission is shown with the position of the gears for neutral, while in the four corners, corresponding to the four positions of the lever, the positions of the gears when the lever is in each one of the positions are shown. These positions indicate that there is a driving gear and two sliding

Fig. 277. Studebaker Transmission Combined with Rear Axle
Courtesy of Studebaker Corporation, Detroit, Michigan

member is moved forward to mesh with the second gear on the layshaft, as shown in the diagram at the lower left-hand corner, and first, or low, speed results. With this gear in its neutral position—as it is left when the shifting lever is swung through the neutral position and over to the right—a further movement to the front picks up the forward sliding gear and moves it back into mesh with the third gear on the layshaft; this combination, as shown in the upper right-hand corner, gives second speed. When the lever is moved back, it moves

Fig. 278. Diagrams Showing Working of Studebaker Transmission

the gear forward, giving high speed and direct drive, as shown at the lower right-hand corner.

Interlocking Devices. Nearly all transmissions have a form of stop lock on the shifting rods in the transmission, which holds the gears in mesh as soon as they have been moved by the operator until he moves them again. In reality this arrangement simply prevents the gears from jumping out of mesh. Generally, the most simple arrangement which will hold the gears is used. In the ordinary form this arrangement consists of hardened steel wedges with light springs back of them and deep grooves in the shifting rods into which these wedges fit.

In Figs. 271 and 272, the notches in the shifting rods can be seen plainly. In Fig. 275, the bolt head *A* indicates the location of one of the shifting locks. In Fig. 277, *A* shows the notches in

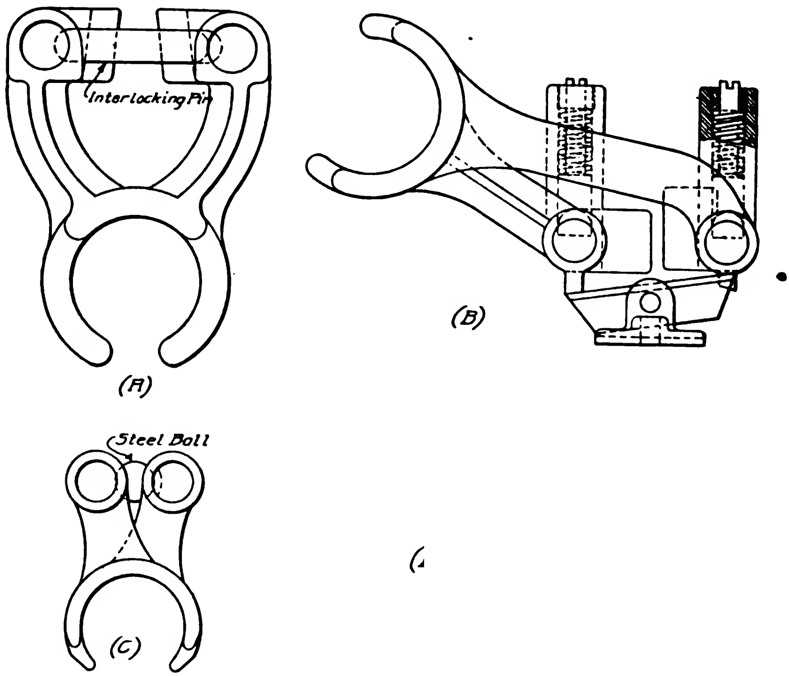


Fig. 279. Various Forms of Transmission Interlocks

the low and reverse rod and *B* those on the second and high-speed shifting rod.

Not all transmissions have the wedge and notch, as Fig. 279 indicates. This figure shows: at *A*, a method of interlocking by means of a pin at the shifting forks (not rods) which project into shallow holes in the two shifters; at *B*, a rocking, or tilting, bar beneath the shifting forks, which is pressed into a notch in either fork when moved from neutral; and at *C*, the use of a steel ball—all three arrangements being used by the American Die and Tool Company. The form at *D* shows the pin used by Grant-Lee Gear

Company, the grooves in the rods being deep enough to accommodate this form in a neutral position so that the rod can be started. But the guide hole in the central housing in which the pin is moved across by the motion of one rod, owing to the shape of the bottom of the groove, prevents the other rod from moving.

Electrically Operated Gears. In substance, the electrically operated transmission has all the hand levers, rods, and other levers replaced by a series of push buttons. When it is desired to change speeds, even before the actual change is necessary, the driver presses the button marked for the speed he thinks he will require. Then, when the actual need becomes apparent, he throws out the clutch and immediately drops it back again, all this forming but a single forward and back movement of the foot. During the slight interval while the clutch is out, the electrical connections shift the gears automatically, so that when the clutch is let back, the gears are meshed ready to drive.

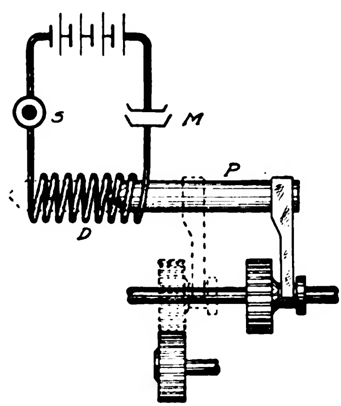


Fig. 280. Sketch Showing How a Solenoid Moves a Gear When Current Flows

Principle of Action. To explain this action briefly, the gears are moved by means of solenoid magnets, which are nothing more than coils of wire, through which an electric current from a convenient battery is allowed to pass. Through the center of each one of these coils passes an iron bar. When a current passes through the coil, it is converted into an electromagnet and draws the iron bar inward. As the other end of the bar is connected to the gear to be shifted, this movement of the bar shifts the gear. Consequently, when the button is pressed so that current flows through one of the coils, that action shifts the gear for which the button is marked.

By referring to Fig. 280, this action will be made more clear. The diagram shows but one pair of gears to be meshed, and the battery, push button *S*, coil *D*, iron bar *P*, and clutch connection *M* are all shown as simply as possible. When button *S* is pressed, current through the coil *D* will draw the bar *P* and mesh the gears as soon as the clutch has been thrown out, thereby closing the circuit at *M*. The application of this to an actual transmission is shown more in detail in Fig. 281, which shows the clutch pedal

Fig. 281. Arrangement of the Solenoids and Pedal in the C-H Electric Gear Shift

and its connection to the six solenoids necessary to produce four forward speeds, one reverse speed, and a neutral point.

On the steering wheel, Fig. 282, the control group of six buttons will be noted on the small round plate at the center, with the addition of the horn button in the center. In Fig. 283 is another arrangement.

In the 1916 forms of electric-control systems, the buttons are grouped in one instance on the top of a small box four or five inches

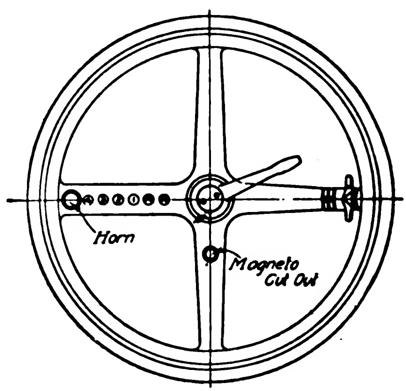


Fig. 282. Arrangement of Buttons for Gear Shifting

Fig. 283. Another Arrangement of Buttons for Gear Shifting

square, which is placed on the steering post below the wheel; in another, on the dash; and in a third, on a rod connecting post and dash.

Pneumatic Shifting System. The pneumatic system of gear shifting is along lines somewhat similar to the electric system, air under pressure being used to move the gears instead of a hand lever and rod combination. For this purpose it is necessary to add an air compressor, a tank to carry the compressed air, and what is called the "shift"—really a complicated valve and a series of plungers—to the car. The valve and plungers respond to a finger lever on the steering wheel, the same as the electric system responds to the buttons. Air is admitted behind the plungers, which moves the gears as soon as the clutch is depressed. It is seen, therefore, that this system, like the electric shifter, permits the anticipation of the needs of the car.

Railway Car Needs. All transmissions previously presented have had but one reverse. For gasoline railway cars, the inability to turn the car requires as many reverse speeds as forward, which means special gearing. Usually, this gearing is accomplished by means of a pair of bevels, each with a clutch, meshing with a single driving bevel. Obviously the two driven bevels will turn in different directions, and each will drive when its clutch is engaged. By shifting the clutch to the one which gives a forward speed, all the speeds of the gear box become forward speeds; by shifting to the one which gives reverse, all the speeds become reverse speeds.

INDIVIDUAL CLUTCH

General Types Used. While the number of adherents to the individual-clutch type of transmission is not as great as that of either the progressive or selective types of sliding gear, it holds its own; and, as time passes, it gains adherents. In this form, all the gears are in mesh at all times, and what has been called "the barbarous and unmechanical" method of clashing gears is entirely done away with. The individual-clutch type is operated on the selective plan but otherwise has nothing in common with the latter.

The forms of clutches used vary greatly, as might be expected. The following are in use today: jaw clutches (both two- and multiple-jaw); internal-external gears, multiple disc, cone, and friction clutches other than the multiple-disc form.

Using Internal Dogs. One type in which the gears are engaged by internal dogs—the gears being in mesh at all times—has four sets of gears, those on the main shaft being keyed or otherwise fixed to the shaft, while the gears on the jackshaft run idle except when the gear-shifting lever is moved forward to an engaging position, which throws an internal dog up into a slot inside the gear. This position makes the gear one with the shaft, and the power is transmitted directly. The dogs in the latest form of this transmission take the form of hardened and ground steel balls.

Disc Type. Many of the early individual clutch types of transmissions used discs, each gear having its own set and each set having sufficient surface to carry the whole power of the motor. While bulky, this had undeniable advantages, for it allowed starting on any gear.

Contracting-Band Type. While advocates of discs are numerous, other devices do not lack friends. Fig. 284 shows a form on the Haynes-Apperson cars that attained much popularity. In it the clutching action is produced by means of contracting bands working on large diameter drums, the drums being keyed each to its own gear. The full explanation of the action is as follows: The engine drives the shaft *A*, upon which are mounted the gears *C*, *D*, *E*, and *F*. These are all permanently fixed to the shaft and rotate with it. Upon the driven shaft *B* are mounted an equal number of gears meshing with the former, but all loose upon the shaft so as to spin idly. Bolted to each of the latter gears is a large drum, while close to it is a framing upon which is mounted a contracting band. The latter framing is keyed to the shaft, so that when it is rotated the shaft must turn with it. In action, then, when any speed was desired, the band was contracted until it seized the drum bolted to the gear which gave that speed; thereupon, the gear, drum band, and framing all turned as a single piece.

Fig. 284. Early Form of Haynes Clutch Gearset

Single-Disc Winton. Winton long advocated the individual clutch gear, his clutch taking the form of a single disc pressed against the gear by means of numerous fingers, Fig. 285. A conical sliding piece G or J expanded the fingers pivoted on M and H so that they pressed against the disc within the gears D, K, or N.

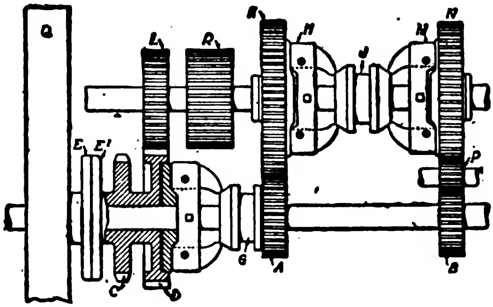


Fig. 285. Early Form of Winton Individual Clutch Transmission

Internal-External Gear Type. Many of the gears already given date back several years, but the gear illustrated in Fig. 286 is more modern, and is being used today by the International Motor Company of New York City and of Allentown, Pennsylvania.

The principle upon which this gear works, as shown by Fig. 286, is that of the internal-external gear. The gears which transmit the power are always in mesh. Each one of these is bushed and runs idly upon the main shaft. Contained within each gear and an integral part of it is an internal gear of twenty-four teeth. Sliding on the

Fig. 286. Mack Commercial Car Individual Clutch Type of Gear Box
Courtesy of International Motor Company, New York City and Allentown, Pennsylvania

squared shaft are four 24-tooth gears; these are specially built for easy engaging with the internally cut gears.

To follow the letters placed on the parts of this gear, high speed is obtained by sliding the piece *2-C-31* forward into gear *2-C-34;* this action swings the piece, shown dotted beneath, so as to throw out the clutch on the lay shaft *2-C-52*. On high speed, the two gears locked together are the only ones to turn, all others being idle. The same piece *2-C-31*, when slid to the right, meshes with the internal gear of the second-speed pinion *2-C-160*. This sliding member slides upon a squared shaft, so the drive is positive. The action of the first, or slow speed, and reverse are the same as those just described, being produced by the shifting of the clutch member *2-C-66*. Attention is called to the ball bearings used on this transmission, which are remarkable only when it is remembered that this is a commercial truck transmission. Students of automobile construction will find many interesting constructional details in this illustration, which is a reproduction of the manufacturer's working drawing.

Still another similar form uses three cone clutches in the transmission, that for the high speed being augmented by a set of pins, or dogs, which, as the clutch gradually takes hold, slip into an equal number of holes in the driven gear. In this way, the two are made as one, which makes slipping impossible—a very important feature.

Transmission Operation. As has been pointed out previously, practically all transmissions operate all gears by means of a long hand lever, placed either at the side of the car or in the center, according to the location of the control. Even on planetary forms, still to be described, at least one of the various speeds is controlled by a hand lever. The electric- and air-shifting methods have made a start, and a good one, but until their number increases materially, these types can be considered as only having started their development.

Transmission Lubrication. A fairly heavy lubricant is generally recommended for gear-box use—either a special form of about the right consistency, or else a home-made mixture of about half-and-half of light oil and hard grease. Some firms recommend a graphite grease. The lower part of the case should be filled to a point, or level, where the largest gears dip continuously. This will insure a constant agitation of the lubricant, which will thus get to all moving parts and surfaces. Having the lubricant too stiff is bad, because then the gears simply cut a path through it without moving the rest. This results in all other parts running practically dry. Too thin a lubricant or too much of it will make a fairly heavy drag on the motor, which loss of power should be avoided. Gear-box lubricant generally is introduced in bulk by the removal of the cover, usually of a large size to allow of this. The outside parts carry their own grease and on cups.

Transmission Bearings. By looking back at the various transmissions shown, it will be noted that ball bearings are used most freely. Roller bearings in various forms are coming into use, as the shorter series produced in the last couple of years has shown designers that thist ype would produce a compact gear box, their size having previously limited their use. Plain bearings are not used at all on good cars.

Transmission Adjustments. Few adjustments are needed in the modern gear box. However, provision for wear is made in the operating rods and levers, both within the case and without. In some cases the shafts may be slightly shifted endwise to secure better meshing of the gears after wear. Bearings, too, are arranged to shift slightly in an endwise direction to take care of wear in other parts and not so much in the bearings themselves.

PLANETARY GEARS

Method of Action. The planetary, or epicyclic, form of gearing offers many advantages, but, strange to say, the American people, although inclined toward simplicity and cheapness in combination, will not have it in this form, and, as a consequence, this excellent gear-reducing means is fast losing favor. The principle upon which all planetaries work is as follows: Connected to the engine is the first gear of the train. The second is one of a series of several gears; these are pivoted in a drum, which may be held stationary by a brake band. The middle, or third, gear in the train, as well as the last, or fourth, is connected to another gear, *a driven gear, not a driver.* Considering but a single rotating train—there usually are three or more—the last-named gears form the fifth and sixth in the whole train. Gears two, three, and four have different numbers of teeth, as well as gears one, five, and six. Holding the band which holds the drum to which the gears are pivoted, allows each of them to rotate around its own axis, but not around the main shaft. This form of rotation gives one gear reduction.

Another band holds another gear stationary and allows the three-gear unit to rotate around the main shaft as an axis; at the same time it leaves them free to also rotate around their own axis. This produces *another* gear reduction. Another form which is popular in so far as planetary gears are popular is that in which internal gears are substituted for one set of the planets, from which the device obtained its name. This does not complicate the device any; in fact, the only way in which it makes any change is in the

Fig. 287. Drawing Showing Ford Planetary Transmission

manufacturing cost of the gear, internals costing more than spur gears.

Ford Planetary Type. Ford has been a consistent user of the planetary gear; in fact, the simplicity and ease of operation of his well-known and widely used car is largely due to this use. The Ford transmission, which is of the all-spur-gear type, is shown in Fig. 287. This is operated by means of two pedals and a lever, one pedal working high and low speeds, while the other pedal controls the reverse. The first-named pedal, however, must be used in conjunction with the forward movement of the hand lever which locks the high-speed clutch, seen in this figure at the right.

FRICTION DISC

Undoubtedly, when simplicity is sought regardless of cost, the friction drive is the drive used. The cost with this form is not one of money, but rather of other things which must be sacrificed if friction drive is used.

Spur Type. In the interest of simplicity, it may be said that the friction form of drive dispenses with the clutch, being of itself both clutch and change-speed gear. The usual form which this takes is the single spur wheel contacting with another flat-face wheel. Since these must be at right angles, the car is nearly always chain driven, the driving wheel being on the rear end of the crankshaft, and the driven shaft across the middle of the car. To secure a more certain drive and at the same time obtain the differential action, the cross-shaft, mounted upon two independent shafts, is often fitted with a pair of wheels, contacting with opposite sides of the driver. As this method causes the two driven shafts to turn in opposite directions, a gear is necessary at the end of one of them.

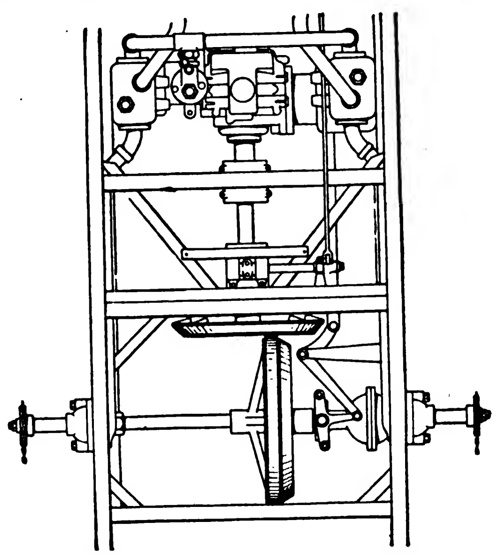


Fig. 288. Friction Transmission with Bevels

The greatest feature of the friction drive is the multiplicity of speeds obtainable, these being infinite in number, since every different position of the driven wheel on the driver results in a different ratio and, consequently, a different speed. To obtain these various changes, the wheel which meets the other edge-on is usually arranged to be advanced up to and withdrawn from the wheel presenting the flat surface. In action, a motion of translation is given to the wheel at the same time as the motion up to or away from the surface. This motion of translation changes its position and consequently its speed.

Over the three-wheel arrangement, the use of the four-wheel arrangement possesses some undeniable advantages, particularly if the two parallel driving wheels are arranged to drive the others in pairs. This arrangement makes the direction of rotation of the wheels alike, and no intermediate gear to change the direction of one shaft is needed. A simplification of this form utilizes the flywheel of the engine as the forward driving disc.

Bevel Type. Bevels have many advantages over spur friction wheels. They are found in combinations, such as a single pair of bevels or three bevels, and in multiple combinations, without limit to the number of bevels. Fig. 288 shows the use of a single pair, but in combination with a flat face on one and a spur attached to the other; this makes the whole consist of four wheels in reality.

Another combination sometimes used is that of three bevels. One of the bevels has a flat face and a spur, making really five wheels. The spur wheel in every case takes the final drive. A direct drive on the high gear is obtained by the use of a cone clutch on this spur and another clutch with which it engages on the driving wheel. One bevel gives forward speeds, and through the other the various reverses are gained. The friction drive, although theoretically the simplest and most ideal form of drive, is not very popular.

MISCELLANEOUS TYPES

Freak Drives. What are termed the freak drives attract much attention from inventors, but little from hard-headed constructors. Thus, the belt drive was once advanced as *the* simple drive, yet it made no progress. Today there are few belt drives used in final driving in America, although a few are still made in Europe. There is a low-price French car, Fouillaron, with this drive; and a single-cylinder Italian car, the Otav, selling for the equivalent of $150, which is also equipped with a belt drive.

Cable and Rope Drives. When cycle cars were first brought out and by many considered as destined to replace both the low-priced cars, on account of their still lower price and simplicity; and motorcycles, because of their greater comfort, superior appearance, and greater carrying capacity, many of the simple drives were revived and applied to the cycle cars. The types used include the cable drive, which attracted much attention at one time in the motorbuggy field, the rope drive, the flat belt, the V-belt, the cloth-covered chain, and many others. With the collapse of the cycle-car boom, these went out of use.

Hydraulic Gear. *Janney-Williams.* The hydraulic transmission has been advanced as a cure for all automobile troubles, representing as it does the elimination of clutch, differential, and the driving mechanism. It consists of a pump to circulate the fluid, and one or two motors, usually attached to the rear wheels and propelled by the fluid. In the Janney-Williams hydraulic gear, which has been successfully used for some time in other fields, but has just recently been tried for automobiles in England, there are three similar pumps, one being used as a pump and the other two as motors. By rotating the driving ring so that it assumes different angular positions, the throw of the small pistons, of which there are nine in all, is varied from zero up to a maximum. Since the action of the fluid in the motors connected to the wheels is opposite to this, it amounts to varying the speed, the number of changes being infinite, as in friction gearing.

Manly. Another hydraulic drive, of equal merit and of American manufacture, is the Manly. This differs from the Janney-Williams only in the form of the motors; the fluid and its use are the same in both cases. This drive has for its object the securing of any desired speed of the driven shaft, either forward or backward, without changing the speed or direction of motion of the driving shaft and of transmitting the power to a shaft, which is either in line with the driving shaft or which lies at any angle to the driving shaft and is separated from it. It consists of a multi-cylinder pump having a variable stroke, which is attached to the driving shaft, and of one or more multi-cylinder motors having a fixed stroke, which are attached to the driven shaft, together with pipe connections, or passages, between them for transmitting the working field. The various cylinders, both of the pump and motors, radiate equidistantly from a central crank chamber, and the pistons or plungers are connected to a single crankpin which is common to all. The fluid used is ordinary machine oil, its lubricating qualities and freedom from the danger of freezing admirably fitting it for such a purpose. When the system is once filled, the oil is used over and over again, being in continuous circulation from pump to motor through one set of pipes, or passages, and back again from motor to pump through another set. The stroke of the pump may be varied at will, but that of the motor is fixed. The variation of the pump stroke is accomplished by a crank, on which an eccentric bushing is mounted. By revolving the bushing with reference to the crank, its center line is brought into alignment with the center of the shaft, and when this position is reached, no reciprocating motion is communicated to the pump plungers. The Manly is constructed under license by the American-La France Fire Engine Company, Elmira, New York, and has proved its worth on very large trucks and on some of their fire apparatus.

In recent years a number of hydraulic transmissions have been brought out, but all these face the fundamental difficulty that when the pump chamber is liquid tight the friction is excessive.

Pneumatic Drive. There has been some talk of a pneumatic drive also, this idea not differing greatly from the previous one of using liquids. In this scheme a large tank of compressed air is provided for the purpose of starting the engine, helping to get up speed quickly, and for use on hills when excess power is needful or at least helpful. If used as planned, it would allow of the elimination of the reverse and would be utilized for braking as well, the present form of band brakes being replaced by air brakes. This is but a prospective scheme, never having been tried; yet in considering the future, it is worth more than a passing thought because of its latent possibilities.

Electric Drive. To speak of an electric drive sounds peculiar, yet that is what should be used for a final drive through the medium of electric motors. This form, spoken of abroad as the *petrol-electric car,* is attaining much headway there. It gains slowly, it is true, but, nevertheless, surely—each year seeing one or more makes added to the already long list of successful cars in this category.

In the petrol-electric cars, the generator is coupled to the engine in the place ordinarily occupied by the flywheel and clutch, and the armature acts as a flywheel. Then the two motors are set on each side, directly in front of the rear wheels, which they drive through the medium of spur gears; the whole is enclosed to keep out dirt, keep in oil, and reduce noise to a minimum.

On the whole, the electric drive is not losing ground, which, in these days of gasoline shaft-driven cars, is perhaps something gained.

In fact, it might be said that the electric drive possesses so many advantages which are worth having, even at a sacrifice, and so few disadvantages that one is safe in figuring that a few more years will see the number of these drives doubled and possibly trebled.

Electric Transmissions. While the drives just discussed might be called electric drives and still be precise, the Owen magnetic car, which is constructed by the Baker, Rauch and Lang Company, makes use of an actual electric transmission, the Entz, at one time used in a Columbia chassis. This is so arranged that all speed changing is done by a small finger lever on the steering wheel, similar to the ordinary spark and throttle levers. The wiring formerly gave

Fig. 289. Drawing Showing Section through Owen Magnetic Transmission

seven speeds forward and two reverse, but a later construction will probably give about twice this number.

As is shown in Fig. 289, this consists of an electric generator, the field magnet of which is connected to the engine crankshaft and takes the place of the flywheel, the armature being connected with the driving shaft. This transmits the turning effort of the engine by means of the current established in its circuit, due to the speed difference of its members on what constitutes the high speed. Any effort exerted by the engine on one member is transmitted, practically without loss, to the other member, or armature. The clutch-generator member makes a very elastic clutching and transmitting means, but cannot transmit more than the full torque of the engine.

For higher torque, use is made of an electric motor, whose armature is mounted on the driving shaft and receives current from the first, or clutch, generator.

In the figure, the clutch generator is shown at the left, its field part marked *FR*, the field winding *FW*, and the pole pieces *PP*. This portion rotates whenever the crankshaft revolves. Within it is the armature *A* secured to the continuous shaft *S*, which is connected through the joint *X* with the driving shaft to the rear axle.

The second part of the complete system is shown at the right and is practically a duplicate of the clutch generator. Its armature A_1 is carried on the same shaft *S* as armature *A*. Outside this is the usual field part with rings *FR*, windings *FW*, pole pieces, and brushes *B*.

Field *FR* can revolve without any motion of *A*; in fact, it is by varying the relative speed of *FR* and *A* that the different speeds are

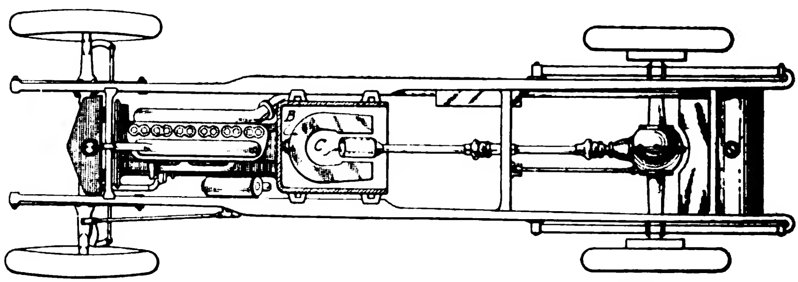


Fig. 290. Sketch to Explain Working of Magnetic Transmission
Courtesy of Baker-R & L Company, Cleveland, Ohio

obtained. For instance, on direct drive the generator is short-circuited on itself and carries armature *A* with it. Then, except for a slippage of 4 per cent or less, between the field *FR* and the armature *A*, the wheels would be driven as fast as the latter rotated. Lower speeds are produced by making the slippage greater. Speed changing, as well as starting and braking, are accomplished by means of the finger lever on the steering wheel. The storage battery is charged at a 10-ampere rate.

Perhaps the explanation which follows will give a better idea to the repair man than the foregoing, which is slightly technical. The rotating field of the generator, marked *FW*, is comparable to a horseshoe-shaped magnet *B*, Fig. 290, also rotated by the engine. The armature *A* at the left-hand. or engine, end of the shaft is comparable to the piece of steel *C*, which is free to rotate and which will do so when the field rotates and attracts it. If this were connected directly to the driving shaft, as Fig. 290 shows the combination

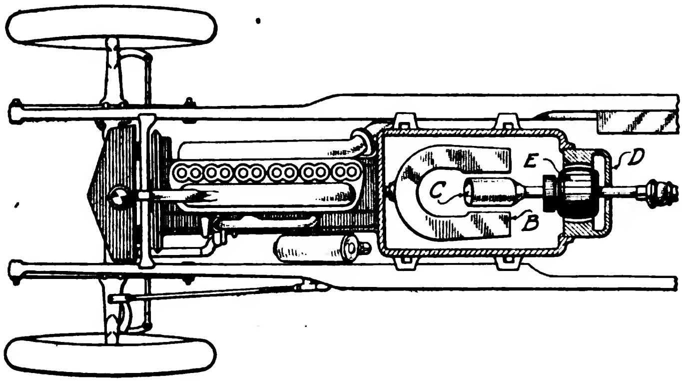


Fig. 291. Second Step in the Magnetic Transmission Explanation

would become a simple electromagnetic clutch and the car would have but one speed. On the level, one speed would be satisfactory, but in deep sand, on a heavy grade, or for any other severe pull, the air space between the rotating field and the armature would bring about the stalling of the engine.

If we add a conventional electric motor just back of *C*, with its field fixed, or stationary, as at *D*. and its armature free to rotate with the armature shaft to which it is attached, about as shown in Fig. 291, *C* will not rotate as fast as *B* when meeting a stiff pull, although it will try to do so. A wire connects the commutator of *C* with the field coils *D*, and the electricity generated by the rotation of *B* relative to *C*, that is, the amount of slippage due to the air gap, is led through this wire to *D* where it acts as power, rotating *E* faster and thus acting as a booster on the propeller shaft.

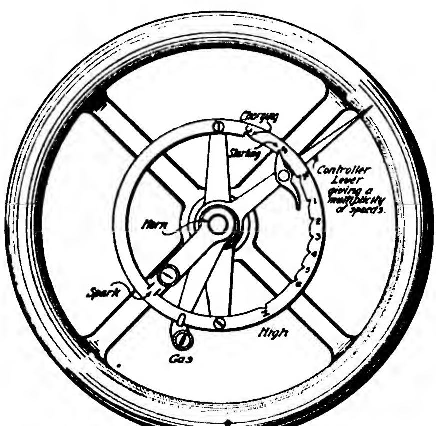


Fig. 292. Steering Wheel Quadrant of Owen Magnetic Car

Fig. 293. Plan View of Complete Chassis of Owen Magnetic Motor Car
Courtesy of Baker-R & L Company, Cleveland, Ohio

By introducing variable resistance in the connecting wire, or rather series of wires, the speed may be varied from zero to the maximum, which, as it happens through this booster action, is considerably in excess of what it would be if the motor were driving directly through on high speed without any electrical or mechanical apparatus. The variety of speeds can be anything desired, and this forms the basis for naming it "The car of a thousand speeds". As a matter of fact only seven speeds are provided for on the steering wheel, which is shown in Fig. 292, but it is perfectly feasible to wire up the car and arrange the quadrant to have twice this number or any other number, as required. On the steering post quadrant, the additional positions of charging, starting, and neutral are to be noted. The neutral position is that in which the engine is idling and the car standing still; or when the car is coming down a grade, the wheels are driving the motor which generates current in the reverse direction, so that the device becomes an electric brake, slowly but surely reducing the speed of the car. The starting position connects the storage battery to the generator armature in order to revolve the engine shaft and thus start it. The charging position can be used at any time to generate electricity for the storage battery.

While this description sounds very different, the chassis is not unlike the average gasoline chassis with a mechanical gear shift, as Fig. 293, showing a view of it from above, brings out. The small unit just back of the motor is a mechanical reverse gear which it has been found advisable to use for one reason, because it gives all the quadrant speeds on the reverse, instead of the usual one. By this arrangement the car has seven fixed speeds forward and seven speeds reverse, together with the possible variations of both, which can be produced by the use of spark throttle and accelerator.

TRANSMISSION TROUBLES AND REPAIRS

Noise in Gear Operation. One of the most common of transmission troubles is a grinding noise in the operation of the gears. This is heard more in bevels than in spurs, but in old transmissions and on the lower speeds it is heard frequently. A good way to quiet old gears, after making sure that they are adjusted rightly and meshing correctly, is to use a thicker lubricant. If thick oil is being used, change to half-oil and half-grease or preferably all grease.

In this respect the repair man or amateur worker may take a leaf out of the book of second-hand car men, who are said to "load" an old and very noisy transmission gear with a very thick almost hard grease in which is mixed some shavings, sawdust, cork, or similar deadening material. When this is done, a graphite grease is generally used, so that the shavings, cork, etc., would not show in case it was necessary to take off the gear-box cover. This material will fill up all the inequalities of the gears and shafts so that temporarily everything fits more tightly, and all the sounding board, or echo, effect is taken out of the transmission case. This sounding-board effect is fully as important as the grinding noise, for many really insignificant noises are magnified by poorly shaped gear cases

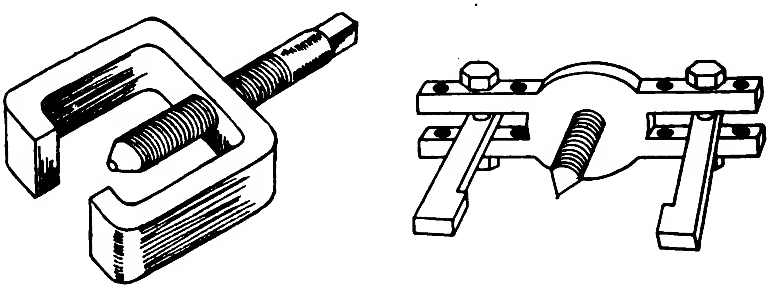


Fig. 294. Types of Gear Pullers

so as to appear very loud, indicating serious trouble which need immediate attention, when such is really not the case.

Another source of gear-set noise is a shaft out of alignment, caused either by faulty setting, by worn or loose bearings, or by yielding or cracking of the case. If it is properly set at one end and is out at the other, the trouble will be more difficult to find and remedy.

Heating. Heating is a common trouble, too, but usually this can be traced to lack of lubricant in an old car or to too large shafts or too small bearings in a new one. Sometimes the grease used will cause heating, particularly when long runs are made with the transmission working hard. This is most noticeable when the grease or lubricant is of such a consistency that the gears simply cut holes in it but do not carry any around with them or do not otherwise circulate the lubricant. This can be remedied by making it thicker so the gears will cut it better, by making it thinner so they will splash it more, or by changing the nature of it entirely.

Gear Pullers. One of the principal necessities for transmission work is a form of gear puller. These are like wheel pullers, except that they are smaller and more compact. In Fig. 294, a pair of gear pullers are shown. The one at the left is very simple, consisting of a heavy square bar of iron which has been bent to form a modified U. Then, a heavy bolt is threaded into the back of this or bottom of the U. This will be useful only on gears which are small enough to go in between the two sides of the puller, that is, between the sides of the U, which when in use is slipped over the gear, the screw turned until it touches something solid, as the end of the gear shaft, and then the turning continued until the gear is forced off.

While not as simple as this, the form shown at the right has the advantages of handling much larger gears, and also of being adjustable. As the sketch shows, this consists of a central member having slotted ends in which a pair of L-shaped ends, or hooks, are held by a pair of through bolts. Then there is a central working screw. To use, the hooks are set far enough apart to go over the gear, then slipped around it and hooked on the back. The central screw is turned up to the end of the shaft, and then the turning continued until the gear comes off. There are many modifications of these two; in fact, practically every repair shop in the land has its own way of making gear or wheel pullers. At any rate, every shop should have one.

Fig. 295. Method of Pressing Transmission Gear onto Its Shaft

Pressing Gears on Shafts. The opposite of pulling off gears is putting them on; very often they are designed to be a press fit, which means exerting tremendous pressure. Every repair shop should have some form of press for this and similar work, something similar to the form shown in Fig. 295. In this figure, the man is just beginning to apply pressure to the shaft to force it into the lower gear. The table must be arranged for work of this kind with a solid spot when the shaft does not come through, and with a hole when it does. The work of pressing is usually done in a few seconds, while the preparation, alignment, and starting of the work takes perhaps half an hour or more. It is work which should be done very carefully.

One way in which arrangement can be made for pressing a shaft a considerable distance into a gear and, conversely, for pressing the shaft out of the gear is that shown in Fig. 296. This figure has the additional advantages of being simple, easily constructed, and cheap. A solid base is constructed with a pair of hinged uprights. These can be dropped together with the work between them, forming a modified triangle, the strongest known shape, resting upon its broadest side and thus having the greatest stability. With this arrangement, the press can readily be used for pressing off parts.

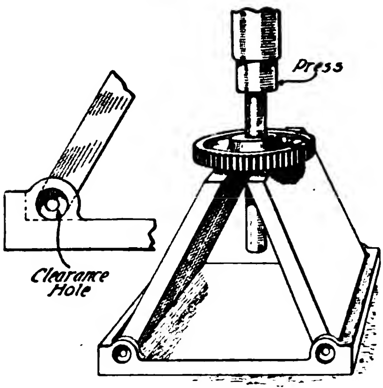


Fig. 296. Home-Made Table for Use in Gear Pressing or Pulling
Courtesy of "Motor World"

Care in Diagnosis. The repair man should use a great deal of care in doping out or diagnosing the trouble in a transmission, for, frequently, what appears at first to be at fault turns out to be all right, and something else is back of the first trouble, which must be corrected before a remedy can be applied. Recently, a repair man figured that a new gear was needed to repair a transmission. This was received from the factory three days later, but when he started to put it in, he found that a bearing was defective; in fact, the defective bearing caused the wear in the gear. This necessitated a further delay of three days in order to get a new bearing.

Poor Gear Shifting. A common transmission trouble is poor gear shifting. This may be due to a number of different things.

For one thing, the edges of the gears may be burred so that the edges prevent easy meshing. When this is the case, any attempt to force the gears into mesh only burrs up more metal and makes the situation worse. Whether this is the trouble or not can be determined very quickly and easily by removing the transmission cover and feeling of the gears with the bare hand; the burred edges can readily be distinguished. If this is the only fault, the transmission should be taken down, the gears taken out and placed in a vise, and the burrs removed with a cold chisel and file.

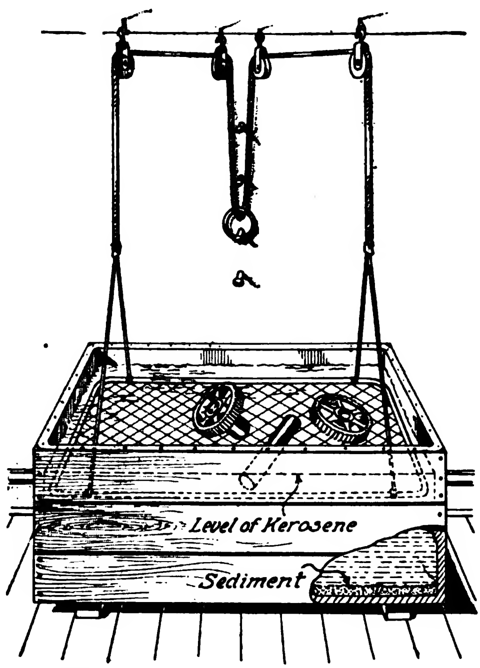


Fig. 297. Tank and Basket for Cleaning Gears and Other Parts
Courtesy of "Motor World"

Poor or worn bearings or a bent shaft or one not accurately machined may cause difficult shifting. If the bearings are worn, the difficulty of shifting will be accompanied by much noise, both in shifting and after. The bent shaft is more difficult to find and equally difficult to fix. A new shaft is usually the quickest and easiest way to remedy the trouble.

Sometimes the control rods or levers bind or stick so that the shifting is very difficult. In case the gears are difficult to "find" or will not stay in mesh, the fault may be in the shifter rod in the transmission case. This usually has notches to correspond to the various gear positions, with a steel wedge held down into these notches by means of a spring. The spring may have weakened, may have lost its temper, may have broken, or for some other reason failed to work. Or with the spring in good working condition, the edges of the grooves or notches may have worn to such an extent as to let the wedge slip out of, or over, them readily.

Cleaning Transmission Gears. When the transmission is taken out of the case and has to be taken apart, and particularly if it has not been cleaned for a long time previously, it is advisable to clean all the parts thoroughly before attempting to work with them. The best way to clean the parts is to have a special cleaning tank. In Fig. 297 one of these is shown, which is not unlike the baskets used in some hardening processes. It consists of a deep metal or metal-lined tank and a basket or tray, which is an easy fit in it, suspended from above by wire cables. The cables are brought

Fig. 298. Handy Framework for Lifting Transmissions out of Chassis

together on the wall, where a ring joining the ends and a series of nails or hooks make it easy to hold it at any desired elevation, either in or out of the tank. The tank is filled preferably with kerosene. As soon as a part has been removed from the transmission, it is thrown into the basket, and when this is filled or all the parts are in it, it is lowered into the kerosene and allowed to stand, for a couple of hours if possible, but, if not, for as long as can be. When thoroughly soaked, the basket should be raised above the level of the liquid and allowed to drain thoroughly. If it can be left for an hour or so to drain, all trace of kerosene will disappear, while the gears, shafts, and other parts will be like new.

Lifting Out Transmissions. When the trouble has been found to be in the transmission case or in some part that necessitates complete removal, it is often a tremendous job to get the unit out. Some units are attached from below and are not so difficult to detach. They are lowered by means of a platform of boards set on two or more jacks. But when it must be removed from above and no overhead beam is available, the hoist shown in Fig. 298 will be found very handy. As will be seen from the sketch, this hoist is simply a triangular framework constructed from angle iron to have the minimum height which will allow removal of the unit. The chain

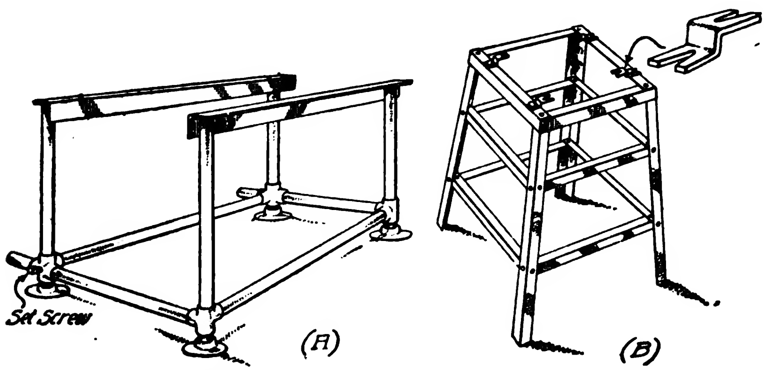


Fig. 299. Two Forms of Useful Transmission Stands
Courtesy of "Motor World"

fall is attached to a hook in the center, and the chains put around the case. When lifted up close into the V of the framework, the whole transmission can be put onto horses and moved along the chassis, or boards can be put under it and over the chassis frame to allow it to be worked there. Or, if desired, it can be lowered onto a creeper or other low platform with wheels and moved out of the way. This rigging can be used for many other similar purposes, although it is not suitable for the removal of an engine, radiator, or other part or unit which extends far above the chassis frame.

Transmission Stands. When the transmission has been removed, if the work to be done upon it is all extended, a stand to support it is desirable; in fact, a necessity, if the work is to be done right. A pair of stands are shown in Fig. 299, the one at the left is made from pipe fittings and angle irons in such a way that the width between the rails can be varied to suit the transmission or engine. The stand at the right is more of a specialized type. It is constructed for a certain transmission and has clips to support it in the same way that it is held in the chassis. The latter frame may be smaller and more compact than the former, but the wide range of uses to which the former can be put make it more desirable in the average shop.

Working in Bearings. When a great many bearings of any one transmission are fitted, it is well to make a jig for working in the cases to an exact size for the bearings, whether these be over-

Fig. 300. Method of Fitting Transmission Case Bearings with Dummy

sizes or not. Such an outfit, Fig. 300, shows an aluminum transmission case with a pair of jigs for scraping its bearings into the case. These jigs are made of steel and are constructed to a very accurate size, the surfaces being hardened so they will show no wear. The jigs are painted with Prussian blue, put in place and turned, the markings scraped by hand, the jigs again put in place and turned, and this process repeated until a perfect bearing surface is obtained. Starting with an unknown size on the case and a known size of bearing which must go in it, a few of these jigs will soon save their cost in labor and time, by quickly producing the necessary size of case to take the bearings.

Saving the Balls. If a great many ball bearings, particularly from transmissions, are used, and many bearings scrapped, it is advisable to save the balls. These balls will come in handy later for replacement or other uses. Moreover, balls are expensive, and good ones are hard to obtain. A handy way to take care of balls, without much work beyond cleaning thoroughly in the kerosene tank, is to construct a cabinet like that seen in Fig. 301. There are four drawers—or more if desired. The bottom of each drawer is a steel plate drilled as full of holes as possible of the next smaller size, that is, a clearance size for the next round figure size. Then the cabinet does the sorting, all balls being put into the top drawer. The next smaller size is retained in the second drawer, the third size in the next, and so on. When using balls out of these drawers, the micrometer should be used to determine their exact size.

Fig. 301. Easy Way of Sorting and Keeping Old Bearing Balls
Courtesy of "Motor World"

Handy Spring Tool. In the Ford transmission-band assembly there are three springs which it is difficult to assemble because of the trouble in holding so many things at once. To eliminate this trouble, the tool, shown in Fig. 302, made from flat bar stock, can be constructed. The handles, if they could be called that, are pivoted together and carry a kind of flat jaw with three notches at one end. When the two of these are squeezed together by means of the screw and handle at the other end, the flat plates will hold the three springs tightly enough so that all can be inserted in their proper positions

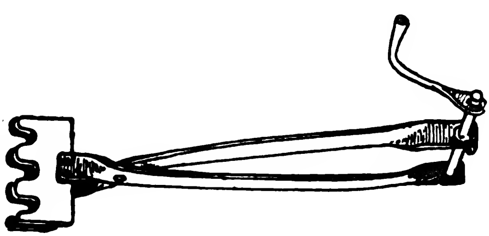


Fig. 302. Handy Spring Tool for Ford Assembly

at once by using but one hand. Tools of this kind, which save a great deal of the workman's time and thus save both time and money for the owner of the car, should, and in fact do, distinguish the well-equipped repair shop and garage from the old-fashioned kind which is in the business only for the money and not too particular how it is gotten.

In transmissions of the planetary type, there is little or no trouble except with the bands. If these are loose, the gears will not engage and the desired speed will not result. If they become soaked with grease, oil, or water, they will not work as well as if kept clean and, in the case of excessive grease, will slip continually. If the band lining becomes worn, it should be treated just as a brake lining is. When inspected for wear and found not badly worn but slippery, it may be cleaned in gasoline and then in kerosene, after which a saw, hacksaw, or coarse file may be used to roughen it. Sometimes greasy bands can be fixed temporarily—say, enough to get the car to a place where tools, materials, and facilities for doing the work are available—by sprinkling them with powdered rosin or fuller's earth. The former should be used sparingly because it will cause the band to bite or grab hold when forcibly applied, and at times has been known to cut into and score a cast-iron drum. As a rule, planetary transmission bands should be handled in the same way as ordinary brake bands, as to lining and relining, roughness of surface, lubrication, etc.

Possible Transmission Troubles. A combination of clutch and transmission in which the principal troubles incident to these units are indicated is presented in Fig. 303. In this type of clutch, the greatest possibilities of trouble lie in the burring of the discs or in a lack of spring adjustment. If the discs burr, the burrs can be filed off with a fine file, while the latter trouble is avoided by merely tightening the spring-adjusting bolt, trying the effect of this and tightening again, until the correct and satisfactory position is obtained.

In transmissions, the possibilities of trouble include the following: burred teeth; gears worn where they slide along the shafts on keys or in keyways; looseness in the main bearings; and play in shifter rods or their locks. Where the gears clash, one against the other in shifting—unless the faces of each have been chamfered and rounded off nicely and are well hardened at these points—a cutting action which gradually wears a high burr in one or both gears is liable to be set up. When the two are in mesh, the burrs are on opposite sides and contact with the meshing gear. This contact will make a continuous noise. Its remedy is the removal of the gear, the filing off of all raised portions, the filing or grinding out of all low spots cut into the teeth, and subsequent hardening to make repetition impossible.

If the gears have worn at the center hole where they slide on the shaft, either in the round hole or at the keyway, this must be fixed at once. In the former instance, the gear can be bushed, and

Fig. 303. Transmission Troubles Illustrated

the bushing bored out to fit the shaft, while in the latter, a slightly larger key may be fitted into the shaft and the keyway may be recut to accommodate it. Where the keys have been let into the shaft, they may become worn in one spot or at the ends. If the wear is all in the key, it can be replaced with another of the same size made slightly harder in the process.

If the main bearings are of the roller type, the wear may be taken up by readjusting the position of the roller on the cone, but if they are of ball or plain bushing form, replacement is almost the only remedy, unless it happens that in the case of a plain bush the bush is split, so that something may be filed off of the two contacting sides, and the holes trued out to this new size. In that case, the advice previously given under the subject of Plain Engine Bearings will be applicable.

Play in the shifting rods may be traced to one of two things: looseness at the connection of two rods or of a rod and a lever; or looseness in the bearings. The former inevitably requires a new and slightly larger pin driven into the place occupied by the previous member. Loose bushings will mean new ones if the trouble is serious, for this form is almost always of the solid and non-adjustable type. In many cases where wear occurs on a solid plain bearing used on the end of a plain round shaft, if peening cannot be resorted to, the shaft may be turned down a very little bit, say $\frac{1}{16}$ inch, the bushing turned out an equal amount, and a thin sleeve bushing made of this thickness all around and forced into the previous member. This saves reboring the case, which is an expensive and difficult job, while both the shaft and bushing jobs are simple ones.

If a serious defect develops in the case, it may be cleaned out and welded. This is not a job for the amateur, but the closing of a simple crack, no matter how long, would be an easy proposition for the owner of a welding outfit; moreover, it would be a very short quick job. Autogenous welding should always be resorted to as soon as a crack or break is detected, for this may save the expense and delay of a whole new case, the welding costing from 50 cents to $1, while the new case easily may amount to $50.

SUMMARY OF TRANSMISSION TROUBLES

Lubricating Transmission Gears. The transmission case should be filled with lubricant to a depth of several inches. Care should be exercised at frequent intervals to see that a proper amount of lubricant remains in the transmission case. Different makers recommend different kinds of lubricants for transmissions. In light cars a mixture often used consists of equal proportions of light grease and machine oil. In heavier cars a heavy graphite grease is often used. The proper lubricant depends upon the types of bearings used; thus for ball-bearing transmissions, no oil need be added.

Change-Speed Lever Indicates Some Impediment in Transmission. It is desirable to look for broken or mutilated gears, broken bearings in transmission shafts, sticking or misalignment of gear shafts or of their operating mechanisms.

Adjusting Annular Bearings. Makers recommend that the inner race be pinched so tight that movement is impossible; the outer race is sometimes allowed a little freedom—.002 to .003 inch.

GEARS

Since the whole subject of transmission concerns itself with gears, it will not be out of place to discuss the gears themselves and describe the many different kinds in use. Speaking broadly, the gears used may be classified according to the position of their axes, relative to one another. Thus we have axes parallel and in the same plane; parallel but not in the same plane; at right angles and in the same plane; at right angles and not in the same plane; at some other angle than a straight or a right angle and in the same plane; and the same, but not in one plane. These classes give us the forms of gear in common use, viz, spur gears, bevel gears, helical gears, herringbone gears, spiral gears, and worm gears.

TYPES OF GEAR-CUTTING MACHINES

Before discussing these various kinds of gears, it may be wise to familiarize the reader with the special features of different types of gear-cutting machines. Formerly, the teeth were cut, one gear at a time, in the milling machine, this being practically a hand operation, since all movements of the gear or cutter had to be made by hand. Later, improvements made it possible to cut more than one gear at a time, which resulted in lowering the cost, but did not eliminate the hand work.

Step by step special machinery was developed for this work, until finally a perfected machine was brought out which did all the work. With this machine, the workman placed the cutter on the machine spindle, set the gear blanks into position, and started the machine, after which it went on automatically, cutting tooth after tooth to a correct shape, until the gear was finished, when it was again necessary for the workman to shut it off and, after taking out the finished gears, put in a fresh supply of gear blanks.

Many machines have been devised and perfected in recent years owing to the demands of the automobile manufacturers. By having a battery of gear-cutting machines handled by a single man, the cost of gear cutting has been brought down to the absolute limit in addition to a decided gain in gear accuracy.

Whiton Gear-Cutting Machine. The Whiton automatic gear-cutting machine is shown in Fig. 304. The cutter is carried by the spindle *A*, which is journaled in a saddle *B* sliding upon the swinging carriage *C*, and is capable of adjustment at any angle necessary to cut bevel gears. The machine, as shown, is arranged for cutting spur gears. The cutter arbor *A* is driven by the pulley *D* at

Fig. 304. Automatic Gear-Cutting Machine
Courtesy of D. E. Whiton Machine Company, New London, Connecticut

the back of the machine, acting through a system of gears not shown. The blank to be cut is held on an arbor fitted into the vertical spindle *E*, with its upper end supported by a center in the arm, adjustably clamped to the column *G*. The traversing screw *H* has a graduated dial. A gage provided centers the cutter, and graduated stops are used for setting over the cutter in bevel gear cutting and for setting over the blank. At *J* are the gears of the indexing mechanism.

Brown and Sharpe Gear-Cutting Machine. Fig. 305 represents a Brown and Sharpe gear-cutting machine. The gear blank is carried on an arbor fitted to the horizontal spindle *A* and supported by the outer supporting bracket *B*. The indexing mechanism is in the rear of the indexing wheel *C*. The cutter is carried by the cutter spindle *D* mounted in the traveling carriage *E*. In smaller machines the base upon which this carriage slides is pivoted so as to be

Fig. 305. Number 6 Gear-Cutting Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

set at any required angle for cutting bevel gears. The machine is entirely automatic in its action. It has an attachment for cutting internal gears.

Automatic Gear-Cutting Machine. The automatic gear-cutting machine built by Gould and Eberhardt is shown in Fig. 306. It is of the same type as that built by Brown and Sharpe and possesses some excellent features. The gear blank and cutter are mounted in a similar manner, and the adjustments are made at much the same points. It is furnished with attachments for hobbing worm gears and for cutting racks and internal gears. The one shown is not adapted for cutting bevel gears.

Becker Gear-Cutting Machine. The Becker Milling Machine Company gear-cutting machine, Fig. 307, is of the milling-machine type. It was designed by Amos H. Brainard, a builder of milling machines. The gear blank is mounted upon an arbor fitting a taper

Fig. 306. "New Type" Gear-Cutting Machine Entirely Automatic for Cutting Spur Gears Only
Courtesy of Gould and Eberhardt, Newark, New Jersey

hole in the work spindle *A* or fixed upon an arbor and mounted on centers. The cutter is mounted upon a cutter arbor *B* journaled in a sliding saddle *C* whose support *D* is pivoted to the machine knee so as to be adjustable to any angle required for cutting bevel gears as well as spur gears. The machine is entirely automatic in its action.

Fellows Gear Shaper. The Fellows gear shaper, shown in Fig. 308, is a distinct type in construction and action. The gear blank is mounted on the vertical work spindle *A*, which has on its lower end and within the casing *B* an indexing worm gear operated by the change gears at *C*. These are driven from the cone pulley *D* by means of the vertical shaft *E* with a very gradual but continuous motion as the vertically reciprocating cutter *F* forms the teeth on the blank, gradually rotating in unison with the rotation of the blank. The reciprocating movement of the ram carrying the cutter is produced by suitable mechanism within the casing *H* operated by the shaft *G*. The machine is automatic in its action and cuts spur gears

Fig. 307. Gear Cutter
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

and internal gears. A modified form of machine is adapted to cutting the teeth of racks. The cutting action is that of planing.

Gleason Gear Planer. The Gleason gear planer is shown in Fig. 309. It is an excellently designed machine with a single tool having a narrow rounded cutting point for planing gear teeth. The gear blank *A* is mounted on a horizontal spindle having at its rear end a suitable automatic indexing mechanism *B*. The tool *C* is carried in a reciprocating tool block *D* which travels upon a swinging carriage pivoted at E directly under the apex of the base cone of the gear blank. The exact curve and direction of its feed are controlled by one of the formers, mounted upon the triangular former carrier, which may be rotated so as to bring either former up to its operative position, making a rest and guide on the outer end of the swinging carriage for the friction roller K. Of the three formers, one

Fig. 308. Gear Shaper
Courtesy of Fellows Gear Shaper Company, Springfield, Vermont

is used for a roughing cut, and the other two for the upper and under sides of the tooth. Being placed at a considerable distance from the pivot upon which the carriage swings, they are made many times larger than the tooth, and great accuracy of form is thereby secured. The roughing cut is frequently made with a rotating cutter on an ordinary gear-cutting machine. Modifications of this machine are built upon the same principle specially for cutting spur gears.

Bilgram Gear-Planing Machine. The Bilgram gear-planing machine, shown in Fig. 310, operates upon a principle similar to that

Fig. 309. Gear Planer
Courtesy of Gleason Tool Company, Rochester, New York

Fig. 310. Gear-Planing Machine

of the machine just described, but with this important difference. In the Gleason machine, the tool moves so as to trace the exact contour of the side of the gear tooth, in addition to its reciprocating movement for cutting. In the Bilgram machine, on the other hand, the tool has only a reciprocating motion, while the gear blank and its supporting mechanism are given the rolling motion similar to that imparted by one rotating gear to another, which is that of a rolling cone. To accomplish this motion, the axis must, in the first place, be moved in the manner of a conical pendulum; therefore, the bearing of the arbor which carries the blank is secured in an inclined position between two uprights to a semicircular horizontal plate, which can be oscillated on a vertical axis passing through the apex of the base cone of the blank. To complete the rolling action, the arbor must, in the second place, receive simultaneously the proper rotation; this effect is produced in the machine by having a portion of a cone (corresponding with the pitch cone of the blank), attached to the arbor and held by two flexible steel bands stretched in opposite directions, one end being attached to the cone and the other to a fixed part of the mechanism, thus preventing this cone from making any but a rolling motion when the arbor receives the conical swinging motion. In the engraving, *A* is the blank to be cut, *B* the ram carrying the cutting tool, and *C* the indexing and rolling mechanism.

TYPES OF GEARS IN AUTOMOBILES

Spur Gears. A spur gear is not only by far the most common kind of gear, but is also the easiest to describe, consisting, as it does, of a round flat disc with teeth cut in its circumference, i.e., around the periphery of the disc, as shown in Fig. 311.

Bevel Gears. Bevel gears, in which the shafts are at right angles and in the same plane or in the same plane but not at right angles, are more difficult to cut and are therefore less used. They are now cut, like the spurs, in an automatic or nearly automatic machine, which requires little attention, but which does require more care than the spur-gear machine. Both spurs and bevels sometimes require a chamfered tooth edge; spur gears as used in the Panhard, or clash-gear, transmission are always in need of it. This work was formerly done by hand, but now a special machine has been manufactured for this purpose.

There are no real restrictions against the use of the spur and bevel, either or both being used interchangeably. Very often they are used in combinations which appear peculiar, as the one shown in Fig. 311. This is the final drive and reduction gear of the Autocar commercial cars, made by the Autocar Company, Ardmore, Pennsylvania. In this gear, it will be noticed that the drive from the engine is through bevels to an intermediate shaft and that the final drive is by spur gears.

Helical and Herringbone Gears. In situations where quiet running is deemed necessary, the use of a helical gear frequently finds favor, since it accomplishes the desired result, although the cost of

Fig. 311. Combination of Gears in the Autocar Final Drive

cutting is high. Of late, these gears have come into general use for camshaft drives and similar places. A pair of helical gears set so that the helices run in opposite directions forms a herringbone gear. This is even more quiet in its action than the single helix and possesses other virtues as well. One well-known firm has adopted it for camshaft driving gears and makes it as described to save cutting-cost, as the cost of cutting a true herringbone would be prohibitive. So a pair of helical gears of opposite direction are set back to back and riveted or otherwise fastened together, forming a herringbone gear at a low cost. Both of these may be used when the two shafts are parallel and in the same plane, but for all cases where the shafts are neither in the same plane nor parallel, some form of spiral gear must be made use of.

Spiral Gears. Spiral gears, as such, are not generally understood, but that variety of the spiral known as the *worm* gear is very simple and easily understood and it has attained much popularity within the past few years. This popularity has been due, in part, to superior facilities for cutting correct worms and gears, but, in the main, to a superior knowledge of the principles upon which the worm works and of the things which spelled failure or success. Thus, one of the earliest experimenters in this line laid down the law that the rubbing velocity should not exceed 300 feet per minute if success was desired or in rotary speed about 80 to 100 revolutions. For automobile use, this was out of the question; but later experimenters found that these results only attached to the forms of gear used by the early workers and did not apply to a strictly modern gear laid down on scientific principles.

The mistake made was in the pitch angle of the worm, which was formerly made small, nothing over 15 degrees being attempted. This was the item that was at fault and that caused this very useful and efficient mode of driving to fall into disuse. As soon as this fact was ascertained and larger pitch angles utilized, better results were obtained, until, with 20-degree angles, 700 feet per minute pitch-line velocity was attained, followed shortly by the use of even higher angles, resulting even more successfully. As the efficiency depends directly upon the pitch angle, these changes brought the efficiency of this form of gearing from the former despised 30, 40, and sometimes 50 per cent up to 87, 88, and even 90 per cent, thus putting it on a par with all but the very best of spur gears and above bevel gearing. In fact, in the light of modern knowledge of worm gears, it could easily be said, without departing from the truth, that it is possible to obtain from this form an efficiency of 93 per cent. In automobile work, the worm gear has been used mostly for steering gears and final drives. In the former, its irreversible quality is brought out, while in the latter, this quality must be made subordinate to a great reduction, which may be attained in a very small compact space. Many modern machines make use of worm gears. Some of the users are: the Jeffery, Baker, Detroit, Hupp-Yeats, and

Woods electrics; Pierce, Packard, Riker, Mack, Atterbury, Blair, Chase, Gramm, G.M.C., Hulburt, Moreland, Standard, Sterling, and other trucks; Dennis (English) busses and trucks and Greenwood and Batley (English) trucks.

Fig. 312. Rear View of Timken Worm-Driven Rear Axle
Courtesy of Timken-Detroit Axle Company, Detroit, Michigan

Spiral Bevels. The spiral bevel is a new development, having been brought out in 1914 as a compromise between the worm and the

Fig. 313. Worm Gear Applied to Rear Axle Drive of Touring Car

Fig. 314. Worm Used on Locomobile Trucks
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

straight bevel. As such, it is supposed to have practically all the advantages of both, except that it does not afford the great speed reduction that can be accomplished with a worm in the same space, being more like the bevel in this respect.

Among those using the spiral bevel are the Packard, Cadillac, Reo, Stearns-Knight, Velie, Kline, Apperson, Buick, Chalmers, Chandler, Cole, Haynes, Hupmobile, Jackson, King, Locomobile, and many others. Figs. 312 and 313 show applications of the worm; Fig. 314, a detail of the worm as used on a prominent truck; and Fig. 315, a detail of the spiral bevel as used on a prominent car.

Fig. 315. Cadillac Helical-Bevel Driving Gear and Pinion

Worm Gears. Progress in the application of worm gears for rear-axle use has been considerable in the last few years. In one respect, at least, designers have found it an advantage. The top position for the worm was not much used at first, as it was thought impossible for it to receive sufficient lubricant there. Consequently, it was always placed in the bottom position, which cut down the clearance considerably; in this position the clearance was less than with the ordinary bevel. With the proof that the worm could be lubricated in a satisfactory manner in the top position, the majority of gears are so placed, thus converting what was formerly a disadvantage into an advantage, for in the upper position the clearance is greater than with bevel gears. This is shown quite clearly in Fig. 312, where it will be noted that the worm-gear housing in the center is actually higher than are the brake drums at either end of the axle. This, too, despite the fact that a truss rod passes beneath the center of the axle. For heavy trucks, especially, and for electric pleasure cars, the worm has proved an ideal drive. In these situations, there is the condition of high-engine or electric-motor speed, coupled with low-vehicle speed requirements, which necessitate a considerable reduction. As pointed out, the worm gives this in a small space.

For 1916, the very apparent tendency in final drives is toward spiral bevels for pleasure cars and worms for electrics and trucks. The tendency toward spirals is very great, amounting practically to a landslide, 57 per cent using it against 10 for 1915. The development of special machinery fot cutting these gears and the understanding of their use has brought this about. In the truck field there has been a similar movement toward the worm, due to similar causes.

Gear Pitch and Faces. The manufacturers of transmissions and of gears for them do not agree as to the best gears. Neither do they agree as to which gears are most quiet or most efficient. In general, coarse-pitch stub-tooth gears are gaining faster than any other form. The 6–8 pitch is fairly general for gears of $\frac{3}{4}$-inch and $\frac{7}{8}$-inch face, and 4–5 pitch for wider gears. One manufacturer, Warner, considers the finer pitch gears and narrower faces as less likely to make noise, since they will not distort as much in hardening as wider gears. In this, other manufacturers agree, but there are some who claim to have had both quiet and noisy operation with both fine and coarse pitch. The tendency toward compactness has not increased transmission-gear faces any appreciable amount, nor has the increased use of better steels and better hardening processes lessened the size of the four noticeably.

Gear Troubles. Most of the common gear troubles have been previously covered at the end of transmissions. There is not as much trouble with gears today as there was several years ago. This is due to better design, better materials, better processes, and better assembling on the part of manufacturers and to more skill in handling, caring for, and adjusting on the part of owners. Of course, the repair man still finds plenty to do, but the percentage of gear repairs is relatively less than ever before.

SUMMARY OF INSTRUCTIONS

CLUTCHES

Q. Why is a clutch needed?

A. The clutch is needed to disconnect the rest of the drive from the engine. The gasoline engine cannot start under a load but must first get up speed. By means of the clutch, which can be thrown out, the engine is allowed to run alone and get up the necessary speed, then the load or drive can be thrown on. This is just as true of the stationary gas engine as of the automobile, motor boat, or aeroplane power plant.

Q. How does the clutch act?

A. It is designed and constructed so that the amount of friction surface, with the spring pressure provided, is sufficient to transmit the whole power of the engine (and slightly more as a factor of safety) when the clutch is in. In addition, it is so designed and constructed that when the clutch is out the spring pressure is taken up in such a way as to be self-contained, that is, its thrust is carried to a member outside of the clutch itself which is able to withstand this thrust. In this way, when the clutch is out, the engine is entirely free, and when the clutch is in, the connection is such that it will carry more than the maximum power of the engine.

Q. To what type of clutch does this apply?

A. This applies to all clutches, regardless of type or design, with the single exception of clutches on traction engines or on agricultural tractors. These are designed in the same way but work just the opposite, being engaged only when the clutch pedal is pressed and disengaged when it is released. On this account, the clutch is arranged so that it can be set to be *in* all the time or *out* all the time. With this exception, the arrangement described applies to all internal-combustion engines, although clutches vary widely in type, size and arrangement.

Q. What are some of the most popular forms of automobile clutches?

A. The multiple-disc and the cone divide honors; and there are a few expanding- and contracting-band forms and some miscellaneous types. The first two included almost 94 per cent of the total in 1914, over 95 in 1915, and almost 97 in 1916.

Q. What are the two divisions of the cone form?

A. The cone form is made in two ways, the direct form and the indirect form. The direct form has the cone introduced directly into the flywheel, which is tapered inwards for this purpose. This makes it a very simple device to construct, the machining of the flywheel forming the female portion of the clutching surface. The indirect form, or inverted cone, differs in that the female portion is made as a separate flange bolted to the flywheel and tapering outward. The cone is placed inside of this, so that it works *out* against the clutching surface instead of *in* against this surface, as in the direct type.

Q. What are the relative advantages of the two forms?

A. The indirect is little used now, although it was popular years ago. The extra bolted-on inverted cone adds to the flywheel weight, for it is large and heavy and gives considerable flywheel effect. However, the flywheel is simplified. The spring is enclosed between the flywheel and the cone, this being considered an advantage in the early days but now considered a disadvantage because it is inaccessible for inspection or adjustment. The cone is pushed in—away from the clutching surface—to disconnect it, while on the more simple direct type, the cone is pushed out—away from the clutching surface—to disconnect.

Q. What are the divisions of the disc clutch?

A. Disc clutches are generally grouped according to lubrication, those which run in oil being called wet, and those which run without lubricant of any kind being called dry. In addition, a distinction is generally made between the disc clutch with a very few plates (one, two, or three), usually called a plate clutch, and the form with many plates (10 or more) which is called a multiple-disc clutch. Either plate or multiple form may run wet or dry.

Q. Explain the difference between the wet and dry multiple forms.

A. In the wet form, the plates, or discs, are plain steel and are submerged in oil, the entire clutch housing being filled with oil. The clutch discs work steel face against steel face, the action of the spring when the clutch is let in gradually squeezing out the oil from between the faces. This gradual squeezing out of the oil gives this form its gradual-application quality, for with six or seven pairs of discs the squeezing-out process takes an appreciable length of time. In the dry form, the plates are ordinarily faced with a special clutching surface of woven asbestos fabric similar to brake lining, this being placed upon every alternate disc, that is, the actual clutching surfaces consist of steel and fabric alternating. The general method of construction is to take one set, say the inner discs, and face both sides of each one. Then none of the outer discs are faced, so that when the clutch is assembled there is a steel face against each fabric face. This form is run absolutely dry; in fact, considerable pains is taken in design and assembly to keep out any form of lubricant.

Q. Explain the difference between the plate and the multiple-disc forms.

A. In the multiple-disc form, a considerable number, say 11, 13, 15, or some such number of discs, is used; the smaller number, as 5, 6, 7, etc., being the driving, and the larger half, as 8, 9, 10, etc., being the driven. In the plate form, a very small number of plates of the largest size which the flywheel will allow is used. As a rule, the flywheel inner surface is machined out to form one of the surfaces, the engaging or disengaging member another, and a single disc between; or, perhaps, another large disc is fixed to the flywheel and two discs used between this and the other two surfaces. The plate form has the advantages of a small number of parts and of compactness; but, on the other hand, the discs are so large and heavy that assembling is not so easy and a considerable flywheel effect is produced. Moreover, it is not so easy to produce an absolutely flat surface in the larger sizes, for which reason the clutching is not so even and smooth. In the smaller sizes, no attempt is made at perfectly flat surfaces, as the inequalities balance one another.

Q. What is the general tendency in cone-clutch surfaces?

A. As to size, the tendency is toward larger diameters and smaller or narrowed clutch faces. As to materials, asbestos woven fabric is gradually replacing leather. Light springs under the fabric form the means of gradual engagement, corks going out with the leather with which they were used.

Q. What is the general form of the clutch spring?

A. Formerly, all clutch springs were of spring wire of the maximum possible diameter and, therefore, very stiff. The modern tendency is toward a distribution of spring pressure by means of a number of smaller weaker springs. The former method almost invariably called for complete enclosure, making adjustments and replacements difficult. The smaller springs are usually placed outside, so that they can be adjusted or replaced easily and quickly. It has been found, too, that by using a large number, say 6, 7, or more, distributed around the clutching surface, a much lighter spring pressure can be used with equally good effect. In fact, many modern cars have so light a clutch spring that it can be disengaged with one finger.

Q. How does the contracting-band clutch work?

A. It has two half-bands which the clutching mechanism draws tight against a drum. In effect, a contracting-band clutch is like a band brake, except that the braking band is in two halves and operates from the center instead of from the exterior surface.

Q. Is this a popular form?

A. No. It is rapidly going out of use; only one or two American cars, with perhaps the same number in Europe, are now using it.

Q. How does the expanding-band clutch work?

A. In a somewhat similar manner to the expanding, or internal, brake; that is, it has two segments of fairly stiff metal section, which the movement of a cam, or expander, presses outward against the inside of the clutch drum (or inside face of the flywheel). This cam, or expander, is worked by the movement of the clutch pedal, or spring —outward so as to expand the band and take hold of the drum for engagement; inward so as to allow the band to contract.

Q. Is this type gaining in popularity?

A. No. On the contrary, it is losing so rapidly that there are practically no cars built in this country with it, although a number of old cars with this form are still running.

Q. What is the usual position of the clutch?

A. Within the flywheel. This saves a great deal of space, a number of parts, and considerable weight.

Q. Why is this position used so freely?

A. Partly because of the savings just mentioned, and partly because of the rapidly growing use of unit-power plants which forces this location. With the engine and transmission as a unit and the necessity for the clutch being between them, the flywheel interior is about the only place for the clutch.

Q. How can the surface, and thus the transmitting power, of clutch discs be increased?

A. By the use of other than plane surfaces. Thus, in the Hele-Shaw form each disc is made with a small cone projecting from it. The outside of this engages with the interior of the cone on the next. Other forms have half-cone or other inclined surfaces and half-plane surfaces. As a straight line is the shortest distance between two points, so a plane flat surface gives the smallest area between any two points in parallel surfaces. From this it is apparent that any surface not plane offers a greater area than does the plane one. However, the plane surface is so much easier and cheaper to make, use, replace, etc., that it has gradually driven out all these forms with greater surface despite their advantages in the way of transmitting power.

Q. What causes a slipping cone clutch?

A. A slipping cone clutch is generally caused by oil, grease, or other lubricant on the clutching surface or by a weak spring.

Q. How can this be remedied?

A. The surface can be cleaned with kerosene, then with gasoline, and dried. Or, if the surface is glazed, it can be roughened by using a file. Or, if the slipping occurs out on the road and no tools are available, any powder or fine material which will give roughness can be used. It is possible to get home with a slipping cone clutch by de-clutching and forcing in some sand. Of course, this is not advisable, but it works in an emergency.

Q. What causes a disc clutch to slip?

A. In a metal-to-metal type, a burred plate or a weak spring or a very thin oil which can not all be squeezed out will prevent engagement. The two latter causes are easily remedied; the former means removing the clutch and taking it apart to find the plate which is burred or roughened. In a faced, or dry disc, clutch slipping may be caused by oil, grease, or other lubricant getting in on the surfaces or by a weak spring.

Q. What other things may cause a clutch to slip?

A. The pedal may be held out, when it appears to be in, by the emergency brake interlock, by a bent or twisted rod, by a rod which presses against something, by a tight-fitting pin in one of the connections, by a worn pin, or by a bent-clutch spider which cannot contact all over because of this bend.

Questions for Home Study

1. Describe in detail the construction of the Studebaker clutch.

2. Tell how you would adjust the Stearns-Knight clutch springs.

3. Give the method of removing and replacing a clutch spring in the Warner clutch.

4. If springs under the clutch facing of a cone clutch do not produce gradual engagement, what is the matter, and how would you remedy it?

5. How does the Cadillac clutch work?

6. How does it differ from other clutches of the same type?

7. How would you lubricate a clutch bearing, with what, and how often?

8. Describe a quick, easy method of replacing corks in a clutch.

9. How would you construct a device to hold clutch springs while replacing them?

TRANSMISSIONS

Q. What is the purpose of the transmission in a motor car?

A. To allow variations in the speed of the car forward from the lowest to the highest, and for reverse, without varying the motor speed greatly.

Q. Why cannot the engine speed be varied directly, doing away with the transmission?

A. The lowest speed used in cars ordinarily would not be possible with the present engine, since it could not be throttled down slow enough. Again, if the gearing were such as to give the present lowest car speeds with the engine low speed, then for maximum engine speeds the highest possible car speed would be very low. In short, gearing is necessary to give a greater variation than is possible with the engine alone. Further, reverse could not be obtained without additional gears and this would necessitate also a method of shifting the reverse gear into, and out of, mesh. Thus, all the requirements of the modern gear transmission would be necessary for reverse alone.

Q. Show by the use of figures the impossibility of doing without the transmission.

A. The circumference of 34-inch wheels is 136.8 inches, or 11.4 feet. With the engine geared direct to the wheels, the speed of the latter would be directly proportional to the former, considering the gear reduction. If an average present-day gear reduction of 3.8 to 1 be considered at 240 r.p.m., which is very low, the car would make

10.3 m.p.h. as its lowest possible speed. And at 2400 r.p.m.—a high maximum for an engine with as low a speed as 240—the highest car speed would be 103 m.p.h. As the average roads would not allow this high a speed, and as the average car has a low speed approximating 3 m.p.h., it is apparent that the gear ratio is too high. By lowering this to 12 to 1 at a low speed of 264 r.p.m. of the engine, a low car speed of 2.85 m.p.h. would be obtained. And with 2640 r.p.m. as the highest engine speed, the highest car speed would be only 28.5 m.p.h. From these two extremes, it is apparent that direct gearing without a transmission is not feasible.

Q. What are the general classes of transmission now in use?

A. There are five general classes: sliding gear, individual clutch, planetary, friction, and miscellaneous types. The first named is most popular and constitutes perhaps 90 or more per cent of all the cars now built. The individual clutch is really a modification of the sliding gear, but is not widely used—not to exceed 3 or 4 per cent. The planetary is the most simple form to operate but, unlike the others, is limited as to the number of possible speeds. Practically the only American maker using this today is Ford. The friction form was intended to give a maximum number of speeds with maximum simplicity. It does this, but other faults offset these advantages. Metz is about the only American car-maker using it regularly. The miscellaneous transmissions include what might be called the unproved inventions—forms which have not been tried out sufficiently to be proved successes. Consequently, this class is small. It includes hydraulic, electric, magnetic, and various other forms of transmissions.

Q. What is the average number of speeds?

A. Three is the most popular number, four is found on a number of high-class cars, the planetary can give but two, the friction form may give five or more, the only magnetic form on the market gives seven. In general, three is considered sufficient; even the highest-priced makers are gradually giving up the use of four-speed gear boxes, and the number of these is less each year.

Q. What are the three methods of gear shifting now in use?

A. The selective accounts for about 94 per cent, the progressive form is not used by more than 2 or 3, and electric shifting is used by but two makers.

Q. How does the selective form work?

A. The operator is at liberty to select any gear he desires and to go directly to that speed from the speed which he is using. This means with common sense reservations; for instance, it would be foolish to go from high to reverse, although this is possible in this form.

Q. How is this accomplished?

A. Within the gear box, the gears are shifted by forms, and the quadrant arrangement is such that the driver can shift his lever so as to pick up the fork which will give the desired speed. Usually there are but two shifting members (in the three-speed form), one giving low speed and reverse, the other intermediate and high. Having picked up the low and reverse fork, he can shift his lever forward for low and backward for reverse; similarly, with the other fork for second and third speeds.

Q. How does the progressive form work?

A. In this type of gear box, the speeds must be used in succession—first the low, then second, then high, and when slowing down from high, to second, then low, then reverse. For instance, if driving in high and a turn is passed in a narrow road, it would be necessary to shift down to second, then to low, then to reverse. The driver could now back his car past the street into a position which would enable him to make the turn. Then he could speed up the car again by using first low speed, then second, and finally high. This maneuver could not be accomplished in any other way. In the same circumstances with a selective gear, the car could be brought to a dead stop with the brakes, an immediate shift to reverse effected, the car backed up, and the gears shifted to low and then high speed forward, thus doing the same thing as before with half as many changes.

Q. How is the high speed generally effected?

A. High speed in all modern transmissions is a direct drive so that none of the various gear reductions are in use. This method reduces the amount of noise by eliminating at once the meshing of two sets of gears, the average high-speed direct drive being effected by clutching one gear up to another.

Q. Is this arrangement always used?

A. No. In some four-speed gears the highest speed is a geared-up form, and the direct drive is used on third speed. This is done with the idea of securing the silence of the direct drive for all average rapid driving, while the geared-up form gives an extraordinary speed for emergencies where noise is immaterial.

Q. In the electric gear shifter, how is the movement of gears effected?

A. The shifter is made with a series of electromagnets, or solenoids, one for each speed and one for reverse. Current flows to these when the proper button is pressed. It is well known that when an electric current is passed through an electromagnet of the solenoid type, the rod, or bar, inside of it is drawn forward. This arrangement produces the speed corresponding to the button pressed. In actual practice, the current does not flow until the clutch pedal is depressed after the button has been pressed.

Q. Where is the transmission located?

A. Excluding freak forms, there are four general positions: in unit with the motor; amidships in unit with the clutch; amidships but separated from the clutch and in unit with the forward end of the driving shaft; and in unit with the rear axle.

Q. Are these same locations used on motor trucks?

A. Yes. Except that the third class is sometimes modified with chain drive, so that the transmission is amidships but in unit with the jackshaft.

Q. Which of these is most popular?

A. The form in which the transmission is grouped with the motor and clutch, that is, the unit power plant, is now the most popular, and the tendency among the makers is to make it more so. It is gaining at the expense of all other locations.

Q. What difference is noted in gasoline railway-car transmissions?

A. As all speeds must be used in the reverse direction, the design is so modified as to allow the driver first to choose the direction and then to utilize all his transmission speeds in that direction.

Q. What is the difference between individual clutch and other transmissions, particularly the sliding-gear type?

A. In the individual-clutch type, no one of the gears is fixed to its shaft, but an individual clutch is provided for each. The purpose of this is to clutch the gear to its shaft so that it can drive or be driven. When shifting gears, the driver moves the usual lever in the usual way, but within the transmission this lever, instead of moving a gear on a shaft to which it is keyed, moves a clutch which keys the desired gear to the shaft.

Q. What is the advantage of this over sliding gears?

A. In the sliding gear, the moving members must take the drive and transmit the power in addition to withstanding the shocks and destructive action of shifting or meshing. In the individual clutch form, the gears have only to transmit the power, while the individual clutches have only the shocks and destructive action of shifting.

Q. How are gears pressed onto their shafts?

A. Usually by means of a hydraulic or a power press—one capable of exerting a pressure of many tons. Generally, it is easier to lay the gear out on the press table and press the shaft down into it, than the reverse.

Q. How are pressed-on gears removed?

A. The process of pressing on is reversed, and the gear is supported in such a way that the shaft can be pressed, or forced, out of it.

Q. How is the transmission removed from the chassis?

A. The usual method in well-equipped shops is to put a rope or chain sling or special cradle around the transmission, then to lift it vertically upwards by means of a block and tackle, electric or pneumatic overhead hoist, chain block attached to overhead tracks, or portable crane.

Q. How are bearings worked in?

A. After slow careful fitting by hand for both diameter and length, using a dummy shaft with dummy bearings, the real bearings should be put in place and run-in for several hours, using power from a line shaft. Transmission bearings should be run-in the same as engine bearings, set up somewhat tight and with an excess of oil.

Questions for Home Study

1. Describe the construction of the Cadillac and Winton transmissions, a railway transmission, the Mack truck, the Ford planetary, a friction form, and a magnetic type.
2. How would you adjust the shafts longitudinally in the Stearns transmission?
3. Tell how to construct a stand for gear pressing.
4. Give a thorough method of cleaning a transmission.
5. What are the usual gear pitches?
6. What is meant by the pitch of a gear?

SECTION OF NASH CAR, SHOWING ENGINE AND TRANSMISSION DETAILS AND REAR SPRING SUSPENSION

Courtesy of The Nash Motors Company, Kenosha, Wisconsin

GASOLINE AUTOMOBILES

PART V

STEERING GROUP

The mechanisms by which steering is effected are among the most important features of a car, if not actually the most important. The truth of this statement will be realized when attention is called to the fact that safe steering is the final requisite that has made the modern high speeds possible, for without safe and dependable steering gears, no racing driver would dare to run a machine at a high rate of speed, knowing that at any minute the unsafe steering apparatus might shift the control, thus allowing the front wheels to waver and the car to run into some obstruction by the roadside.

The same argument applies in an even greater degree to the case of the non-professional driver, who wants to be on the safe side even more, perhaps, than do the dare-devils who drive racing cars. Nearly all of our roads are curved and, to make all of these turns with safety, the steering gear must be reliable. Again, in mountainous country where there may be a sheer drop at the roadside of hundreds of feet, it becomes necessary that the steering mechanism be very accurate and that it obey, at once, the slightest move on the driver's part. To secure this accuracy, there must be no lost motion or wear of the interrelated parts.

These things mean that the whole steering mechanism must be safe and reliable; strong and accurate; well made and carefully fitted; well cared for; and finally, the design and construction must be based on a theoretically correct principle, for otherwise the mechanical refinements will have been wasted. Perhaps it will be more logical to treat the mechanical requirements first by showing how the present type has been evolved from the failures of earlier forms.

STEERING GEARS

General Requirements. In turning a corner a car follows a curve, the outer wheels obviously following curves of longer radius than do the inner wheels and, therefore, traveling farther. In straight-ahead running, the wheels run parallel at all times and travel the same distance. These two facts are the basic ones which make the steering action so complicated: First, that on straight-ahead running the wheels must travel the same distance; and second, that on turning curves the outer wheels, whichever they may be, must travel a greater distance.

This double requirement leads to the usual form of steering arrangement, called after its inventor, the "Ackerman". It was Ackerman who brought out the first vehicle in which the front wheels were mounted upon pivoted-axle ends, these ends being pivoted on the extremities of the central part of a fixed axle, while the pivoted ends carried one lever each. These levers were connected together by means of a cross-rod, while at one end another rod was attached, which was used to move the wheels. By moving this latter rod, both wheels were compelled to turn about their pivot points, since the cross-rod joined them together, and if one moved the other had to move also. This was Ackerman's substitute for the fifth wheel which had been used up to that time and is even today on all horse-drawn vehicles.

Inclining Axle Pivots. The situation is further complicated by the fact that the ideal arrangement, that is, the fixing of the steering pivot at the center of the turning wheel in order to allow the maximum turning movement for the minimum motion of the hand, is not suitable for general use. In practice, however, it is placed as close to the ideal position as possible, which, in the ordinary case, is within three to six inches.

This approximation to the ideal has been made by inclining the stud-axle pivot inward, so that its center line prolonged would strike the ground at a point coincident with the center line of the tire. This same result is also brought about by inclining the stud axle itself downward. The construction gives added safety, in that the force of head-on collisions is supposed to be delivered at or near the line of incidence.

The axle-spindle center may be brought close to the wheel hub by means of a double yoke, but this was tried and abandoned as too cumbersome for the results effected. A method of placing the steering pivot in the center of the wheel was also developed. In this case the pivot was enclosed in a hollow hub; but as this made the pivot, which is liable to wear, inaccessible, it also was abandoned. However, later tendencies point toward a revival of this construction.

The result is that today we are using a form which, though far from being ideal, fulfills every practical requirement. This form is usually constructed as in Fig. 316, which shows a skeleton plan view of an automobile. In this, the line AB represents in length, position, and direction, the front axle of a car, while ML represents in a similar manner the rear axle. A and B also are the pivot points for the axle-stud ends or, as they are more commonly called, the

Fig. 316. Diagram of Steering Connections

steering knuckles or steering pivots, which are represented by the lines AD and BC.

The rear (or front, as the case may be) ends of the steering knuckles are joined by the connecting rod DC. The Ackerman construction is such that the center lines of the steering arms, or levers, AD and BC, prolonged, must pass through the center point of the rear axle at K; the reason for this is that the front wheels are supposed to turn about the center of the rear axle as a center.

Action of Wheels in Turning. If the wheels are supposed to turn through an angle, the action of the above arrangement will be seen. Suppose the steering gear (not shown in Fig. 316) is turned so as to move the steering lever AD to the new position, shown dotted at AD_1. This movement will also move the other lever BC to a new position, shown dotted at BC_1. It will be noted in this position that the angle through which the right-hand lever BC has swung is not as great as that through which the left-hand lever AD has moved, although the two levers are attached together by means of the cross-connection DC.

The wheels are mounted upon the extremities of the steering knuckles at F and I; EG represents the left wheel, and HJ the right wheel. These turn about the pivot points A and B, with the movement of the steering knuckles to the new positions, shown dotted at $E_1F_1G_1$ and $H_1I_1J_1$. In this position, prolongations of the lines through the pivot point and the center of the two wheels will meet the rear-axle center line prolonged at separate points as OP, the two lines converging slightly. This same convergence may be noted by prolonging the center line of the two wheels E_1G_1 to Q and H_1J_1 to R. This divergence means that the two wheels are turning on curves of different radii, and since the outer wheel H_1J_1 shows a longer distance from its center line prolonged to the rear-axle line $OPMKL$ than does the inner wheel, that is, has the longer false radius, PI_1 being longer than OF_1, it follows that the turning action will be correct.

This is somewhat complicated and rather hard to follow, but the figure seems simple and should be examined closely, even drawing it out step by step, as outlined above, for the purpose of making the steering action clear. Laying this out for one's self will bring out the reason why the steering knuckles do not move through the same distance and thus bring about a different movement of the wheels.

Steering Levers in Front of Axle. That the final movement of the wheels will not be changed if the levers, Fig. 316, are laid out in the same way but in front of the axle will be evident by prolonging the levers to S and T, respectively, making the lengths AS and BT the same as the former lengths AD and BC. Connecting the two by the rod ST completes the front arrangement, which is seen to give the same results as the other. The choice of a front or rear location depends upon certain things, such as the safety of the cross-rod, etc., which will be brought out later on. Some machine manufacturers even go so far as to fit both front and rear levers to the same machine.

While shifting the lever from rear to front in Fig. 316 does not change the result at all, in Fig. 317 it does. In this construction, known as the Davis, the steering levers are set in front, but taper inward instead of outward, so that their center lines prolonged meet the center line of the car prolonged at a distance from the front axle equal to the distance between the front and rear axles, or equal to the wheel base.

In addition, the connecting rod is carried in guides placed on the front of the axle, so that its path of travel is always parallel to the front axle. Consequently, the levers must be made slotted or telescopic. The result of this combination of movements is an

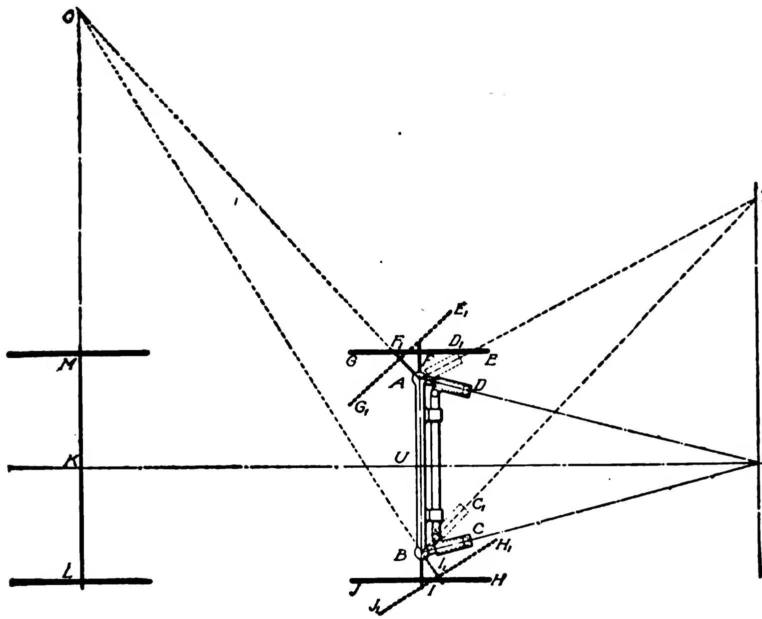


Fig. 317. Patented English Steering Device, Said to be Theoretically Perfect

absolutely correct angle to both wheels for any angle of lock. This can be explained by a reference to the diagram.

In Fig. 316 the prolongations of the wheel center lines, or radii of turning, do not strike the center line of the rear axle—about which they are supposed to turn—at a common point, the difference being the amount they are out of true, viz, the distance between the points O and P. If Fig. 317 be lettered to correspond with Fig. 316, the prolongations of the knuckle center lines AF_1O and I_1BP in Fig. 316 become the two converging lines AF_1O and I_1BO meeting at the point O on the center line LMO of the rear axle prolonged. This is as it should be and shows the case of correct steering and turning.

In this case, all four wheels are turning about the point O, the two rear wheels with the radii OM and OL, and the two front wheels with the radii OF_1 and OI_1, respectively. This gives a theoretically correct case in which all wheels will round any curve as they should and not slip or slide around, damaging the tires in the process. The Davis type of steering gear, it may be remarked, is not in general use, its construction adding a number of parts to the more usual form, shown in Fig. 316, which gives close enough results for average use.

Like the sliding-gear transmission, a steering gear is a form of mechanism which, although used on nearly all automobiles, is, from a theoretical and mechanical standpoint, far from what it should be.

General Characteristics of Steering Gears. *Standard Types.* The movement or deflection of the front road wheels is obtained by

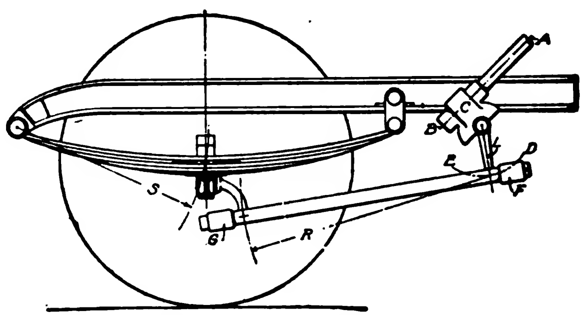


Fig. 318. Typical Steering Gear and Connections to Front Axle

a crosswise movement of the tie rod which links the steering-knuckle levers attached to the wheels. This tie rod, sometimes referred to as the cross-connecting rod, is actuated by the drag link GF, Fig. 318, which is pivotally mounted on the steering-knuckle lever L. The drag link has a linear movement along the frame and is parallel with it.

The drag link is also pivotally mounted at the ball arm of the steering gear C, and when the drag link is moved forward or backward by movement of the ball arm, the tie rod is moved at right angles, deflecting the wheels. The drag link has a semi-rotary motion; that is, its upper end is turned through a part of a revolution while its lower end, to which the drag link is attached, swings through a fairly large arc, according to the capacity and design of the steering gear.

As the ball arm swings through its arc, the drag link attached to it rises and falls slightly, the movement being indicated by the dotted lines in Fig. 318. The partial circular motion in a vertical plane is converted from the rotation of the steering gear in a horizontal plane by several methods. The gear shown in Fig. 319 is known as the worm and sector type, which is illustrated in Fig. 318.

In Fig. 319 the steering column or post *CD* carries a worm *F* which is in mesh with the gear *E*. Rotating the column *CD* in the direction indicated by the arrows, or counter-clockwise, will result in the worm turning in the same direction. The gear *E* will rotate on its horizontal shaft in a downward movement, as shown by the arrow, and as the ball arm, or lever, is attached to the shaft, the member *L* will move backward, or to the left, as shown by the arrow intersecting the ball. With the worm type the two gears are usually in two different planes at right angles to each other, one vertical and the other horizontal. This is an advantage in that it lends itself readily to the construction of a simple steering-gear system. Thus the post is in a vertical or modified vertical line, as is also the motion of the steering arm, and the consequent movement of the steering rod is more or less confined to a vertical plane. With the worm and gear this is obtained in a simple manner. The gearshaft is in a horizontal plane passing through the center line of the worm. If the worm rotates in a direction which approximates a horizontal circle around a vertical axis, the worm gear will turn in a vertical plane about a horizontal axis. A lever attached to the end of this shaft will, consequently, move in the desired

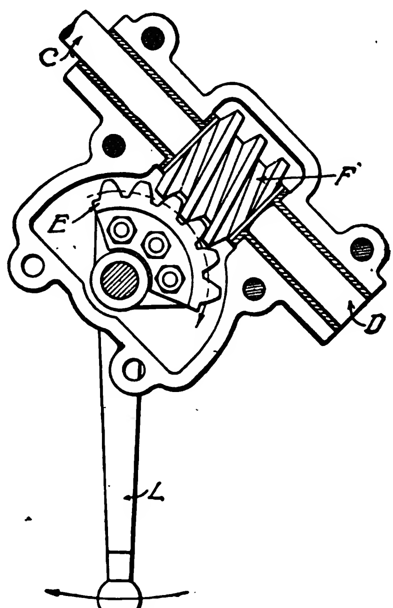


Fig. 319. Worm and Partial Gear of Typical Steering Gear

plane—the vertical one mentioned before—and the desired requirements are met.

The conversion of rotary motion in a horizontal plane to partial rotation in a vertical plane is shown in Fig. 320, the action here being slightly amplified. The steering, or hand, wheel *A* with spokes *B* is turned to the left, turning the steering column *C* (a hollow tube) in the direction indicated by the small arrow. *D* is the steering gear with its ball arm *E*. The turning of the hand wheel moves the ball end *F* and drag link backward. The front end of the drag link is attached to the steering knuckle *M* at *H* and turns about the center line *KL* of the steering knuckle *J*, the end turning through

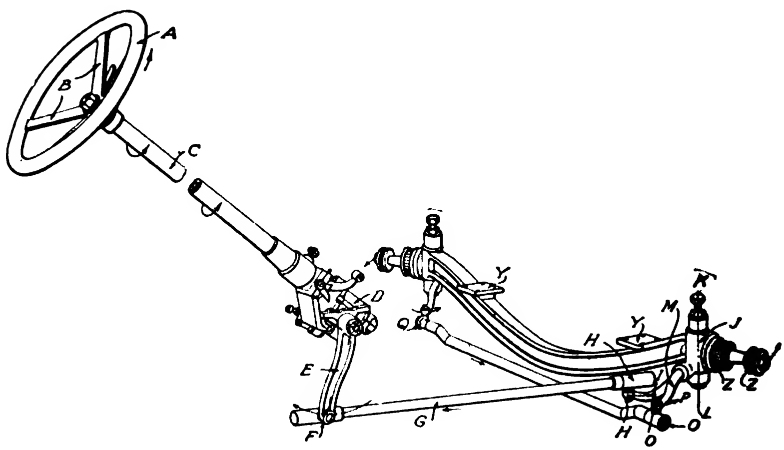


Fig. 320. Steering Mechanism and Front Axle of Pierce-Arrow Car
Courtesy of Pierce-Arrow Motor Car Company, Buffalo, New York

the arc *HI*. The lever *M* is attached to the knuckle *J* and turns with it. Its end turns through the arc *OP*, moving the tie rod *OQ* to the right and turning the other knuckle in the same way and direction. *Y Y* are the spring pads and *ZZ* the tapered roller bearings supporting the road wheels.

Classification. There are three general forms of steering gears: the worm, the bevel, and the spur. These may be subdivided, which might lead one to assume that there are a dozen or more different forms. The mechanical lever has been discarded because of its tendency to impart all road shocks to the driver; it is fully reversible at all times. Irreversibility is employed because it transmits to the road wheels any turning movement imparted by the driver without reversing or carrying back to the operator the original movement of the road wheels.

Many attempts have been made to substitute another form of mechanism for steering gears; this consists of various rod, lever, chain, and spring combinations. All of these have failed, however, because they lacked the fundamental requisite of irreversibility.

Aside from the many schemes mentioned which seek to avoid the use of the regular gear in the standard manner, there have been a number of unsuccessful attempts to avoid its use in other ways. Fig. 321 shows some of the gears which have been tried. At *1* is seen a device in which the rotation of a large bevel gear turned a small bevel pinion, the rotation of the latter serving to screw a long straight lever with a threaded inner end into or out of the interior of the threaded bevel pinion.

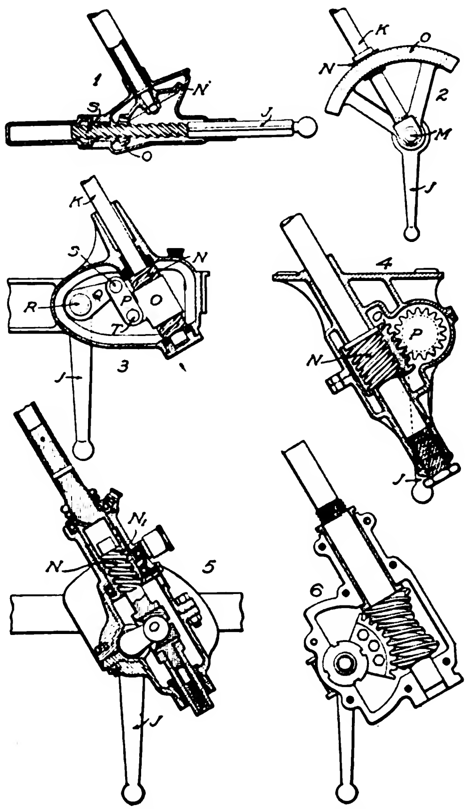


Fig. 321. Obsolete Forms of Worm Steering Gears

In the figure, N is the actuating bevel turned by the movement of the operator's hands, while O is the smaller actuated bevel pinion. Within this is seen the worm end S of the lever J, the ball at the outer end being connected to the steering knuckle. Since the bevel alone lost a great deal of power in friction, while the worm arrangement and the sliding action of the lever in its bearings did likewise, the total effort to turn this must have been enormous. At *2* is shown another form, which is the double-bevel arrangement; a small bevel N attached to the steering post K turns the larger bevel O, which is pivoted at the axis M about which the lever J attached to the segmental bevel O turns.

A most peculiar arrangement is shown at *3*, this being a combination of a worm and nut, two levers and a steering arm, as well as a connecting link for the two levers. Turning the hand wheel turns the worm, which moves the nut up or down. Since the nut is connected by means of the link to the lever, the motion of the nut up and down is transmitted to the short lever; this, in turn, moves the long-arm, or steering, lever. In the figure, K is the steering post, N the worm, O the nut, P the connecting link pivoted at the two ends T and S, Q the short-arm lever, and J the steering lever, the two latter being integral and pivoted at the point R. At *4* is shown a combination of a double internal worm with a rack and gear. In this, the turning movement of the inner worm causes the outer worm to travel up and down. Upon the exterior of this outer worm is cut a rack which is meshed with the gear, its up and down movements turning the gear around and thus effecting the steering, the steering lever being attached to the gear. N is the internal worm, O the external worm with the exterior rack, P the gear which meshes with it and carries the lever J as a part of it. At *5* is shown a combination of a double worm with a double ball and socket arrangement. The turning of the outer worm N_1 causes the inner worm N to rise and fall, the lower end of this carrying a ball-and-socket joint O, the end of the ball being formed integral with the steering lever J, which also has a ball and socket attachment at the other end. At *6* is shown a steering gear which was tried and discarded, but which is now coming to the fore and bids fair to oust many other forms of gear. It is variously called a globular worm, helicoidal worm, or Hindley worm, the worm forming a curve closely approximating the curve of the gear with which it is to mesh. This gives a greater number of teeth in mesh at any one time, spreading the wear over a larger surface and thus lengthening the life as well as accuracy of the steering gear.

Spur and Bevel Types. The spur- and bevel-toothed construction of gears may be reversible, and these types are to be found on low-priced cars, as the cost of cutting the gears is small. The spur gears have straight teeth, the edges, or sides, of the teeth being straight and parallel with the axis of the shaft on which the gear turns. In bevel gears the teeth taper toward a point and are inclined to the axis of the shaft. Another construction is the spiral gear. Both types may be made reversible and irreversible as desired.

Worm-Gear Types. With a very few exceptions, automobile engineers favor the worm type of steering gear, and it will be found on the highest priced cars. It has the advantage of being irreversible and is utilized in several forms. In the worm class of gears, some types are closely related, while others vary widely. For example, the complete sector and gear type differ only in that the wheel operated by the worm makes a complete circle or part of a circle. The full gear can be turned through 90 degrees and replaced on the shaft without presenting a new surface to the worm. Some hold that the worm must be subject to some wear, especially where it is most used. They contend that turning over the pinion brings new teeth to engage with the worm and that these teeth will not mesh properly when turned at an angle of from 20 to 30 degrees.

Fig. 322. Worm and Partial Gear Type of Steering Gear

Worm and Partial Gear. Fig. 322 illustrates a gear of the worm and partial gear type. Advantages claimed for the design are durability, ease of action, and adjustability to wear. The parts are accurately cut and hardened, and the worm is provided with a ball thrust on either side. With this type, the teeth, which are in the middle of the sector and in mesh, perform the greatest work when the car is driven in a straight line and are most susceptible to wear. To compensate for this wear, the center teeth are cut on a slightly less pitch radius so that lost motion may be eliminated without affecting the upper and lower teeth of the sector and to prevent binding when turning at right angles. In the illustration, *A* is the steering column to which the worm *C* is secured, *D* is the sector in mesh with the worm, *E* is the ball arm, or lever, *B* the gear housing, *F* the spark and throttle bevel gears and levers, and *G* the lubricant plug.

Adjustment. Two principal adjustments are provided. End play of the worm is eliminated by loosening the jamb nuts and lock screws on the column housing. Displacing the oil plug *G* will disclose an adjusting collar which is set with a screwdriver. Adjust collar until all play is eliminated, but the worm must turn easily. The lock screws, above referred to, are so located in the gear housing that when one is directly over a slot in the adjusting collar the other is between two slots. Consequently, after adjusting the collar it is essential that the proper screw be selected for locking the adjustment. Both locking members must be prevented from turning, by using the nuts. Wear of the teeth of the worm and sector may be eliminated by means of an eccentric bushing, which, when turned, moves the sector into a closer relation with the worm. This is accomplished by removing a locking screw at the left of the ball arm and moving the arm, which turns the eccentric bushing. In case of extreme wear, it may be necessary to displace the ball arm and set the locking-screw section in a different position on the end of the hexagonal end of the eccentric bushing so as to bring the arm in such a position that it can be locked by the screw. End play of the sector shaft is eliminated by removing a locking arm and turning an adjusting screw in, after which the arm and lock screw are replaced and both set up tight.

Worm and Full Gear. A full gear and worm type of steering gear is shown in Fig. 323, with the gear cover removed. This type is irreversible, and the advantage claimed for it is that it can be easily removed and so readjusted that an unworn section of the gear may be brought into contact with the worm. This is a simple form, and it is possible to replace a worn gear with a new one, as the gears are not expensive.

Fig. 324 shows a much more complicated form of worm and full gear in which the inventor has attempted to gain something by the use of a double steering gear, that is, two complete sets of worms and gears set opposing one another, the gears being made to mesh with each other just like a pair of spur gears. Since the lever can be attached to but one of the turning gears, the other gear with its actuating worm is useless. The inventor doubtless intended the two worms to oppose each other and thus be self-sustaining as to thrust, but such would not be the case, the actual thrust being in opposite directions in the two cases of the upper and lower worms, the total thus being double the usual amount.

Adjustment. The part most subject to wear is that section of the gear which meshes with the worm when the front wheels are traveling in approximately a straight line. Because of this wear, the teeth of the wheel are subject to deterioration. Usually the adjustment for the wear is made by bringing the worm into a closer relationship with the gear by using the eccentric bushings which support the worm shaft. This adjustment is practical when the lost motion is due to poor adjustment rather than to wear of the teeth. With the majority of types, it is possible to displace the steering arms, move the steering wheel about half a turn, then replace the worm wheel so that an unworn section opposite the worn teeth will be brought into engagement with a comparatively unworn portion of the worm proper. The eccentric bushings in this case can be utilized to obtain a correct meshing of the worm and gear teeth. End play of the worm

Fig. 323. Typical Worm and Full Gear Steering Device

can be removed by adjusting the ball thrust bearings on either side of the worm. Sometimes these bearings become dry, or the lubricant becomes gummy, causing the shaft to turn hard. Wear of plain bushings in the steering-gear case is responsible for lost motion; the remedy is to replace the bushings with new members.

Worm and Nut. Next to the worm and gear, either full or partial, the form of steering gear most used is the worm and nut, which is made in several different combinations. Thus, the nut may operate the steering lever directly through the medium of a secondary lever, or it may actuate a block, which, in turn, moves either the lever direct or the secondary lever. In Fig. 325 another form of

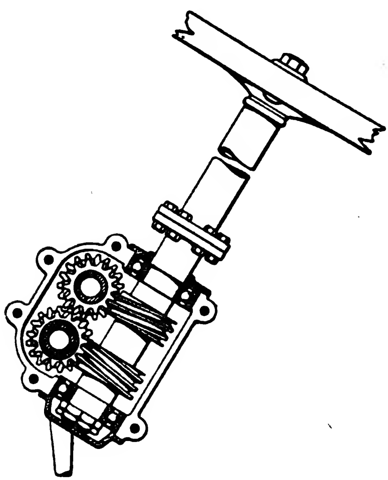


Fig. 324. Double Worm and Gear Steering Device

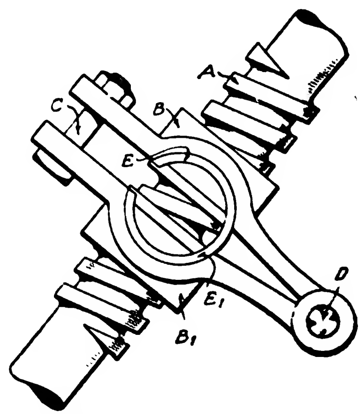


Fig. 325. Worm and Nut Steering Device

the worm and nut variety is shown. This has a nut which the turning of the worm moves up and down but which is split, the two halves being bolted together. A spherical seat is formed in the two halves of the split nut into which a ball-end lever is set, the bolt serving to clamp the two pieces together and hold the lever there.

This is the end of the secondary lever, which is connected by means of another lever to the steering lever itself. In the figure, *A* is the worm, *B* and B_1 the two parts of the nut, *C* the clamping bolt, and *D* the hinge at the other end. *E* and E_1 represent the spherical seats for the ball end of the other lever.

Having the nut in two widely separated parts reduces the wear on each, since the bearing surface is spread out more than would be

Fig. 326. Steering Gear Used on Heavy Manhattan Trucks

the case with an uncut nut. In addition, the split nut allows the changing of the ball-end lever at any and all times.

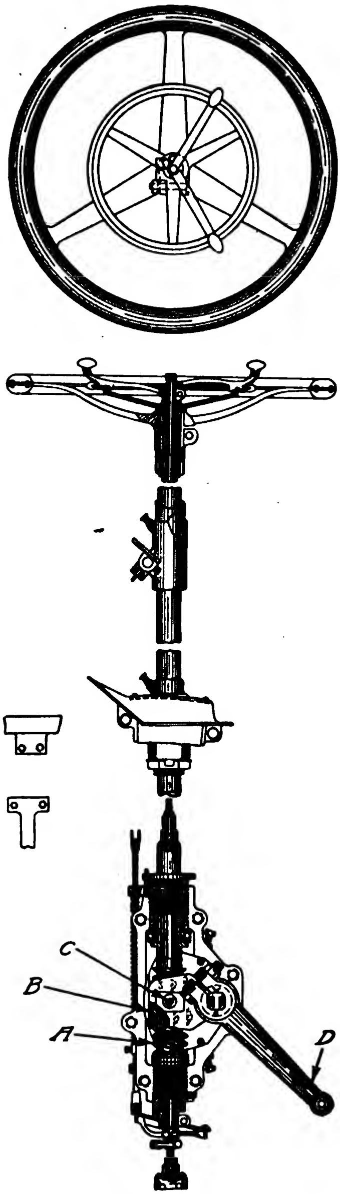


Fig. 327. Sectional Details of Steering Gear of Winton Cars
Winton Motor Car Company, Cleveland, Ohio

In Fig. 326 is shown a form of worm and nut steering gear which is used on very heavy trucks and commerical cars. In this gear, the double worm is used; the inner worm carries, at its lower end, a block which is pivoted in a combination lever and shaft, to which the steering arm is attached. In the figure, *A* is the hand wheel turning the rod *B* within the steering-post tube *C*. This rod is driven into and keyed at its lower end to a member *D* which has internal worm threads. Another member *E* has a circular upper end on which are worm threads, while its lower end is slotted. The worm at the upper end meshes with the internal worm threads in piece *D*, while the lower slotted end carries, between the two arms of the slot, a rectangular block *F*. This block is hardened and ground all over and is fastened to the forked end of piece *E* by means of the hardened and ground pin *G*. This pin also passes through the arm *H* of the shaft to which the steering arm is attached. The steering arm is free to rotate about the center. This rotation moves the steering lever *L* in the arm of a circle.

The steering action is as follows: Turning the hand wheel turns the outer worm. This worm cannot move, so the inner worm is forced to move up or down, as the case may be, and moves the block with the pin through it, which, being fixed in the arm extension of the shaft, must turn the shaft. To this arm is attached the steering lever, so the latter must move. Although a rather complicated gear to explain and also to make, this gear, when finished, is an excellent one, and has been used for five or six years on heavy trucks with excellent results.

The Winton steering gear, Fig. 327, is not decidedly different from the one just shown, as will be noted by a close inspection of the parts. *A* is the internal worm, which is turned by the hand wheel, while engaging this worm are the block *B* and pin *C*, the block being partly cut away to show the engaging gear teeth. This block moves the jaw arm of the steering lever *D*. This jaw is not complete in this gear, but is cut away to save weight. The jaw arm, too, is connected directly with the steering lever, the jaw, arm, and shaft making one piece. The light work to which this was put made possible the economy in the number of pieces and in the weight of each. As before, turning the hand wheel turns the worm, which, in turn, moves the block and pin up and down and thus moves the jaw arm, which moves the steering lever.

Adjustment. The adjustment for lost motion in the worm and split-nut type of gear is generally made by loosening a cap screw on the column and screwing down an adjusting nut which has a right-hand thread. This adjusting nut acts directly on the thrust bearing, forcing the screw and half nuts, which slide, against the yoke rollers. In making the adjustment to a gear of this type, it is advisable to turn the road wheels to the extreme angle position, because the gear is the least worn at this point, and if it is adjusted only enough to take up the play when in this position, there will be danger of binding. Sometimes, when the adjustment is made with the road wheels straight, the gear will bind at the extreme positions.

Worm and Worm. In the worm and worm form of steering gear there is a worm within a worm, not wholly unlike the ones just described. Fig. 328 shows an example of this, which has a worm *C* attached to the steering rod *H*, which is turned by the steering wheel *A*. Within and without this are worm threads, an external worm *B* meshing with the internal worm on the inside of *C*, while an internal worm *D* meshes with the external worm on *C*. The action of turning the hand wheel, then, moves one of these upward and the other downward.

The lower end B_1 of the inner worm member presses against a hardened end of the steering-lever arm E, while the lower end D_1 of the outer worm member presses against the other hardened end E_1 of the same piece. There is no lost motion, or play, in the gear; when the hand wheel is turned, one worm rises and the other falls, as just described; the piece E will let one end rise and the other fall, as it is acted upon by the lower extremities of the two moving worms. This piece is pivoted at F and carries at its outer end the steering lever G, which thus moves in the customary manner. Within the steering post are the spark and throttle tube and rod I and J, which

Fig. 328. Section of Gemmer Steering Gear
Courtesy of Gemmer Gear Company, Detroit, Michigan

carry right through the whole gear and out at the bottom, where the spark and throttle-actuating levers are attached.

Adjustment. The adjustment of the worm and worm type, an example of which is illustrated in Fig. 328, is generally effected by a nut located at the upper end of the gear housing. This nut is provided with flats to accommodate a wrench hold. The end of the worm-wheel shaft is squared, and to this square the steering-lever arms are attached by means of a pinch clamp and bolt.

Bevel Pinion and Sector. Among the other types of steering gears is that of the bevel pinion and sector, shown in Fig. 329. The bevel pinion moves the bevel-gear sector back and forth as it is turned, this motion being transferred to the steering arm attached on the same shaft to which the bevel sector is secured. This type of gear is said to be effective, but it is not irreversible, and shocks to the road wheels may be imparted to the steering wheel and move it.

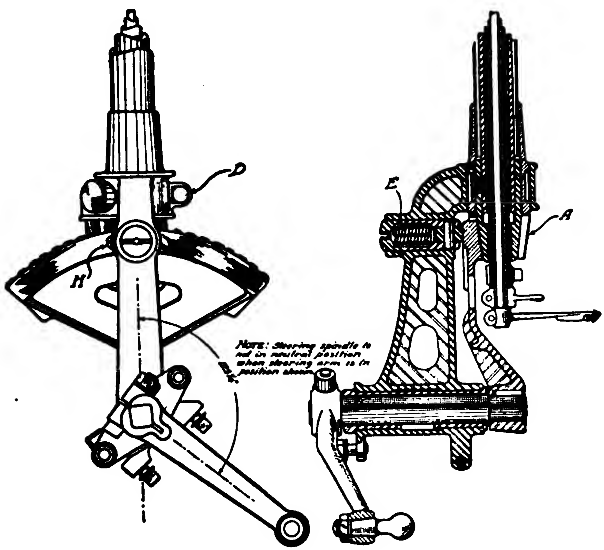


Fig. 329. Bevel Pinion and Sector Type of Steering Gear
Courtesy of Reo Motor Car Company, Lansing, Michigan

Adjustment. The bevel and sector gear has two adjustments. The pinion may be moved up or down, as required, by unlocking the clamp bolts (one of which is shown at *D*) which permits the moving of the entire steering column up or down so as to obtain the proper relative position to the pinion and its sector. The position of the sector endwise may be adjusted by the block member A, which bears against a roller guide, forcing the sector into mesh more or less closely with the pinion. The spring E is provided to prevent rattling, and the screw H is a guide for the plunger and should not be disturbed in making the adjustment.

Hindley Worm Gear. There are a number of things about the Hindley type of worm which make it an excellent one to use for steering gears. A realization of this advantage is bringing about a greatly increased use of this form; so it will be appropriate and timely to look into its form, construction, and advantages.

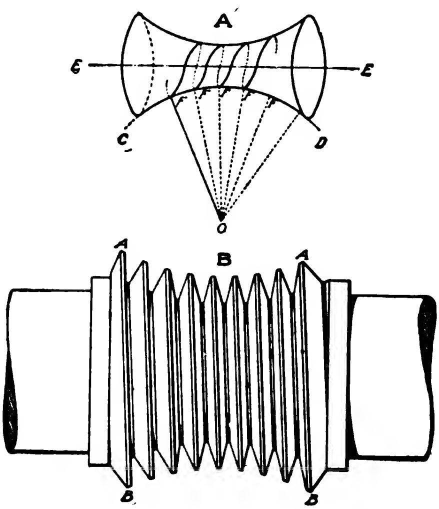


Fig. 330. Details of the Hindley Worm

The question of what makes the Hindley different from other worms naturally arises. The ordinary worm has the same diameter from one end to the other, the blank before the cutting of the teeth resembling a section of a cylinder. The Hindley, on the other hand, is not of uniform diameter, but has a smaller center diameter and enlarged ends. This gives it a waist, or hour-glass, shape.

An illustration will make this clear. Fig. 330 shows at A how the Hindley shape is generated and at B a finished gear, revealing plainly the reduced center diameter. In the upper figure, EE is the center line, or axis, of the worm, and O the center of the gear which is to mesh with it. CD is a circular arc struck from O as a center. If, on this curve CD, equal spaces be struck off, using a distance equal to the pitch of a single-threaded worm or the lead of a multiple-threaded one, as at F, and radial lines be drawn from the center O to these points, these lines will be normal to the surface of the worm at those points; in short, the worm must pass through them, as roughly sketched in the figure. In the lower part B, of the figure, is illustrated a worm made on this principle, ready to be put into position.

This form of worm is used for the double reason of presenting more wearing surface—since it has at least three teeth in contact at any one time, as compared with one or at most two in the ordinary worm—and greater resistance to reversibility. The worm is used for steering gears because it is partly or wholly irreversible, its motion being a sliding one; nevertheless, all worms may be so cut as to be either wholly or not at all reversible. The sliding motion of the two parts in contact, as opposed to the rolling motion in the case of other mechanical movements of a similar nature, is greatly increased if there are three teeth in contact instead of the more usual one. If the friction of sliding be increased, the amount of reversibility will be decreased in the same proportion, for the added sliding friction will increase the natural reluctance of the worm to transmit power backwards. So much is this the case that it pays to use the Hindley form, despite its greatly increased cost of cutting.

Ford Steering Gear. The steering mechanism of the Ford car—a patented construction—differs radically from the conventional types in that its hand wheel does not directly rotate, or turn, the steering column or rod, but it imparts the necessary turning movement through the gearing and the use of a small shaft to which the hand wheel is attached. A phantom view of the gearing is shown in Fig. 331.

The steering column with its short shaft and drive pinion is enclosed in a tube or housing which is set at an angle and bolted to the dash. The housing does not extend the entire length of the column, as the lower end of it is mounted in a bracket that is rigidly bolted to the frame. The steering-gear post, or column, has a triangular flange at right angles to the rod, and each point of the flange has an integral stub, or pin, carrying a small spur pinion. The center of the rod is drilled and bushed to take a small shaft to which a fourth pinion, or drive pinion, is keyed. The upper part of the housing is shaped so as to provide a gear case, and the inner periphery of this case is cut to obtain spur teeth or, in other words, an internal ring gear. This gear is stationary.

The hand wheel is attached to the short shaft, and its drive pinion is held in place by a brass cover of the internal gear case. As the drive pinion of the shaft is in mesh with the three pinions mounted on the stubs of the steering column proper, and these three pinions are in mesh with the internal ring gear, any movement of the hand wheel will rotate the drive pinion on its shaft. This movement will cause the three spur pinions to rotate in an opposite direction against the internal gear, thus reducing the movement of the steering column as compared to that of the hand wheel. The three spur pinions compensate for any pressure of the drag link and the tie rod.

The operation of the Ford steering-gear mechanism explains the basic principle of the operation of the hand wheel; that is why the wheel is turned in the same direction that the driver desires the car to

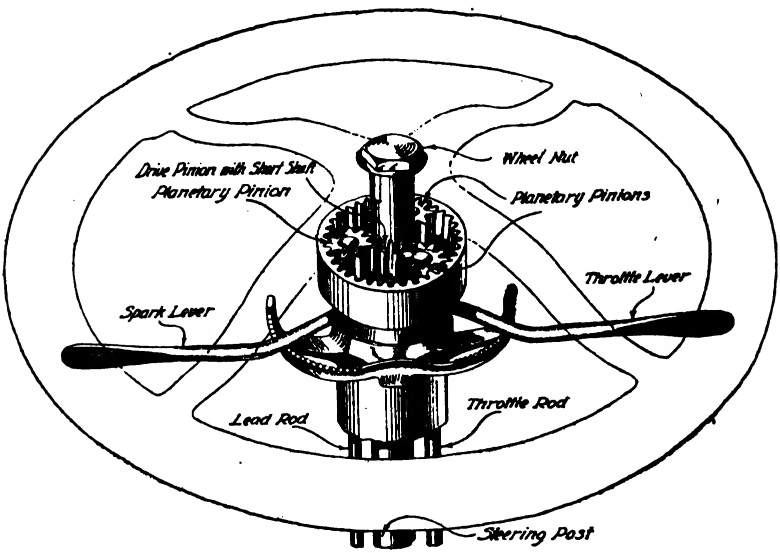


Fig. 331. Ford Planetary Steering Gear—An Unconventional Type

go. If the hand wheel is revolved from left to right, for example, the movement causes the three pinions mounted on the pins of the steering column to rotate from right to left; the pinions rotating against the stationary internal gear turn the steering rod in the same direction taken by the three pinions. The column swings an arm attached to it from right to left, and, as the rod is secured to this arm, it moves in the same direction, swinging the front road wheels so that they move from left to right, and to a degree that will correspond with the turning, or movement, of the hand wheel. It should be understood that the movement from left to right refers to the front half of the road wheels. If the driver desires to direct the vehicle to the left, the wheel is turned to the left.

The drag link of the Ford steering gear differs from conventional designs in that it is at right angles to the frame and is practically two-thirds the length of the tie rod. The end of the steering column is provided with an arm carrying a ball, and the drag link, or steering-gear connecting rod, as it is listed by Ford, has a ball-socket cap which fits over the ball of the steering rod. The drag link also has a ball socket at its other end, which fits over a ball arm on the tie rod. The tie rod, called the spindle connecting rod because it connects the spindles, is provided with yokes at either end, and these yokes are pivotally connected to the spindles by a bolt passing through them and through an eye in the spindle. The Ford drag link differs from others in usual practice in that it moves to the right and left, while those used on other cars move forward and backward. No provision is made with the Ford drag link for absorbing shocks or for automatically compensating for wear as usually is the case with the conventional type of drag link.

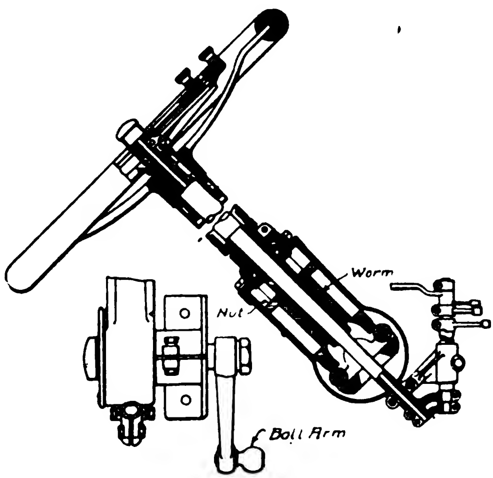


Fig. 332. Screw and Nut Gear Used on Trucks

Semi-Reversible Gear. The steering gear used on commercial cars, particularly trucks ranging from 3- to 7-ton capacity, must not only be capable of operation with a minimum effort, but it must absorb a great many of the minor shocks and a per cent of the larger shocks. The semi-irreversible type is most favored because of the above-named reasons. The design shown in Fig. 332 is of the screw and nut type. The nut is a solid piece, completely enveloping the screw, and the threads of the screw are in constant and complete engagement with the threads in the nut. The screw has a rotary motion and the nut has a longitudinal motion. The means of transmitting this longitudinal motion of the nut to the rotary motion of the steering arm is by circular discs at the lower end of the nut.

These discs present constant bearing surfaces to the recesses in the nut, and are provided with slots into which the projecting levers from the rocker shaft fit. The screw pulls the nut up or down in the housing, and there is no tendency for this nut to be moved sideways.

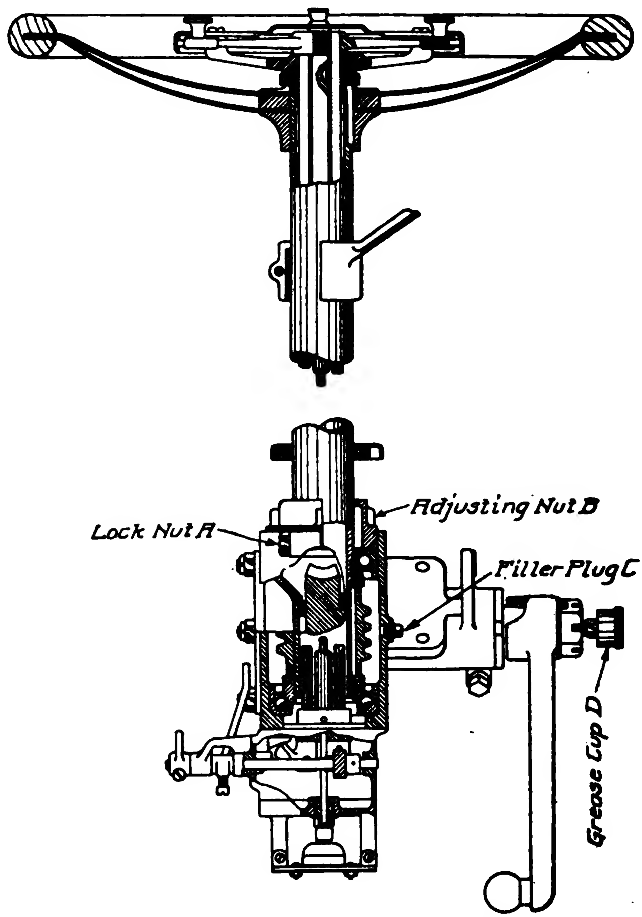


Fig. 333. Worm and Gear Steering Arrangement—Semi-Reversible

The levers projecting from the rocker shaft into the swivels which rotate in the lower part of the nut are in direct line with the screw, so that the push and pull of the nut is in a straight line.

Removing Steering Gear. To disassemble the majority of steering gears it is necessary to remove the unit. With the type shown in Fig. 333, which is a semi-irreversible worm and gear, the removal may be accomplished by displacing the control levers at the top of the column and dropping the unit down through the frame. The adjustment of this type for end play is made by loosening the locking nut *A* and turning down the nut *B* until the play is eliminated.

STEERING-GEAR ASSEMBLY TROUBLES AND REPAIRS

Lost Motion and Backlash. Lost motion of the steering wheel does not always indicate that the steering gear is at fault, for wear in the steering-gear assembly usually takes place first in the clevis pins, yokes, and connections of the drag link. The spindles, spindle bolts, and wheel bearings are factors. Despite the fact that the front road wheels are deflected but a few degrees the spindles, bolts, or bushings may be worn, as these parts are subject to radial and thrust loads. The spindle bolt, which does not move, tends to wear oval; adding to this tendency the wear of the spindle bushings, one has considerable lost motion to contend with. Wear of the wheel bearings contributes to the apparent lost motion of the steering gear as do the connections of the drag link. Taking all of these factors into consideration, and allowing but a small fraction of an inch for play of each worn part, the sum total may result in considerable movement of the hand wheel before the road wheels are deflected.

Lost Motion in Wheel. While there should be a certain amount of movement to the hand wheel before it actuates the road wheels, the lost motion, as a rule, does not exceed $\frac{1}{4}$ or $\frac{3}{8}$ inch when the gear is new. This amount is essential as without some free movement the steering of the vehicle would be tiresome. Wheels may be keyed or pinned to the column. When play exists as the result of a worn key, pin, or slots, the remedy is to re-cut the seats and make and fit a new key or pin. With some types of wheels the use of a wheel puller will be necessary to displace them. Another cause of lost motion, when the wheel is tight and linkage free from play, is a loose key retaining the worm or gears of the steering gear proper. A simple test of the hand wheel is to hold the tube, or post, securely and move the hand wheel. The amount of play in the drag link can be ascertained by grasping it about midway and trying to move it backward or forward or in the normal direction of travel. Hold the ball arm of the steering gear when making this test.

The amount of backlash present in the irreversible and semi-irreversible types of steering gears may be determined by disconnecting the drag link, grasping the ball arm, and moving it up and down and back and forth. Worn bushings in the steering-gear case are frequently the cause of movement of the column as a whole. Another component that should not be overlooked in the search for the cause of lost motion is the ball arm. Movement of this member on its shaft can usually be eliminated by tightening the nut.

STEERING WHEELS

Different Forms of Hand Wheels. *Wood Rim.* A variety of material is utilized in the construction of the wheel, which has super-

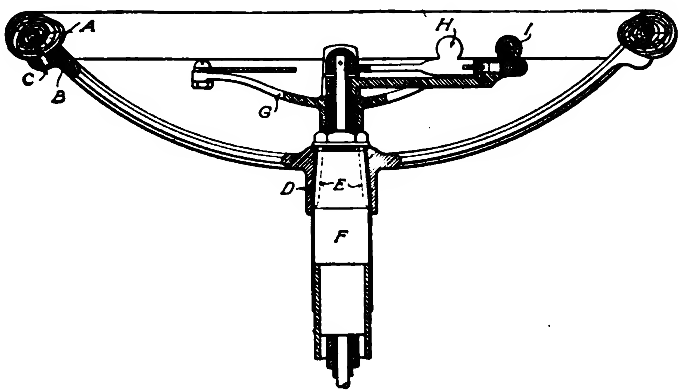


Fig. 334. Section through Typical Steering Wheel

seded the lever or tiller. The section or sections of the wheel or rim are circular, oval, or elliptical; the oval, or ellipse, is turned upward. The strength of the wheel varies according to the material used and the process of assembly. The all wood wheel has not the strength of a built-up wheel with a metal core, but it is simpler and cheaper to manufacture. With the exception of the molded rubber type of rim, the majority of the wheels, particularly those fitted to high-grade cars, are built-up. Mahogany, circassian walnut, and black walnut are the materials favored. The wood is cut to short sectors of an annular ring of about 2 inches in width and so glued together as to eliminate joints.

The method of attaching the rim to the spokes of the wheel spider is by screws, and this method is illustrated in Fig. 334. *A* indicates the wood member, *B* the arms, or spokes, which have a boss through which the screw *C* passes into the wood. The hub of the spider *D* is attached to the steering post by two keys *E*.

Metal Core with Wood Covering. When the wheel design is made up of a metal core the ring is cast on the spider or integral with it. Coverings of wood concealing the ring are used, although with some types, a section of the ring may be noted. This type of wheel possesses great strength and the wood veneers can be secured at more frequent intervals than in the design previously described.

Different Wheels for Commercial Use. *Truck Types.* For the light delivery wagon, taxicab, and similar cars, no difference in the steering wheel is made, but when it comes to the heavier service, there is a need for a heavier wheel. This does not mean a heavier rim only, but a heavier, more rugged gear all the way through. The weight on the front wheels of a heavy truck is very great, and the tires, which are of solid rubber, may have frictional contact with the pavement of several inches in width. All this combines to make turning the vehicle from the driver's seat more difficult.

For this reason the driver must have a greater leverage, which means a larger diameter of the wheel. Then, too, the rim should be bigger in section in order to withstand the harder use of commercial service, and to provide for the large hands of the operators. Greater strain upon the rim of the wheel, on attempting to turn heavier weights with it, means that the rim must be fastened to the spider more securely. This means more arms, the four generally used for pleasure cars being increased to five for trucks. While this helps a great deal, since it provides five screws instead of four, it is not sufficient, and most of the big trucks today are equipped with steering wheels in which the rim is built over a central metal rim of the spider.

Pleasure-Car Types. Usual pleasure-car practice varies from 14-inch up to 16-inch wheels, while commercial car sizes begin at 16-inch and run up to 18-inch wheels on light trucks, and as high as 20- and 22-inch wheels on heavy trucks. Rim sizes vary considerably, a favorite for touring cars being an oval with from $\frac{3}{4}$- to $\frac{7}{8}$-inch vertical height and a length of about $1\frac{1}{16}$ to $1\frac{3}{16}$ inches. These figures have no connection with commercial work, the smallest being 1 inch and on up to $1\frac{1}{8}$ inches in height, with the long diameters varying from $1\frac{1}{4}$ up to $1\frac{3}{4}$ inches. For speed work, racing, and the like, it is usual practice for the operator to wind the surface of the wheel with string, this giving a rough surface upon which the hands will not slip. This is practiced, too, by many truck drivers, who claim that the strains of steering the big vehicle are not felt as much when the wheel is thus wound.

To preserve the nice appearance of the steering wheel and still

Fig. 335. Molded Rubber Steering Rim on S.G.V. Car
Courtesy of S.G.V. Company, Newark, New Jersey

give the roughened surface to which the hands will cling easily, even in wet weather, many manufacturers are making a wheel of molded rubber, the use of this material allowing the formation of the wheel in any desired section, as is seen in Fig. 335. As a concession to appearances, these wheels are usually made with a plain upper surface; the lower or under surface, however, being made in a series of depressions and humps, between which the fingers find a good resting place. This gives a good grip, as the under side of the wheel seldom gets wet.

Folding Steering Wheels. Although tilting steering wheels were introduced several years ago, they did not meet with favor until the Cadillac adopted them as standard equipment. The wheel, which is 18 inches in diameter and has an aluminum spider, is hinged to drop downward, a design facilitating entrance and exit at either side of the car and making it possible to attain the driver's seat without squeez-

Fig. 336. Hinge Type of Steering Wheel Used on Cadillac

ing. The Cadillac wheel is shown in Fig. 336, while that used on the King car, illustrated in Fig. 337, is of the tilting type. To operate the design, the wheel is turned until the wheel spider arm carrying the release button is convenient to the thumb of the right hand. The button is pushed to the right, and, by using both hands, the wheel is pushed forward and upward. The Herff type, shown in Fig. 338, is of the true hinged form; the rim is thrown up and out of the way, that is, the rim only, as the quadrant carrying the spark and throttle levers remains. There are several other types marketed, but their working principles are similar.

Throttle and Spark Levers. In the usual case, the arms of the steering wheel have the quadrant for the spark and throttle levers fastened to them. The levers are operated within the space inside of the rim of wood and above the spider of metal; the latter is usually at a lower level by several inches, as shown in the figure. In Fig. 334, however, the quadrant is not carried by the spider arms, but on a separate framework *G*, or spider of its own, up above the hub of the wheel. Over this framework the spark and throttle levers *H* and *I* work, serrations of teeth in the quadrant preventing the levers from moving, except when they are sprung off by the pressure of the fingers operating them. In some cases, these teeth are done away with and friction surfaces are substituted; springs holding the contact surfaces together are so light as not to interfere with the moving of the levers by hand.

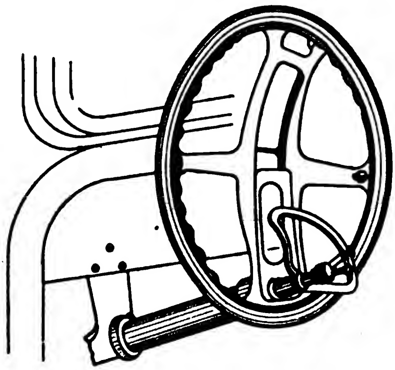


Fig. 337. Tilting Steering Wheel on the King Car

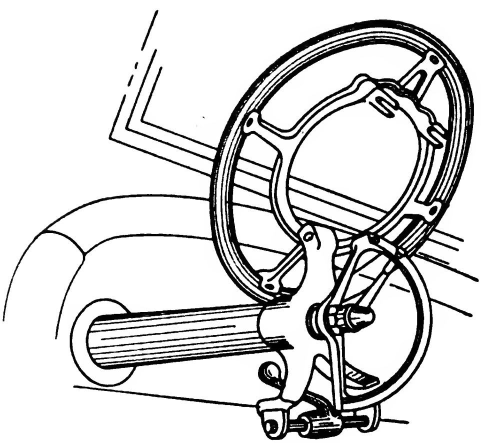


Fig. 338. Herff-Brooks Folding Steering Wheel

STEERING ROD, OR DRAG LINK

Operation. By the steering rod, or drag link, is meant the member connecting the ball arm, or lever, of the steering gear to the lever attached to the steering knuckle. This is clearly illustrated in Fig. 339. The steering gear is marked *D*, the steering arm projecting down from it C, while the steering rod which connects the lower end of the arm with the lever on the knuckle is marked AB. F is the knuckle pivoted in the axle, which carries the two-end lever E, one arm of which has the steering rod attached to it at B, while the other carries the cross-connecting rod joining the two knuckles together. Since the pivot point is fixed, any movement imparted to the knuckle must result in its swinging about the pivot point and carrying the wheels with it.

This movement is imparted by the steering rod to the end B of the arm E. The steering rod itself simply

Fig. 339. Typical Steering Arrangement on Pleasure Car

a constant level, although moving in a circle, the rod must have a universal joint at one end. This is really a necessity from two points of view: to allow the rear end to move up and down vertically while the front end swings around in a circle; and also to allow the front end to swing in a circle set in one horizontal plane, while the rear end remains stationary or practically so in that plane. In short, the two ends move continuously, each in its own plane, but the two planes never coincide—the one is always vertical, while the other always stays horizontal. This necessitates at least one universal joint. Many makers play on the safe side, and lower the cost of production by making the two ends alike—a universal joint on each one.

Types of Construction. A glance at the construction shown in Fig. 340, and also in Fig. 341, shows a steering lever made with a ball end, or partial ball end, upon which the steering rod is hung. In this, the partial ball is formed in the center of a bar, the inner end of which is threaded and screwed into the steering arm, with a nut on the outside to prevent its backing out. The ball itself is made separately and slid on over the rounded end of the shaft, or axis. After this a sleeve is put on, followed by a nut which holds the sleeve up tight against the ball. The function of the sleeve is to give the spherical end of the rod plenty of play in a sidewise direction. This is a cheap form of construction, but could have been made in one piece had it been desirable or necessary to do so. Such a form has a metal-to-metal contact, which is hard upon both ball and socket, necessitating frequent and costly replacements. These replacements are obviated by backing the ball socket up with a spring or springs, as is shown in Fig. 341. This form of construction is now quite generally used; the socket of the ball in the inner end of the rod is set inside of a sleeve with a spring on each side of it. These springs not only take up the road shocks but the wear as well, the shoulder against which they rest being adjustable. In this figure, *J* is the lower end of the steering lever with the ball end. This lever is mounted in the ball socket *G*. *A* is the body of the steering rod, which is expanded at the end to a larger diameter, this being designated in the figure as *B*. Within this expanded portion, the sleeve *E* at one end acts as a shoulder for the spring *F*.

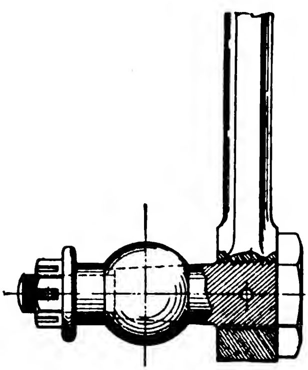


Fig. 340. Steering Lever with Ball End

At the other end, the outside of the sleeve is threaded to receive the collar *C* with the hexagon end *K*. Within this, a second spring *L* holds the socket up to its position. The location of the collar *C* determines the tension of the spring *L*, and this is locked in its position by the screw *V*. Should there be wear, which necessitates the moving of the ball toward the open, or left, end, the whole thing is disassembled and a longer sleeve inserted in place of the one shown at *E*. On the other hand, ordinary wear is compensated for by taking up on the collar *C*, first loosening the lock screw *V*.

In Fig. 342, a rod is shown assembled at the top and disassembled into its components at the bottom. The two ends differ, one being

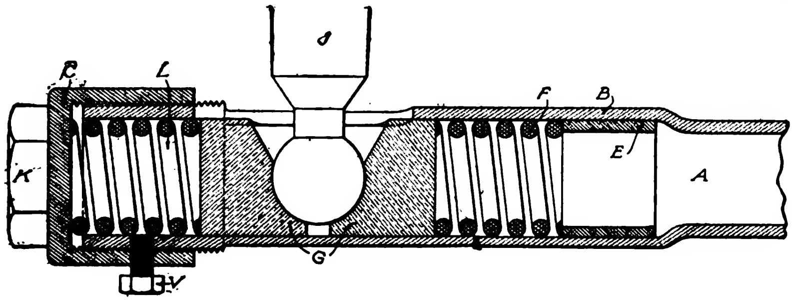


Fig. 341. Adjustable Form of Ball-End Steering Rod

but a simple yoke with a plain bolt through it, marked *D*. The other, however, is a ball end with an adjustment and with springs to take up shocks.

All these parts are marked in the figure and may be located by letter. The body of the rod is marked *A*, the expanded end *B*, which has a groove *H* cut in it. Into the inner end of this groove is fitted, first, the spring *F;* second, the two halves of the ball socket *G;* and

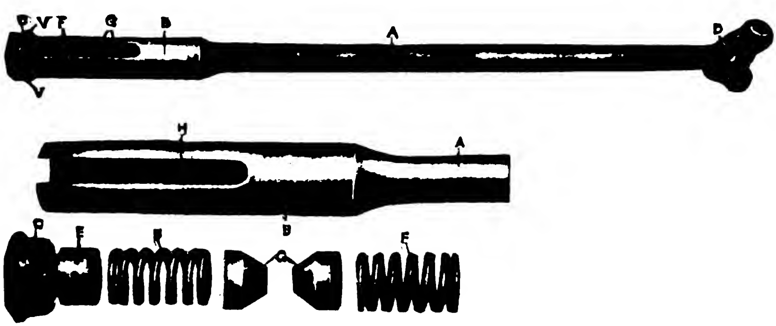


Fig. 342. Cross-Connecting Rod Assembled and in Parts

third, another spring. The sleeve *E* closes the outer end, and over the exterior is screwed the adjusting nut *C*. The nut and sleeve are held in place by the locking pin *V*, which passes through the outer nut, the shell end of the rod, and the inner spacing sleeve, the ends being riveted over to hold it in place. This form limits the adjustment to a full half turn of the nut, while the pin would soon need replacement if much adjusting were done, as some of its length would be lost each time it was riveted over because of the chipping away to allow it to be taken out.

Cross-Connecting, or Tie, Rods. The object of the cross-connecting, or tie, rod is to connect the right- and left-hand steering knuckles so that the road wheels will be turned alike. The general practice is to place the rod back of the front axle, a location avoiding the possibility of damage if an obstruction in the road is encountered, but in some instances the tie rod is placed in front, as in Fig. 339.

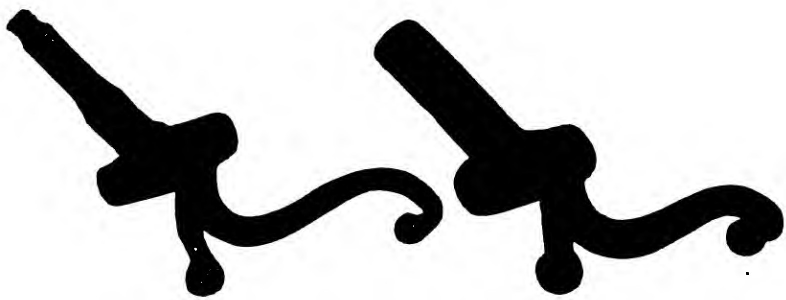


Fig. 343. Finished S.G.V. Chrome Nickel-Steel Steering Knuckle and the Same before Machining

Fig. 344. Left Steering Knuckle of S.G.V. Car before and after Machining

The tie rod is made adjustable to compensate for any change that may be necessary to preserve the alignment of the wheels, and, generally, the rod is adjustable at either end. The yoke ends of the rods are made adjustable, screwing on or into the rod proper and secured by lock nuts or other suitable fasteners. The adjustment is easily made. Decreasing the length of the rod increases the gather, or distance, between the forward section of the front wheels, while increasing it causes the wheels to toe in. This applies to the tie rod behind the axle.

Function and Shape of Steering Knuckles. The steering knuckles serve as a pivot for the road wheels, enabling them to move in a horizontal plane. The design of the knuckle depends upon the axle, and the pair used on a car are different as one has a lever for carrying the drag link. Both have integral spindles to which the tie rod is attached. Figs. 343 and 344 illustrate the difference between the knuckles.

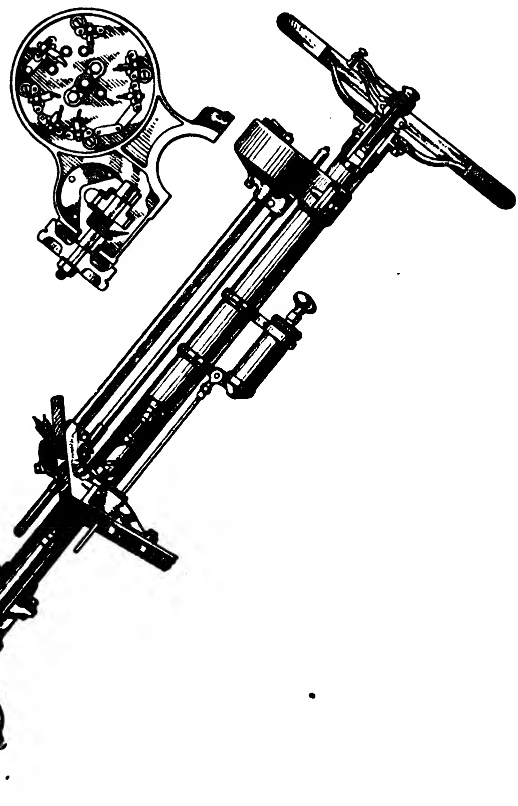


Fig. 345. Packard Steering Gear Parts

Fig. 343 shows a right knuckle, forged from a blank of chrome nickel steel, while the one at its side is the finished part. *A* is the place for the outer wheel bearing, *B* the position of the inner bearing, *C* the hole for the pivot, or knuckle, pin, *D* the upturned steering arm, and *E* the arm to which the tie rod is attached. Fig. 344 is an example of a left steering knuckle of the same pair, both before and after machining. The letters in Fig. 343 apply to this knuckle.

Lubrication of Steering-Gear Assembly. The proper lubrication of the steering-gear assembly adds to its life, but this work is not, as a rule, thorough. The steering gear proper should be packed with grease, the ball and socket joints of the drag link and steering-arm lever with a light grease; the clevis pins also should be lubricated. The steering-knuckle pins are provided with either grease or oil cups.

A point generally overlooked in the lubrication of the steering gear is the steering-post spark shaft and throttle-sector anchor tube, shown in the illustration at Fig. 345, which is of interest in that it illustrates the assembly of the Packard car. The post carries the control-box unit. The spark shaft and throttle tube frequently lack lubricant and should be cleaned and coated with a graphite grease before replacing when the gear is being reassembled. The lower extremity of the spark and throttle members carry levers or small bevel sectors which operate the linkage of the ignition apparatus and carburetor. Clamping screws are generally used to secure these parts.

SPECIAL TYPES OF DRIVE

Fig. 346. Front Drive and Steer on Homer Laughlin Car

Front-Wheel Drive. In the conventional type of pleasure motor car, the energy of the engine is applied to the rear wheels which propel the car, the drive being a pushing one. A pleasure car, or rather a racing machine, with a front-wheel drive—which is a pull, and held by some to be more economical—was brought out several years ago but not marketed. During the latter part of 1916, a company was formed to market an eight-cylinder pleasure vehicle, utilizing a front-wheel drive and steer and a friction drive with an automatic pressure control.

Difficulties of Transmission. The Homer Laughlin car, a bottom view of which is shown in Fig. 346, makes use of an original type of universal joint to transmit uniform angular velocity. Its design was brought about by the fact that the rate of transmission of angular velocity through a universal joint is not even when the shafts are at an angle. This is the fundamental difficulty every designer of a front drive has to overcome or suffer the twisting of the axle.

The front wheels and the flywheel must rotate at practically a uniform speed, at least through each revolution. The irregular rate of transmission through the universal joint must be taken up some-

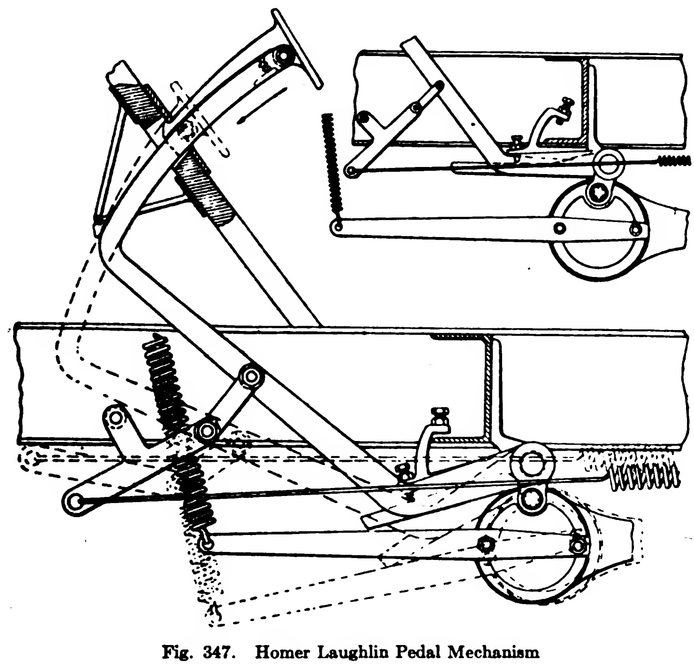


Fig. 347. Homer Laughlin Pedal Mechanism

where. The normal action of a universal joint at certain angles is to make four jerks in a revolution, as it has four fast points and four slow points. The Laughlin joint gives uniformity of rotation with 75 per cent on each side of normal, the difference being taken up by the flexibility of the transmission parts.

Friction-Disc Transmission. The transmission is of the friction-disc type, but the disadvantage of this form of drive—the fact that the control is reversed—is eliminated. The usual clutch control is provided, but the pressure is automatic. This pressure is obtained by an eccentric connection by means of which designers obtain irreversible application of spring pressure. The transmission locks at the correct pressure through the friction of the eccentric. The spring controlling the friction for driving provides the proper pressure for running, but it is not sufficient for starting or climbing long hills in the low gear. The pedal shaft operates a dog that presses down on the eccentric sheave extension. To de-clutch, the operator presses the pedal down, releasing the clutch. The pedal has two points at which it latches, providing extra pressure, and an extra spring is brought into service for the high and low speed. This spring operates through a toggle linkage. As the pedal rises, the applied power increases. When the car attains momentum, the driver depresses the pedal until it latches. The running pressure is sufficient to hold the engine in all gears except the low and reverse.

Control. Complete control is obtained through one gearshaft, the lever working forward for progressive, and back for reverse. Automatic latching is obtained in every gear, the latch working in sockets sunk in the jackshaft. Chain drive is employed between the transmission and front axle. The brakes are located on the rear axle. Fig. 347 shows the method of obtaining a conventional pedal control of the transmission through the irreversible application of spring pressure—one spring for ordinary service, the other for low gear work—controlled by the eccentric on the jackshaft of the driving mechanism.

Four-Wheel Driving, Steering, and Braking. The four-wheel drive—a construction in which all four wheels of the vehicle drive, and frequently steer and brake—is confined to commercial vehicles. A brief consideration of the actions which may have to take place at the same time in such an axle will give a very good idea of the problem which must be worked out. The wheels must be free to turn about the axle as an axis, being driven from their hollow centers; the wheels must also be free to turn about the pivot point as an axis swinging in a horizontal direction and must be driven steadily all the time. All the turning, swinging, and driving action must be outside of and beyond the spring supports of the chassis, since the body cannot turn; but the axles must at the same time support the springs. Further, if all four wheels are to carry brakes, they must be applicable at any and all times and at any and all angles of inclination of the wheels, either in a vertical or horizontal direction, and they must be so equalized as to apply equally to all wheels, no matter how the force is applied to the system, and no matter in what position the wheels may be.

The advantage of the four-wheel drive and with it the four-wheel steer and brake is granted by eminent engineers, as is also its

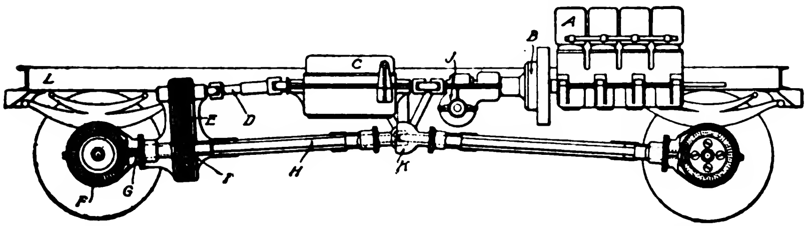


Fig. 348. Side View of a Four-Wheel Drive, Steer, and Brake Motor Truck

necessity for heavy commercial trucks, but its use has not been extensive for the simple reason that it is a complicated arrangement at best. In many cases, the design has been so complicated and unmechanical as to cause failure, and the reports of these troubles have given the four-wheel driving, steering, and braking device a sort of visionary air, so that any one talking of it is supposed to be a dreamer. Such is not necessarily the case, for many different practical four-wheel combination driving, steering, and braking devices have been brought out, built, tested, and proved efficient.

A number of four-wheel designs for commercial cars are being marketed, and have proved the contention of their makers that they are economical in operation and maintenance.

Four-Wheel Steering Arrangement. With the design shown at Fig. 348, steering knuckles are eliminated, the wheels being con-

Fig. 349. Details of Axle of the Four-Wheel Drive Truck Shown in Fig. 348.

nected to the axle ends through the medium of vertical trunnions. These trunnions bear on the wheel ball-bearing ring, which is ample in diameter and turns freely because of its size and the use of ball bearings. Within this ring, the axle terminates in what is practically a universal joint, driving through to the outside of the wheels. The wheels are thus free to run about a point in the axle ends, at the same time taking their power through the inside rotating shaft. Fig. 349 illustrates one of these axles with the parts lettered. Here *H* is the point of attachment of the driving propeller shaft, *G* the cast-steel one-piece case, *F* the differential gear within the large driven bevel gear *O*, *MM* the vertical trunnions upon which the wheels rotate, and *NN* the universal joints which drive the wheels.

How the steering is obtained is shown in Fig. 350. At the front of the chassis is the steering wheel *P;* turning it partially rotates the longitudinal shaft *Q*, which extends the length of the chassis. This shaft carries levers *RR* near its two ends, which are connected to

Fig. 350. Diagram Showing Steering Action of a Four-Wheel Drive Truck

the steering rods *SS*. These rods connect to the steering levers *UU*, which are fixed to the wheels themselves instead of to the steering knuckles as in the ordinary case, for this car has no steering knuckles. In addition to the steering rods attached to the longer of the two steering levers, there is a cross-connecting rod *TT* at each end, which connects the two steering levers. Thus, when the levers *RR* move the rods *SS*, and through these the levers *UU*, which in turn move the wheels *VV*, the rods *TT* also come into play and move the levers *WW* and the wheels *XX*. Therefore, the movement of the steering wheel in any given direction, as to the right, turns all four wheels, the front two to the right, and the rear two to the left so that they form arcs of the circle in which the front ones are turning. The truck thus makes the desired turn to the right in one-half the distance or time of the ordinary truck. Four-wheel steering then has the advantage over two-wheel, or ordinary, steering, of requiring only one-half the space and one-half the time to accomplish a given turn. The vehicle described would turn completely around in a circle of 40 feet, the outermost circle shown in Fig. 350 being 56 feet in diameter.

Chain Four-Wheel Drive. Fig. 351 clearly illustrates a bottom view of the Hoadley four-wheel drive, four-wheel steer, and four-wheel brake truck. The power of the engine is transmitted through shafts, gears, and universal joints to the differentials; there is a third differential in the gear box at the center of the frame. Final drive is by chain; both ends of the truck are exactly alike in so far as the four-wheel drive is concerned, and the fifth wheels run in ball bearings. Steering is accomplished by means of worm gearing, the shaft being clearly shown, and both sets of wheels are steered simultaneously.

Jeffery Quad. An example of the successful development of the four-wheel drive is the Jeffery Quad, Fig. 352, which has given an excellent account of itself in government work. In this type it will be noted that the inclined driving shafts, shown in Fig. 348,

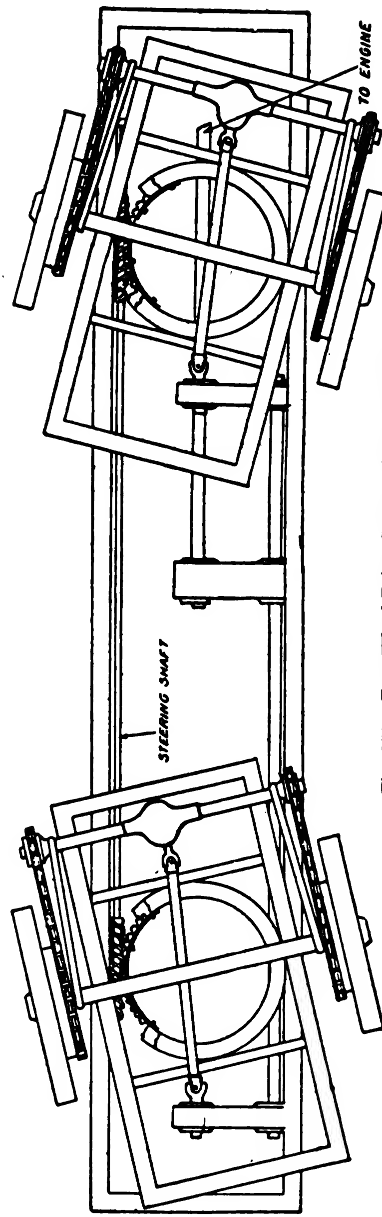


Fig. 351. Four-Wheel Drive, Steer, and Brake System

have been carried up to the gear box with a universal joint on either side. This construction has resulted in a much more inclined shaft in each case, but it has also eliminated the tail shaft *D*, the use of a silent chain *E* with its housing, the central universal joint, and the spherical bearing *K*, and, in addition, it has simplified both shafts.

In the four-wheel drive vehicle the engine was placed on the center line of the car; on the Jeffery it is set off to one side, while the two driving shafts to the front and rear axle, which form a continuation of each other, are set off to the other side. This result is produced by making the transmission very wide with three side-by-side shafts, as shown in Fig. 353. The engine drives the splined shaft *H*, on which are gears that transmit the rotation to the intermediate shaft *C*, which through the final gears *E* and *F*, drives the final shaft, which is in two

Fig. 352. Plan View of the Jeffery Quad, Showing Disposition of Units
Courtesy of Thos. B. Jeffery Company, Kenosha, Wisconsin

parts, *B* driving one pair of wheels, *G* driving the other pair. Note that the differential has been incorporated in this type of drive, so that it is possible to have a different drive for the front wheels from that for the rear wheels.

The rest of the construction is too simple to require a detailed description beyond the simple statement that the gear box gives four forward speeds and one reverse. When the two ordinary shifters are in the neutral position shown, reverse is produced by shifting the double reverse gear on shaft *D* along until its left-hand member meshes with the second-speed gear on shaft *A* and its right-hand member with the low-speed gear on shaft *C*.

Universal joints fit on the two tapers *B* and *C* with shafts inclined to the two axles. On top of the stationary axle of the I-beam section is fixed a small box which contains the bevel gears and an additional differential with suitable bearings, the whole being enclosed. These can be seen in Fig. 352, that on the rear axle being

Fig. 353. Plan View of the Transmission of the Jeffery Quad, Showing the Shafts for Both Axles

plainly shown, while the one in front is partly obscured. This member is shown in detail in Fig. 354, which gives the longitudinal section along the driving shaft at the left, in which the axle H is noted, the bevel gear I, and the bearings for radial and thrust loads

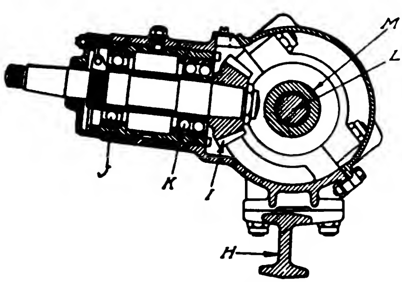


Fig. 354. Sections Showing Bevel Drives at the Axles on Jeffery Quad

at J and K, respectively. The driven shaft is seen at L, with the sleeve M around it, the sleeve being used to drive to the differential case, since the larger, or driven, bevel C is not sufficiently large to house the differential P.

Fig. 355 is a diagram showing the details of the axle end and wheel construction. In this, *H* is the I-beam section of the axle bed shown in Fig. 352, and *N* one of the shafts, which carries at its end the universal joint *Q*, with the end of the shaft extending beyond the joint *R*. The latter carries the spur gear *S*, which meshes with

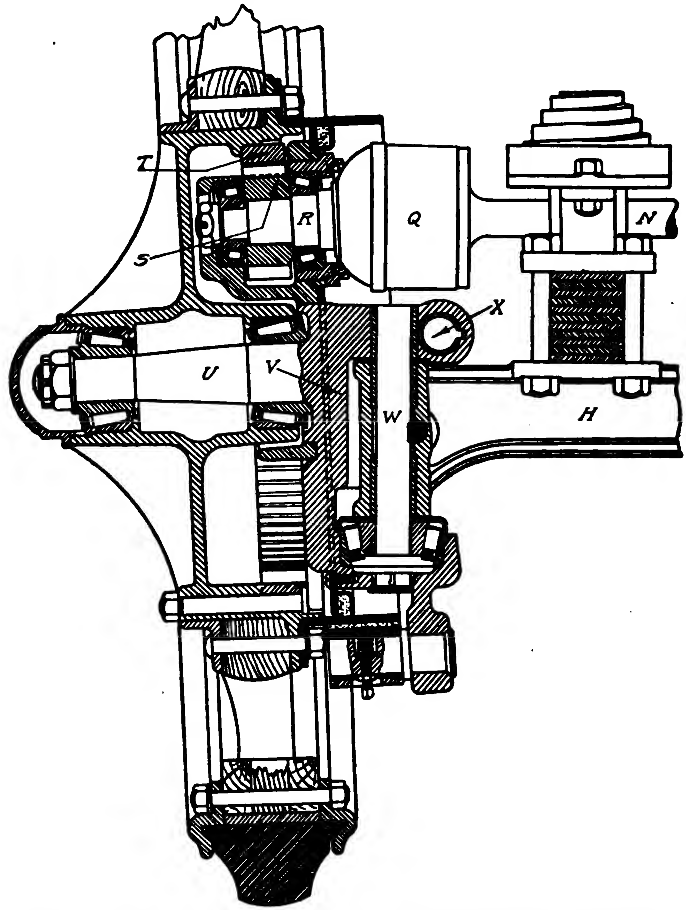


Fig. 355. Section through a Wheel and Axle End of the Jeffery Quad, Showing Method of Driving and Steering

the internal gear *T* fixed to the wheel and drives the vehicle in this manner. It will be remembered that this is not necessarily a front wheel, but any one of the four.

The wheel turns on the spindle *U*, which is part of the steering knuckle *V;* this knuckle turns upon the pivot *W*. The lever which turns the wheel is attached at X, the pair (either both front or both rear wheels) being connected by means of a cross-rod; at one end of this rod there is a connection to a rod which runs the entire length of the chassis. This rod is operated by means of the steering gear, and imparts the same motion to the front wheels as to the rear, except that the two are in opposite directions, that is, front wheels turn to the left and rear wheels to the right, so that they will follow around in a correct circle.

Advantages of Four-Wheel Drive. It is claimed for the four-wheel drive that its four-wheel steering reduces the mileage traveled to the minimum in that the car can run closely to corners and travels less in crowded traffic, in turning around, and in approaching and leaving loading platforms. The push of the rear wheels and pull of the front wheels enables it to surmount obstacles instead of bumping over them, and its greater traction permits it to travel soft roads not easily negotiated by the rear-drive type of trucks and cars. The four-wheel drive type will turn in a 48-foot circle, and, with its locking differential, obtains traction on slippery roads.

Electric Drive. When the final drive is electric, or when the source of power is an electric motor, the matter of four-wheel driving is much simplified, the wheel carrying the electric motor attached directly to it and turning with it about the knuckle pin. Both wheel and motor are turned by means of a worm and gear above, the wheel being attached to the upper end of the steering-knuckle pin prolonged. Turning this turns the wheel and motor.

This steering wheel is turned by the worm, which is on one end of a cross-shaft. This shaft is carried in bearings above the stationary bed of the axle and has near the center a bevel gear that meshes with another bevel, which is, in turn, attached to the lower end of the steering post. Turning the steering wheel turns the post and the bevel gear, which turns the bevel pinion and with it the worm shaft. The shaft turns the worm and the worm wheel which actuates the road wheels. The driver thus has a triple reduction between himself and the wheels, giving him this much advantage in steering: there is the leverage of the wheel of large diameter, the ratio of the sizes of the two bevels, and the ratio of reduction of the worm gearing, which, in addition, is irreversible. The steering gear is thus eliminated and four simple gears substituted for it.

Couple-Gear Type. In the Couple-Gear wheel, which is an American product, the motor is placed inside of the wheel—a type especially designed and constructed for this purpose. With the motor in this position, the wires enter through the hollow hub, altering its construction very materially. As compared with the electric motor on each wheel, previously described, this form has the advantage of greater simplicity, fewer parts, superior appearance, and protection against the elements, while the enclosed position of the motor, which is the most delicate part of the machine, protects it against road obstructions and accidents. This arrangement also simplifies the steering problem, since the car is steered just the same as any other truck, much of the complication incident to an electric motor on each wheel being eliminated.

Fig. 356. End View of Couple-Gear Electrically Driven Wheel with Tire Removed

Fig. 356 is a view of the wheel with the tire removed and the whole disconnected from the axle ends. Aside from this, it is complete and ready for use. Note how the axis of the motor is set at a very slight angle, just sufficient to allow a pair of very small driving gears at the two ends of the armature shaft to drive on opposite sides of the wheel. The wheel is assembled with a pair of driven gears on either side, these being separated a comparatively small distance, about $2\frac{1}{2}$ to 3 inches. As stated, the armature shaft has a small bevel pinion on each end, each of these meshing with the driven gears, but on opposite sides. It is this arrangement which gives the device its name of Couple-Gear. In this figure the brake band has been removed, but the brake drum will be seen just inside the wheel at *A*. Beyond this is noted the spindle *B*, which is made hollow for the wires from the battery and turns in a bearing on the axle.

In the second illustration, Fig. 357, an axle, either front or rear, with the wheels removed, is presented. In this cut the left wheel is entirely removed, but the one on the right shows the axle spindle *B*, the method of fixing it in the axle support at *C*; the armature housing *D* is normally within the wheel and not visible. One feature peculiar to this arrangement is the steering, which is effected by means of a vertical post with a small spur gear at its lower end *E*. This meshes with a curved rack *F*, which is machined on the outside of a pivoted member *G*, to which a pair of arms are attached. One of these arms *H* has a rod *I*, which runs to and operates the right-hand spindle *B*, while the other *J* has a similar rod *K*, which operates the left-hand wheel. When all four wheels are to be driven in this manner, the post is vertical, but the connection with the rack *F*

Fig. 357. The Couple-Gear Axle and Parts, Showing Method of Operation
Courtesy of Couple Gear Freight Wheel Company, Grand Rapids, Michigan

becomes horizontal, with a continuation to the rear axle which operates the various arms, levers, and rods there in the same manner.

This particular system is used for heavy commercial work only, and in this it has been particularly successful as a tractor, a front axle and a pair of wheels being substituted for those of a heavy trucking wagon. Then, with a sling under the body or beneath the driver's seat for the batteries, and with proper wiring, control levers, and steering wheel, the truck becomes electrically driven.

FRONT AXLES

TYPES

Classification. Generally speaking, front axles may be divided into about five classes: the Elliott, the so-called reversed Elliott, the Lemoine, the front-drive form, and the fifth-wheel form.

These typical forms of axles are themselves subject to further subdivisions. For example, there are many different forms of Elliott axles, each manufacturer having what is practically his own form. Again, the Lemoine, when used by other firms, has been built in a practically new form, taking the second maker's name. Thus the form of front axle made by Lemoine for Panhard is so different as to be called the Panhard, and not the Lemoine. The same is true of the Lisses axle made by Lemoine. In this country, it is claimed that the axles made by Timken are sufficiently different from the Elliott and reversed Elliott, from which the principle was taken, as to deserve the name of Timken axles. It should be borne in mind that in the following description of the various axle types the forms of material, and the shape, size, and kinds of bearings used do not alter

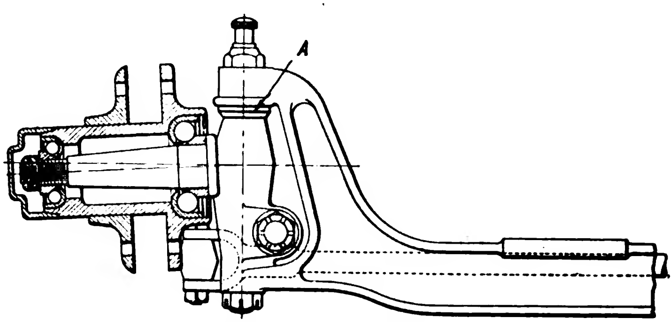


Fig. 358. Elliott Type of Front Axle and Steering Knuckle

the principle upon which the axle is constructed, although they do alter the appearance.

Elliott Type. In general, a front axle consists of a bed, or axle center; a pivot pin or knuckle pin upon which the knuckles may turn; and the knuckles themselves with the attachment for turning them. The Elliott type, Fig. 358, the form in which the end of the axle takes a U-shape, is set horizontal and goes over the knuckles. The knuckles have plain vertical ends bored for the pivot pin, which passes through and has its bearing in the upper and lower halves of the axle jaw. In this form, the thrust comes at the top, where the axle representing the load rests upon the top of the knuckles that represent the point of support.

Reversed Elliott Type. In the reversed Elliott front axle, as the name would indicate, the action is just reversed in that the axle end forms a straight vertical cylindrical portion bored for the pivot pin, while the knuckles are so formed as to have jaw ends which go over the axle ends. The thrust comes at the bottom of the knuckle, where the axle bed rests upon the upper face of the lower jaw of the knuckle, the axle representing the load and the knuckle the support, just the reverse of the previous case.

This will, perhaps, be made clearer by illustrations. In Fig. 358, as already mentioned, the axle has the jaw ends, and the thrust comes at the top. This is indicated in the figure by the letter *A*, which calls attention to the thrust washers at the top. Fig. 359 shows an axle of the reversed Elliott type, this being the front axle

Fig. 359. Reversed Elliot Type of Front Axle and Steering Knuckle

for a heavy truck. In this the thrust washers *A* are at the bottom, and are of hardened steel, ground top and bottom to a true surface; the upper surface is doweled to the axle, while the lower is doweled to the knuckle. This form has the real advantage of concentrating all of the difficult machine work and assembling it into one piece, the knuckle. The Elliott type, on the contrary, makes the knuckle and axle difficult pieces to handle in the machine and afterward, this being shown in the cost. Ease of machining the bed of the axle is a great advantage, for the axle will average about 44 inches in length for a standard tread of 56½ inches, and longer for wider treads, up to a maximum of about 48 inches for the wide-tread standard in the South.

The ordinary automobile machine shop is not fitted up for work of this size, particularly in machine tools other than lathes, and this job could not be done on a lathe. The result is that it becomes a task to handle it, necessitating special and expensive rigging for that one job. This was the case with the axle shown, a boring mill of the horizontal type and a large size milling machine being used on it. Both of these had to have special fixtures, which were useless at other times, to hold and machine these parts. At that, this job was much easier than an axle of corresponding size in the Elliott type would have been.

Lemoine Type. The Lemoine type of front axle differs from those described in that the axle proper bears upon the top or bottom of the knuckle-pin part of the knuckle, the two being made as one; that is, an extension or a jaw of the axle does not support the knuckle as with the Elliott type. When the steering knuckle of the Lemoine type is mounted below the axle stub, the latter is carried higher than with the reversed Elliott, so as to rest upon the top of the knuckle. An advantage of the construction from a manufacturing viewpoint is the cost of machining. With this design, the thrust load is practically entirely at the bottom upon the knuckle, which also must take all side loads; it is fastened in a sidewise direction at but one point—the bearing in the axle. The side shocks are taken on the end of a beam fixed only at the other end, whereas with the other types, the load is distributed between two supports, or divided equally over two sides, the point of support being midway between them. With the Lemoine type discussed, the bottom bearing must compensate for radial and thrust loads—a difficult condition to meet.

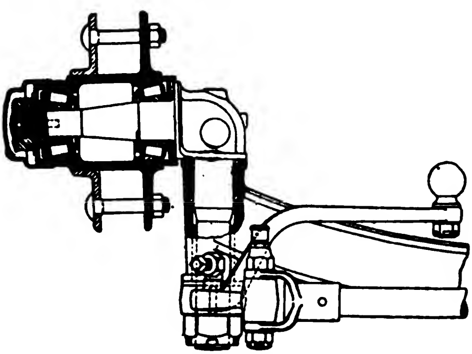


Fig. 360. Inverted Lemoine Type of Axle as Used on Overland Cars

While the design is easy to machine, assemble, and handle, its disadvantage is that the knuckle has a double duty, having, as it does, both radial and thrust loads to care for because of its one-piece construction. This type of axle is, however, very popular with foreign designers.

Inverted Lemoine. A novel type of axle has been created in the 1916 Overland car, Model 75, called an inverted Lemoine. In this type, as Fig. 360 shows, the wheel spindle, or stub axle, is at the top of the steering knuckle instead of at the bottom as in the case of the regular Lemoine type. The knuckle has a single, fairly long support in the end of the I-beam front axle, the forging being much simpler on this account. In fact, this makes the axle nearly straight, which doubtless accounts in large part for this unusual design. One real advantage of this design is that it allows the car weight to be low in relation to wheel bearings, thus assisting in steering.

Courtesy of Nordyke and Marmon Company, Indianapolis, Indiana

Marmon Self-Lubricating Axle. The new Marmon front axle, Fig. 361, is of the inverted Lemoine type similar to the Overland, shown in Fig. 360, but at first glance it looks quite different. For one thing, the bearing in the axle end is different, and in this lies an exclusive and valuable feature. The stub-axle pivot pin, made integral with the stub axle, is placed in a split bushing, which is a tight fit at the bottom—where the thrust collars are formed in it—and at the top, but not in the middle. When this bushing is in place, the knuckle and bushing are forced into the axle end from above, and a kind of hub cap screwed on at the bottom. This holds it permanently in place.

Near the middle of the split bushing there is a narrow slot to which a central bolt hole is connected. On being assembled, the inside is filled with lubricant, which cannot escape; but, as it wears away, the central bolt can be removed, more lubricant can be poured in until it is full, and the bolt replaced to prevent leakage. In this way the axle is self-lubricating, and, as the oil is used up very slowly, it needs practically no attention.

Fig. 362. Front Elevation of Car, Showing Camber of the Front Wheels

Like the Overland, this arrangement of the axle end brings the axle down low, relative to the weight, and consequently steering is made easier. The lowering of the axle also brings the points of spring support down and thus lowers the whole car.

Camber Somewhat Complicates Axle Ends. All front wheels are dished, that is, the spokes do not lie in a flat plane but in the form of a cone, with the point of the cone at the outer end of the hub and the base of the cone at the rim of the wheel. Now all roads and most all pavements are made with a camber. The center of the road is made higher than the sides so that the road will drain. It is necessary, in order to have the lower spokes plumb or perpendicular to the road surface, to throw the center line of the wheel out of the vertical plane 2 or 3 degrees. This offset is also called camber, and it complicates the construction of the axle ends to such an extent that they must be machined with this slight angle either in the knuckle or in the axle, or distributed over the two places.

Fig. 362 shows the effect of this camber upon the front appearance of the car, the slight angle of the front wheels giving the car a bow-legged appearance.

Gather Further Complicates Axles. What the carriage men term "gather" further complicates the axle ends. This is the practice of setting the axle so that the front wheels are closer together at the front than at the rear, that is, they toe in. The idea of this is to make steering easier and, more particularly, to make the car self-steering on plain, level, straight-ahead roads. It is scarcely noticeable from in front, but is from above. Although many cars still have it, it is not used as much now as formerly.

MATERIALS

The materials utilized for front axles include castings of steel, manganese bronze, iron, and other metals, in the form of forgings, drop forgings, drawn or rolled shapes, and pressed shapes. Wood has been but little used and only in the past.

Cast Axles. Castings for front axles have been looked upon with grave doubt and fear by designers and owners, because of the fact that road shocks are more severe for front than for rear axles, and because of the fear that a casting may have a blowhole or some other defect. In addition to the natural distrust of castings for this work, it was feared that such material would crystallize more quickly than would a better and more homogeneous material like steel. There is, of course, a certain amount of crystallization in all materials, but far less in a close-grained fine-fibered structure like forged or rolled steel than in any form of casting. Aside from this, castings present many other advantages which are well worth while. Thus, the spring pads may be cast integral with the axle with practically no extra charge, while the same forged integral with a drop-forged axle may easily add several hundred dollars to the cost of the dies. Again, with casting patterns, the fillets may be changed easily to give a greater section here or to reduce a section there, while a similar action with any forged axle means a new set of dies, costing perhaps $600. There are many other machining helps which may be provided in cast axles without any extra cost.

Notwithstanding these many advantages, the casting for the front axle has been and is distrusted, and the makers who have used it have flown in the face of popular prejudice, for the public has mistrusted it even more than the makers. For this reason, the casting has been little used, and the writer fails to recall a single car with a cast axle now on the market.

Forgings. Forgings, as distinguished from drop forgings, are much used for good front axles, but are expensive. The writer knows of one excellent truck builder, striving to build the best truck in the world, who is using a hand-forged front axle, the end of which is shown in Fig. 359. It is forged down from a 6-inch bar of selected steel and the ends worked out so as to leave the bed proper a 2½- by 2½-inch section, which later has been increased to 3 inches square. This made a very costly piece of work, but the stand-up qualities shown in actual work more than made up for it as long as people could be found to pay the price demanded for a truck made along these lines.

Many smaller makers follow out the same scheme, the lighter work allowing the axles to be forged up much more quickly, more easily, and more cheaply. The smaller the amount of material to be heated, the less difficult will be the work, and the more quickly will progress be made. The general trend of axle practice today, however, is to turn over the axle job to specialists in that line, most of whom employ drop forgings, drawn- or rolled-steel tubing with drop-forged ends, or similar rapid-production forms of construction.

Drop Forgings. Drop forgings are now more used than any other form, although the first cost is great, for the dies must be very carefully worked out in a very high grade of steel; the result is a large expense of possibly $600 to $750 before a single axle is turned out.

As a matter of fact, with drop forgings, after the die is once made, the axles may be turned out rapidly, accurately, and with little labor and cost. Given the dies, therefore, there is no doubt that this method produces an axle at a very low first cost. Moreover, the method itself produces better quality, for any process which works steel or wrought iron over and over again improves its quality, provided the steel is not burned in the process of heating. Not only are the majority of axles made of drop forgings, but of those not so made some part is almost sure to be a drop forging, as, for example, those made of steel tubing which have their ends or other parts made by the drop-forging process. In Fig. 363 is shown a drop-forged axle used on a truck.

Tubular Axles. The I-beam section of front axle is universally used, and while the tubular type formerly enjoyed some popularity, its use today is confined to a very few vehicles. When employed, its ends are drop forged or drawn, or rolled steel may be used with the ends welded or otherwise secured. The disadvantage of the tubular type is the fastening of the ends which is more or less offset by the lowered cost of material.

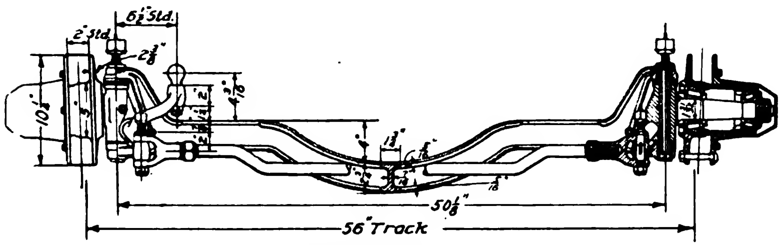


Fig. 363. Typical Drop-Forged Axle Used on Truck

Drop-Forged Ends. Nearly all the ends for axles made in this way are drop forgings, very few castings being used, while the spring pads, or spring seats, as they are sometimes called, are split into upper and lower halves and bolted on.

The loading conditions of all front axles are such that the load rests on the axle at two points inside of the supporting points—the wheels. Thus, the continual tendency of the load acting downward and of road shocks acting upward is to bend the center of the axle still further downward. Since a tube which has been bent once has been weakened, it follows that this tendency to weaken it presents a further source of trouble.

Pressed-Steel Axles. The pressed-steel type of axle, which made its initial appearance in 1909, and is not generally employed, consisted of a pair of pressed-steel channel shapes—one being slightly larger than the other—set together with the flanges inward so as to present a box-like shape. When thus arranged, the two sections were riveted together by a series of rivets running vertically along the center part of the channels. The ends consist of drop forgings, machined to size or space between the channels when assembled, and then set into place between the ends and riveted. The pressed-steel construction obtained a secure attachment to the bed. This axle was of the Elliott réversed type.

Change of Axle Type Simplifies. Often the change from one type of axle to the other is not made because the latter is better but because of some incidental saving in the manufacture. Thus, in

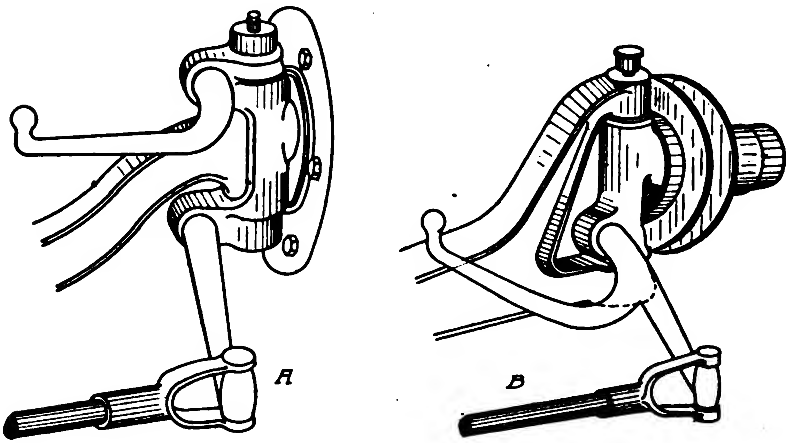


Fig. 364. Differences in Construction of Reversed Elliott and Elliott Types of Axle Knuckle

Fig. 364, we see the reversed Elliott type at the left at *A* and the Elliott type at the right at *B*. From a manufacturing point of view, the former is much cheaper to construct, for the axle and knuckle costs would just balance one another, but the forging and machining of the one-piece steering arm shown in *B* would be more than double that shown in *A*. Moreover, the number of dies and their cost would be about three times as much, while the customer would have to be charged two or three times as much for repair parts. That is, in a modern low-priced car, produced in tremendous quantities, the advantages and costs connected with the two-piece steering arm of *A* would influence the choice of that design, regardless of other advantages or disadvantages.

AXLE BEARINGS

Classification. Thus far nothing specific has been said about axle bearings. These are, according to construction, of three kinds: plain, roller, and ball. From the standpoint of the duty which they are to perform, bearings may be divided into radial-load and thrust bearings, all three forms mentioned above being used for both purposes, but arranged differently on account of the difference in the work. Each one of the three classes may be further subdivided. Thus, plain bearings may be of bearing metal or of hardened steel, or they may even be so constructed as to be self-lubricating. Again, plain bearings may mean no bearings at all as in the old carriage days when the axle passed through a hole in the hubs, and whatever wear occurred was distributed over the inside of the hubs, resulting

Fig. 365. Front Axle End, Showing Roller Bearings for Wheel and Steering Knuckle

after a time in the necessity for either a new set of hubs or a new axle, or for the resetting of the axle, so that the hubs set further up on a taper. Roller bearings may be of several classes, some makers using both straight and tapered rollers. In addition to these there are combinations of the straight and tapered types, and bearings with two sets of tapered rollers acting back to back, the action being that of straight rollers, with the end-adjustment feature of the tapered type. There are also many types of ball bearings, as, for example, plain ball bearings—those working in flat races, those working in curved races, those working in V-grooved races, and single balls working alone. There are also combinations of balls in double rows.

Roller Bearings. Fig. 359 shows the use of tapered roller bearings for the hubs and of hardened-steel thrust washers for the thrust load, the figure showing, in addition, a plain brass bushing in the axle for the knuckle pin to turn in. In Fig. 365 is shown a more elaborate use of roller bearings of very excellent design. In addition to the axle bearing, it will be noted that the top bearing of the steering knuckle is of the roller type.

Ball Bearings. Although there is a growing tendency to utilize a short adjustable type of roller bearing, many designers favor the ball bearing. The two most common forms are the cup and cone type, which cares for radial and thrust loads, and the annular form which

Fig. 366. Front Axle and Steering Knuckle of Superior Construction

is suited for supporting annular loads. The annular form is not adjustable, and when it wears it must be replaced with a new bearing. The cup and cone type is adopted by makers of low-priced and medium-priced cars, has an angular contact, and is adjustable.

In some instances, particularly with high-grade cars, ball bearings are used for the knuckle bearings as well as for the hub. Fig. 366 is an example of an axle end, which for real bearing worth, has probably never been surpassed; this is the axle end and steering knuckle of a very high-priced car, not now made, but one on which no expense was spared to make it perfect. The illustration shows the wheel hubs running on two very large diameter ball bearings, while the knuckle also turns on two very large ball bearings arranged for radial loads. At the top is another ball bearing arranged for thrust; this bearing taking up all thrust loads from the weight above or from road inequalities. Fig. 367 illustrates the cup and cone type, This design utilizes ball bearings for the hubs and plain steel thrust washers on the knuckle.

FRONT AXLE TROUBLES AND REPAIRS

Alignment of Front Wheels Troublesome. The lack of alignment of front wheels gives as much trouble as anything else in the

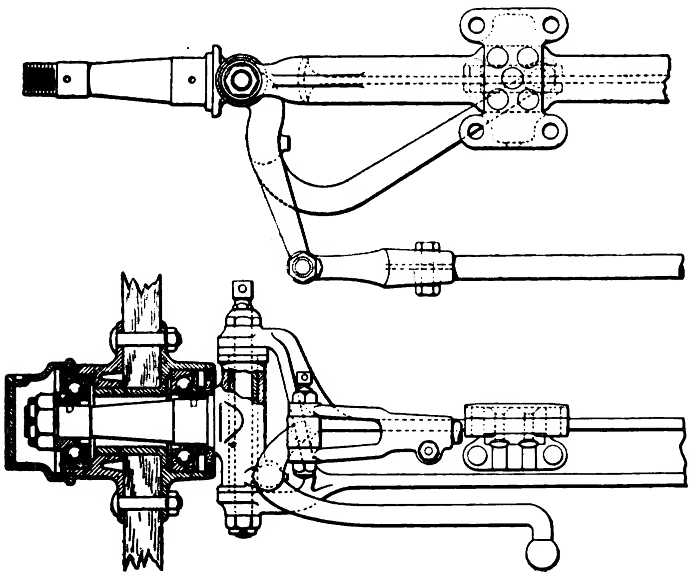


Fig. 367. Front Axle Details of Waverley Electric Car
Courtesy of the Waverley Company, Indianapolis, Indiana

front unit. This lack not only makes steering difficult, inaccurate and uncertain, but it also influences tire wear to a tremendous extent. As Fig. 368 indicates, even if the rear axle should be true with the frame, at right angles to the driving shaft, and correctly placed crosswise—correct in every particular with the shafts both straight so that the wheels must run true—the fronts may be out with respect to the frame, out of track with the rears, or out with respect to each other.

In order to know about the front wheels, they should be measured; while this sounds simple, it is anything but that. In the first place there is little to measure from or with. A good starting place is the tires, and a simple measuring instrument is the one shown in Fig. 369. This instrument consists of a rod about ½ inch in diameter and about 3 feet long, fitted into a piece of pipe about 2 feet long, with a square outer end on each, and a set screw to hold the measurements as obtained. By placing this rod between the opposite sides of the front tires, it can be ascertained whether these are par-

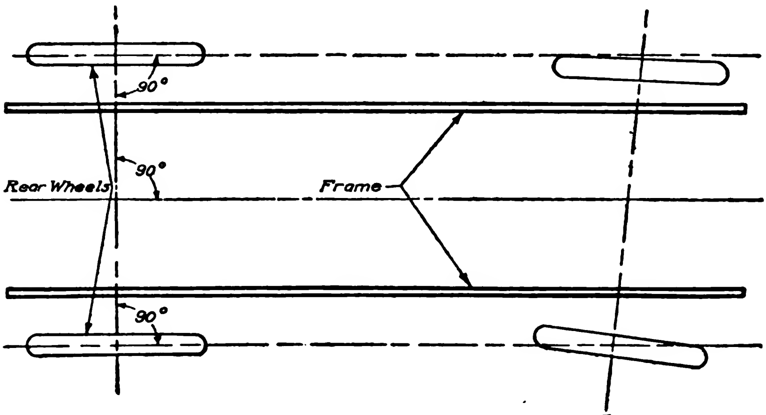


Fig. 368. Diagram Showing Front Axle and Wheels Out of True

allel, and whether they converge or diverge toward the front. But knowing this, the driver or repair man is little better off than before, because this may or may not be the practice of the makers of the car, and it may or may not cause the trouble.

In short, a more accurate and more thorough measuring instrument is needed, Fig. 370. Such an instrument can be bought, but a similar outfit can be made from ⅜-inch bar stock, using thumb nuts

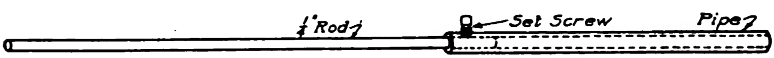


Fig. 369. Simple Measuring Rod for Truing-Up Wheels

where the two uprights join the base part, and also at the two points, or scribers, on these uprights. Having the floor to work from, the heights can be measured, and thus the distance between tires may be taken on equal levels. Thus, a bent steering knuckle can be detected with this apparatus. Similarly, the center line and frame lines of the car can be projected to the floor, and by means of the instrument, it can be determined whether the axle is at a perfect right angle with the frame lines, and whether the wheels are perfectly parallel. Given the frame line, too, it can be determined whether the wheels track with one another.

Straightening an Axle. When an axle is bent, as in a collision, a template is useful in straightening it. This can be cut from a thin sheet of metal, light board, or heavy cardboard. It is an approx-

Fig. 370. Accurate Measuring Rod for Truing-Up Wheels. Better Design than Fig. 369

imation at best and should be used with great care. Fig. 371 shows such a template applied to an axle which needs straightening.

When the axle is bent back to its original position, a pair of straightedges laid on top of the spring pads will be of great assistance in getting the springs parallel, as the worker can look across the straightedges with considerable accuracy. This is indicated in the

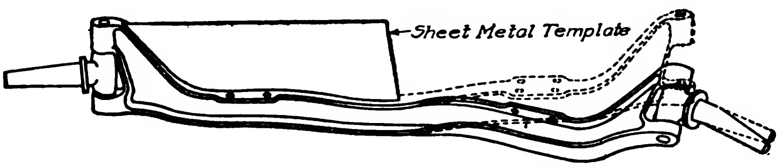


Fig. 371. Template for Showing if Axle Is Bent

first part of Fig. 372, which shows the general scheme. It shows also how the axle ends are aligned, using a large square on top of a parallel bar, but of course this cannot be done until the last thing, at least not until the spring pads are made parallel.

Front axles of light cars may be straightened without removal, provided the bend is not in the nature of a twist and not too short. Take two hardwood planks 7 feet long, 10 inches wide, and 2 inches thick. Next, cut four ¾-inch blocks 10 inches long and 3 inches wide. Lay the blocks flat between the planks, space them about 2 feet apart, and bolt the whole securely. This obtains a girder 7 feet long, 10 inches wide, and 4¾ inches thick. Next, take two pieces of 4×4 timber 3 feet long and cut a tenon on one end of each. Make three ¾-inch eye bolts, 12 inches long, with nuts and plate washers for each. Place one of the eye bolts between each pair of blocks and screw up the nuts and washers sufficiently so as to rivet them. This permits of moving the eye bolts to any position between the blocks. Two small steamboat ratchets and several short but strong chains complete the equipment.

Fig. 372. Diagram Illustrating Method of Truing-Up an Axle

With an axle bent back in the center, lay the girder on blocks in front of the car so it will be level with the axle, place the tenons of the 4×4 timbers in the space between the planks of the girder, one on either side of the bend, and connect the axle to the girder by means of a chain, the ratchet, and the eye bolt. When the ratchet is tightened up, it draws the ends of the 4×4's against the axle on either side of the bend. Tightening the ratchet still further removes the bend. This work may be accomplished in 20 minutes or less or in about one-tenth the time it will require to displace the axle, heat it, and straighten on an anvil, etc. The apparatus can be used for straightening many different bends; all that is necessary is a different arrangement of its parts.

For example, a downward bend can be straightened by placing the car above the girder, connecting the axle to the girder, and using a short screw jack to remove the bend. This device can be used with success in shops dealing with light- or medium-weight cars.

Spindle Troubles and Repairs. Wear of the spindle, or knuckle bolt, and its bushings, as well as play in the steering-gear linkage, brings about wobbling of the front wheels when the car is in motion. Some experienced persons mistake wear of the knuckle and the bushings for play in the wheel bearings, and attempt to remedy the trouble by adjusting the bearings. It is a simple matter to determine the component at fault. To test for bearing play, drive a block of wood between the knuckle and the axle, then grasp the wheel at the top and

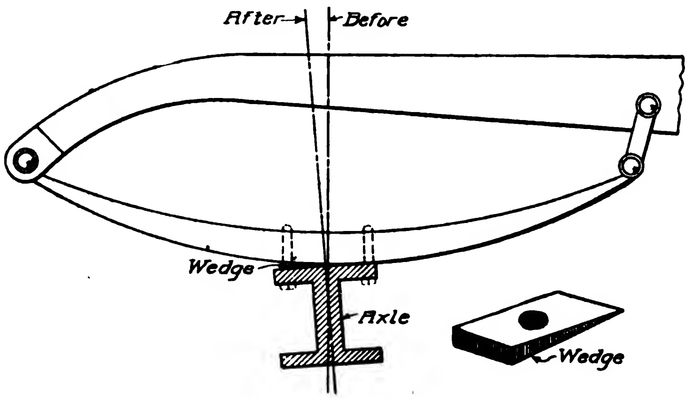


Fig. 373. Use of Wedge to Cure a Wobbling Wheel

bottom, or at points diametrically opposite, and test for looseness. If none exists, the play is in the knuckle pin and its bushings. The remedy is to fit new bushings and new knuckle pins.

Wobbling Wheels. Wobbling of the front road wheels is generally due to play in the joints of the steering mechanism, and it is not only troublesome, but also sets up undesirable stresses on the steering-gear linkage. This flapping of the wheels may be present with the steering gear and linkage in perfect operating condition, and similarly when the springs, hangers, etc., are in good condition and the proper toe in, or gather, of the wheels exist.

When the wheels wobble it may be assumed that the front springs have so settled that the steering pivots are not quite vertical fore and aft, particularly with reference to that type of pivots which do not incline outwards and where the wheels are canted or dished to bring their points of ground contact in line with the pivots. A cure for this trouble is to place wedges between the front springs and spring seats so as to alter the angle of the steering pivots, as shown in Fig. 373. Metal wedges are used, about $\frac{1}{8}$ inch thick at the large end, and tapered to a knife-like edge. The wedge is placed at the forward end of the axle, and a little experimentation will give the results desired. In wedging, as few wedges should be used as is necessary to obtain the desired result.

CHASSIS GROUP

In arranging a logical presentation of the numerous components of the motor vehicle, the chassis is separated from the body. It includes the power plant and mechanism utilized in transmitting the energy of the engine to the road wheels, also the frame and suspension, the axles, etc. However, only frames, springs, and shock absorbers will be discussed in this section, as the other parts of the chassis have been treated.

Characteristics of Parts. *Frames.* The chassis frame practically is the foundation of a motor vehicle, since all of the power transmitting and other units are attached to it. Motor-vehicle construction depends, to a certain extent, upon the general design of the chassis, the construction of the power plant and transmitting units, their mounting, the method of final drive, the wheelbase, etc. The size of the material used depends upon the weight of the units carried and the capacity of the vehicle, and varies from thin and small sizes on very light pleasure cars to heavy structural I-beam frames on commercial vehicles.

The use of pressed steel is becoming more popular, as is also the tendency to narrow the frame at the front to obtain a shorter turning radius. The majority of designers favor what is termed a kick-up at the rear, which affords better spring action and permits of a low suspension of the body. The use of tubing and wood has practically been abandoned. There is a slight return to favor of the underslung suspension, a form that was popular several years ago but which did not then obtain the results claimed for it, as the springing gave some trouble.

Springs. The primary function of the spring is to absorb the road shocks that would otherwise be communicated to the mechanism and passengers. Considerable progress has been made in the past year toward improving springs, and not only are they better proportioned, but improved material and methods of mounting have, to a great extent, eliminated breakage. The leaf type, developed by the horse-drawn carriage industry, is the form universally employed on motor vehicles, both pleasure and commercial.

A review of the 1916 springs for cars showed that the three-quarter and seven-eighths elliptic spring was favored by 46.5 per cent of the makers, while some form of cantilever spring was second with 28.7 per cent for rear suspension. This year the advocates of the cantilever have gained many new recruits. In the matter of front springs, the semi-elliptic may be said to practically monopolize the field. The coil spring is a thing of the past.

Shock Absorbers. The fitting of shock absorbers as standard equipment is not as noticeable as it was in 1916 and the year previous. The use of high-speed engines with light reciprocating parts, and the employment of high-grade light material in other components of the chassis, together with better springs, serves to absorb shocks created by traversing rough roads. A few makers supply shock absorbers, but, as a rule, the car manufacturer leaves the selection to the purchaser. Many different types of shock absorbers are marketed, and use is made of varying principles.

FRAMES

General Characteristics. When the automobile was first introduced, comparatively little attention was paid to the frame, as the other components of the chassis, such as the power plant, gearset, axles, etc., were held to be of greater importance, consequently the frame did not receive the consideration it should. After experiencing considerable difficulty, however, due to accidents and other failures which were traced directly to poor frame design, the automobile engineer found that it was possible to build a frame of great strength with less weight than the troublesome types. This statement applies to the frame of the commercial car as well.

The improvement in frame design is the result of the tendency to provide perfect alignment of the power plant, clutch, and gearset, making use of what is known as the unit power plant on some models, while on others, particularly of the heavier type, flexible mounting of the units has been resorted to. The tendency is toward the use of a flexible mounting of all individual units, at least to some degree, in order to relieve them of the stresses brought about by frame weaving when the road wheels mount an obstacle on the road surface.

Classes of Frames. The most prominent types of frames, divided according to their use, are the pressed-steel frame, the structural frame, and the structural I-beam frame; the latter is confined to commercial cars. These classes may be subdivided according to the general construction and material, as well as to the distribution of the chassis units.

The material employed is either pressed or rolled steel. The wood frame or combinations of wood and metal frames are practically a thing of the past, and are to be found, with one or two exceptions, on old cars. The steel frame may be constructed in the following shapes: channel, L-beam, angle, T, Z, tubing, flat plates, and combinations of any two or more of these. Other forms are possible. For example, the channel may be turned with the open side in or out, the two constructions being widely different; or the angle may have the corner down and out, down and in, up and out, or up and in. Similarly, the T-shape may be a solid T turned up or down, or it may be a hollow T-section with space between what might be called the two sides of the leg; this shape may be turned either up or down, while the Z-shape may be turned horizontally or vertically. Many frames are constructed with the open end of the channel section turned in, and use is made of a steel underpan of flat section attached to the under side of the main frame. In several instances there is a tendency to make the frame and underpan as one piece, in which case the frame section assumes the shape of a channel with an exceedingly long lower flange.

Another type of frame is that having a continuous section throughout. Others have a varying section. Thus, the ordinary steel frame of modified channel section may have a depth of perhaps 5 inches at the center, a width of upper flange of 1½ inches, and a width of lower flange of 2 inches. A frame similar to this would taper down to the ends to perhaps 20 inches in vertical height, and to 1 inch in width of both top and bottom flanges. Then, again, frames which are bent upward or downward at the ends or in the middle really differ from those frames which preserve one level from end to end. The practice of bending the chassis frame is very prevalent of late, the upturning of the ends bringing about a lower center of gravity, making for stability and ease of entrance and exit to the body.

Tendency in Design. There is a marked tendency toward making the chassis frame wider at the rear and narrower at the front. In one or two cases the designer appears to have gone to the extreme in this respect. The advantage of the narrow front construction is that it enables the car to be turned in a shorter radius. The use of a wide rear frame provides more space to support a wider body. A more recent development is to make the longitudinal bars of the frame parallel over the front spring and near the rear spring, and to have them tapered from behind the front to the rear springs. A certain amount of material is said to be gained by this construction, as no heavy reinforcement or sudden offset is necessary to the frame. By

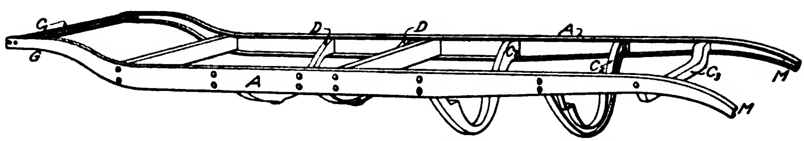


Fig. 374. Typical Automobile Frame of Pressed Steel

widening the frame at the rear it makes possible the placing of the springs directly underneath the frame. Some car makers have the sides of the frame straight over the entire length, but tapered from the front to the rear.

Fig. 374 illustrates what is termed a single drop or a kick-up. This is a type of pressed-steel construction, of channel section, and the deepest and strongest section is at the center where the greatest stresses occur. Some frames are built with a double drop, having a downward bend just forward of the entrance to the rear part of the car body, followed by an upward turn just back of the same entrance. The upward turn at the back is carried higher than the main part of the frame for the purpose of obtaining a low center of gravity. Then there is what is termed the bottle-neck construction, a bend inward which resembles that in the neck of a bottle. This obtains a short turning radius. Originally, frames were narrowed in front, the difference in the width between the front and rear being at first an inch or so on each side, gradually increasing until it became 5 and 6 inches. This type did not prove efficient, and the trend favored the taper previously explained.

A not uncommon form of frame is shown in Fig. 375, which compensates for an abnormal rise of the rear axle without the possibility of its striking the frame. Some frames have a bend at the ends to take the spring fastenings.

Pressed-Steel Frames. The pressed-steel type of frame is very popular with designers and is largely used on commercial cars up to and including 1-ton capacity. This is popular because it is the lightest in weight for equal strength of the structural iron or rolled channel and I-beam section. The cost of pressed steel is somewhat higher,

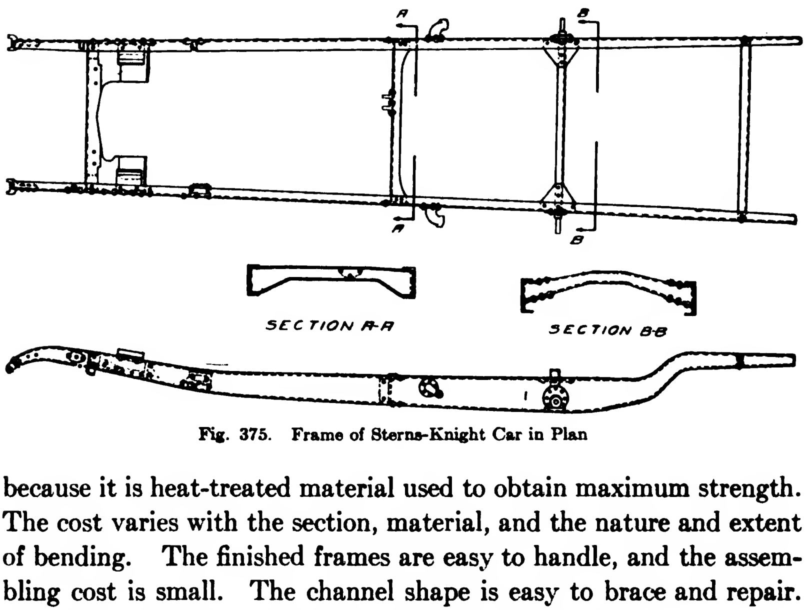


Fig. 375. Frame of Sterns-Knight Car in Plan

because it is heat-treated material used to obtain maximum strength. The cost varies with the section, material, and the nature and extent of bending. The finished frames are easy to handle, and the assembling cost is small. The channel shape is easy to brace and repair. These and other advantages have brought about its use.

The cheapest construction is the straight side rail, and, when conditions permit, it is usually tapered at front and the rear, and the forward end is sometimes shaped to receive the spring hangers. When the side members are inswept to permit a short turning radius, it is necessary to make the flanges of the side rail of considerable width at this point, tapering gradually to the rear, to provide the proper strength at the point of offset.

Sub-Frames. The modern tendency is to eliminate the sub-frame—a step due to the flexible mounting of the power plant and unit construction—because it simplifies the frame. It has also been made easier by the tapered frame, which is narrowest at the front where the units are attached. The most common method of supporting the engine is the three-point. Sub-frames are used, however, as they serve the purpose both of supporting some unit and of strengthening the frame.

Sub-frames may be of two kinds, viz, those in which the sub-frame is made different for each unit to be supported, and others in which one sub-frame supports all units regardless of size, shape, or character of work. The type of sub-frame made to support each unit usually works out to two pairs of cross-members, one for the front of the unit and one for the rear; while the type which supports all units regardless of size works out to longitudinal members, supported, in turn, by two cross-members, front and rear. The added weight for the first-mentioned type is less than for the other, since it comprises only four cross-members; while the last-named type consists of two cross-members equal to two of the others and of two very long members parallel to the main-frame members, each much longer and thus much heavier than the corresponding cross-members. In the two frames already shown, Fig. 374 shows the unit type of sub-frame with only cross-members, while Fig. 375 shows the more modern type in which the power plant is of the unit type and rests directly upon the main frame, being the three-point suspension type in which the forward point is on a frame or special cross-member, while the rear two points are the crankcase supporting arms resting directly on the main frame.

Rigid Frame. A pressed-steel or rolled-stock rigid frame has its advantages, particularly with reference to the commercial vehicle. It permits the body to be rigidly secured to it, and as it does not give with the inequalities of the road, the body is not racked. An advantage of the rolled stock is its cheapness, except, of course, for the lighter models of the assembled type for which frames can be secured at low figures. Another advantage of the rolled stock is the ease with which the wheel base may be altered.

Effect on Springs. The effect of frame construction upon the design and duty of springs should be considered. This feature

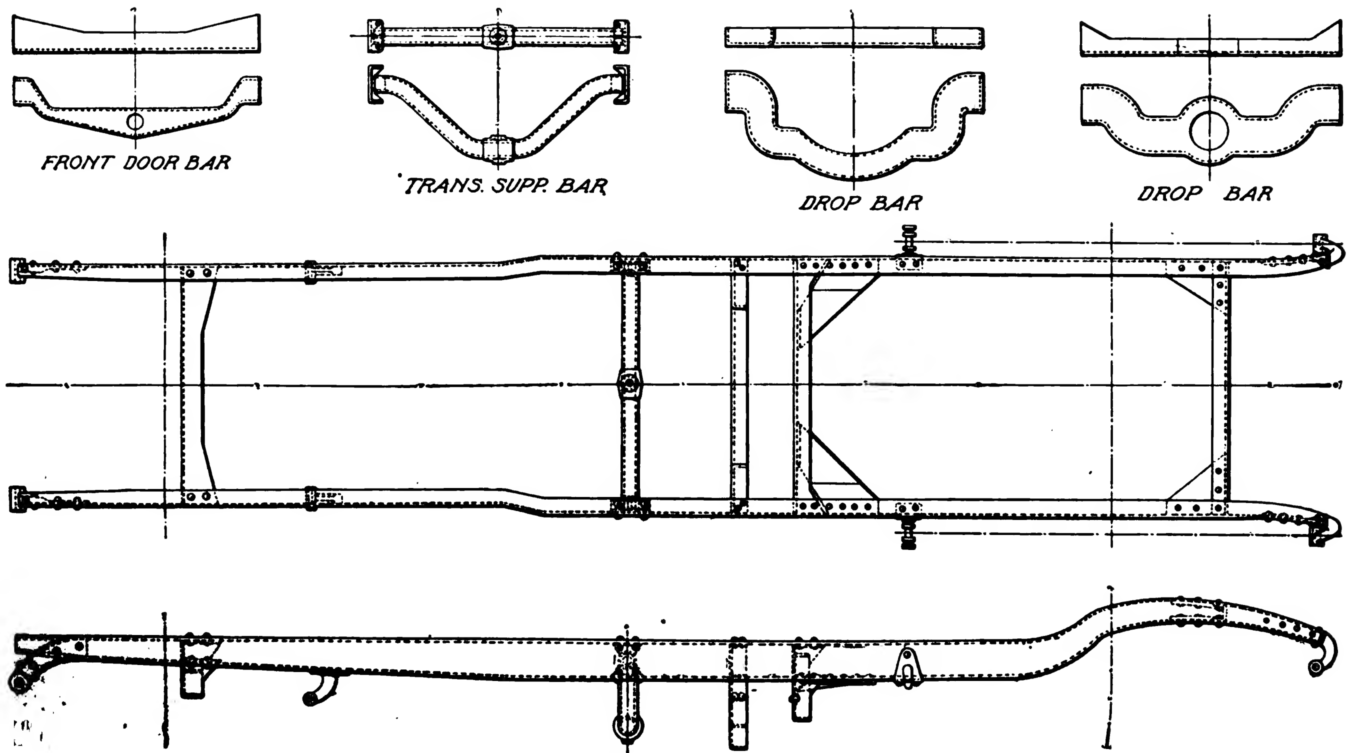


Fig. 376. Plan, Elevation, and Sectional Details for Chassis Frame with Narrowed Front
Courtesy of A. O. Smith Company, Milwaukee, Wisconsin

is not generally understood, but it has an important bearing upon the life of the car. A rigid frame relies upon the springs to allow for all axle displacement. If a front and a rear wheel on opposite sides are raised several inches at the same time, the frame is subjected to a torsional stress. If the frame is rigid, springs of considerable camber must be employed in order to absorb the shock without being bent past the limit of safety, and they must be sufficiently flexible to absorb all the shock without any tendency to lift the other wheels from the ground. To accomplish this shock absorption, a different type of spring is used on a rigid chassis from that employed on a flexible frame. The use of underslung spring suspension has come into favor for this reason, as it permits the frame to be carried fairly low, without sacrificing spring camber or necessitating a dropped rear axle.

The flexible frame, when diagonally opposed wheels are raised, does not impose all the stresses on the springs but it absorbs a part of them. For this reason, springs on a flexible chassis are flat or nearly so, with a limited amount of play. Flexible construction also permits the frame to be carried equally as low as with the underslung spring, and yet the spring is perched above the axle, where it is more nearly in line with the center of gravity, thus reducing side sway.

TYPES OF FRAMES

Pressed Steel. Pressed steel is purchased in sheet form, cut to the proper shape in the flat, and then pressed into channel form under great pressure. It is made of steel rolled into sheets and is somewhat closer grained than ordinary steel. There is no breaking of the flake in the rolling process. The pressed-steel frame, as previously pointed out, permits of greater simplicity in assembling, since the parts can be easily bolted or riveted. Fig. 376 is of the type of pressed-steel frame having a tapering section, a kick-up at the rear end, five cross-members —one of them a tube—and is narrowed in at the front to give the largest steering lock. Otherwise it presents only standard practice.

Wood. Wood is universal and easy to obtain. While no longer classed as cheap, it is not expensive; moreover, wood is kept in stock nearly everywhere. Users of wood for side-frame members claim that the wood frame is not only lighter but stronger. In addition, the wood frame would undoubtedly possess more natural spring and

TABLE IV

Comparative Strength of Steel Channels and Laminated Wood Frames

Material	Size (in.)	Weight per Linear Inch (lb.)	Resisting Moment	Resisting Moment per Unit Weight
Pressed Steel	$\frac{3}{16} \times 4\frac{1}{2} \times 1\frac{3}{4}$	.408	114,830	280,955
Ash	$1\frac{3}{4} \times 6$	.266	142,275	534,870

resiliency, so that it would make a lighter and easier riding frame. A section of a wood frame is shown in Fig. 377.

This shows a frame made of laminated wood. There are three very thin sections of selected ash, marked *A*, which are glued together, then screwed and bolted to prevent the glue from opening up. To further this purpose, a strip *B* is fastened on the top and bottom in the same manner. These strips are laid with the grain running horizontally, while the main pieces are laid with the grain running vertically. This construction makes a very strong and light-weight frame; the comparative figures for a steel section and the section shown, as given from the tests of the engineers of the Franklin Company, is shown in Table IV. These tests, which are authentic, seem to bear out the contention that the wood frame is both lighter and stronger than the steel frame.

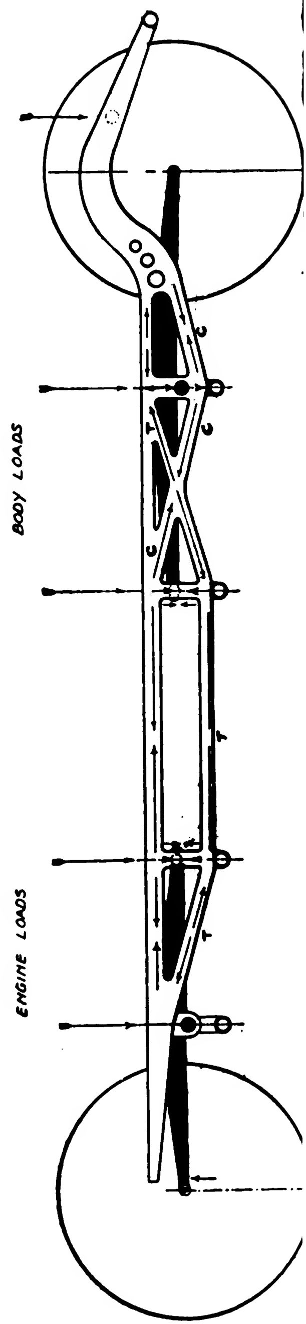
Fig. 377. Section through Wood Side-Frame of Franklin Car

Novelty of Fergus Frame. A new American car, the Fergus, shows more novelty in frame construction, as well as in every other conceivable way, than any other. Instead of blindly following accepted practice in the matter of frame design and construction, the makers have struck out boldly along new lines.

The Fergus car was developed as a result of fifteen years' experience in fine repair work, and is an attempt to eliminate the usual "owner troubles". While not intended as a "foolproof" car, the Fergus comes nearer being one than any other developed up to this time. In addition to actually "fool-proofing" the car, the aim of the makers was to eliminate much of the work incident to caring for the modern car by replacing the usual "owner-attention" with an automatic system.

In the frame, a combination of steel girder and lattice work has been produced which has the appearance of being absurdly light. However, as the diagram of stresses in its members, Fig. 378, indicates, everything has been figured out with the utmost care, and the design has been supplemented by unusual workmanship.

The complete frame, Figs. 379 and 380, shows that a large part of the saving is produced by the method of suspending the units. Were these hung on the side members, as in the ordinary case, the frame certainly would not do, but as it is, they are hung on immensely strong brackets, steadied by the side members, but rigidly supported by large tubular cross-members. The brackets and cross-members do the work ordinarily assigned to the side members of the frame, the side members simply joining and holding together the various brackets and cross-members.



An examination of the design reveals the astonishing extent to which the brackets have been combined, the rear engine member, for instance, also acts as the rear support for the front spring, for

Fig. 379. Forward Portion of Chassis of Fergus Car, Showing Method of Attaching Springs, Front Axle, and Engine

the step support, and for the dash support. At the sides and rear there is a similar combination of functions.

Recent Types of Frames. An innovation in frame design is the Marmon, shown in Fig. 381, the side rails and running boards of which are made in a single unit. The great width of the running board,

Fig. 380. Rear Portion of Chassis of Fergus Car, Showing Simple Spring and Rear-Axle Construction

varying from 11½ to 16 inches, serves as the bottom flange of the frame, and is therefore of Z-section. The vertical section of the frame is 10 inches high, and has height enough to replace the running board fenders without appearing narrow. At the front and rear ends of the frame, the running boards are curved upward, strengthening the frame

Fig. 381. Marmon Aluminum Frame, Showing Running Board Construction

as well as supporting the fenders into which they merge. The frame, beyond these points, both forward and rearward, is made of channel section of the conventional type. The rear of the frame is 45 inches wide and tapers to 30 inches at the front spring hangers. The great depth of the frame section makes it very stiff, so that the body sills

Fig. 382. Brush Pressed-Steel Frame
Courtesy of Hale and Kilburn Company, Philadelphia, Pennsylvania

can be entirely eliminated, and yet the doors will not work loose or bind when the top is up or down.

Fig. 382 illustrates a type of frame similar to the Marmon, the Brush frame, controlled by the Hale and Kilburn Company, of Philadelphia.

Steel Underpans. The underpan has assumed a great deal of importance in the last two years, for makers have more and more realized that it is highly important to protect many of the parts from road dirt, flying stones, water, etc. Designers have, therefore, given

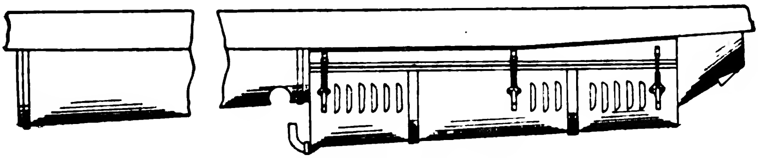


Fig. 383. Two-Piece Pressed-Steel Underpan Used on Winton Cars
Courtesy of Winton Motor Car Company, Cleveland, Ohio

considerable attention to its shape, size, and method of attachment. In some types, it apparently runs underneath both engine and transmission and is made more or less a part of the main frame. Therefore, its quick removal on the road would be difficult, if not impossible; yet road accidents sometimes make it necessary for the driver to take this pan off to get at the lower side of engine, clutch, or gear box.

For this reason, underpans generally resemble more closely that shown in Fig. 383. This is a side view, showing the semicircular form of the pans, as well as the two-piece construction. The forward part under the engine, which would be taken down fairly often, is held in place by three spring clips on either side. Lifting these clips off is only a second's work; in addition, there is a filler piece in front, helping to make the pan fairly air-tight. The depth of the pan increases slightly toward the rear, so as to form a slope down which liquids will drain; the rear end is fitted with an upturned elbow, so that it will not drip until it accumulates a considerable quantity of liquid. Continual dripping indicates a full charge, and the pan is drained by turning the elbow over.

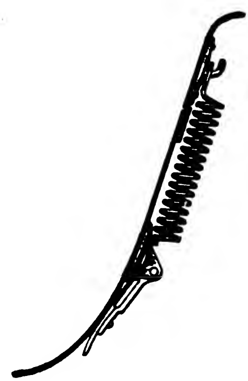


Fig. 384. Detail of Spring and Section of Winton Underpan

In Fig. 384, a detail of the arrangement of the pan shown in Fig. 383 is presented. This indicates both the permanent part of the underpan, which is attached to the frame, and the removable part, which is freed by loosening the spring clips shown.

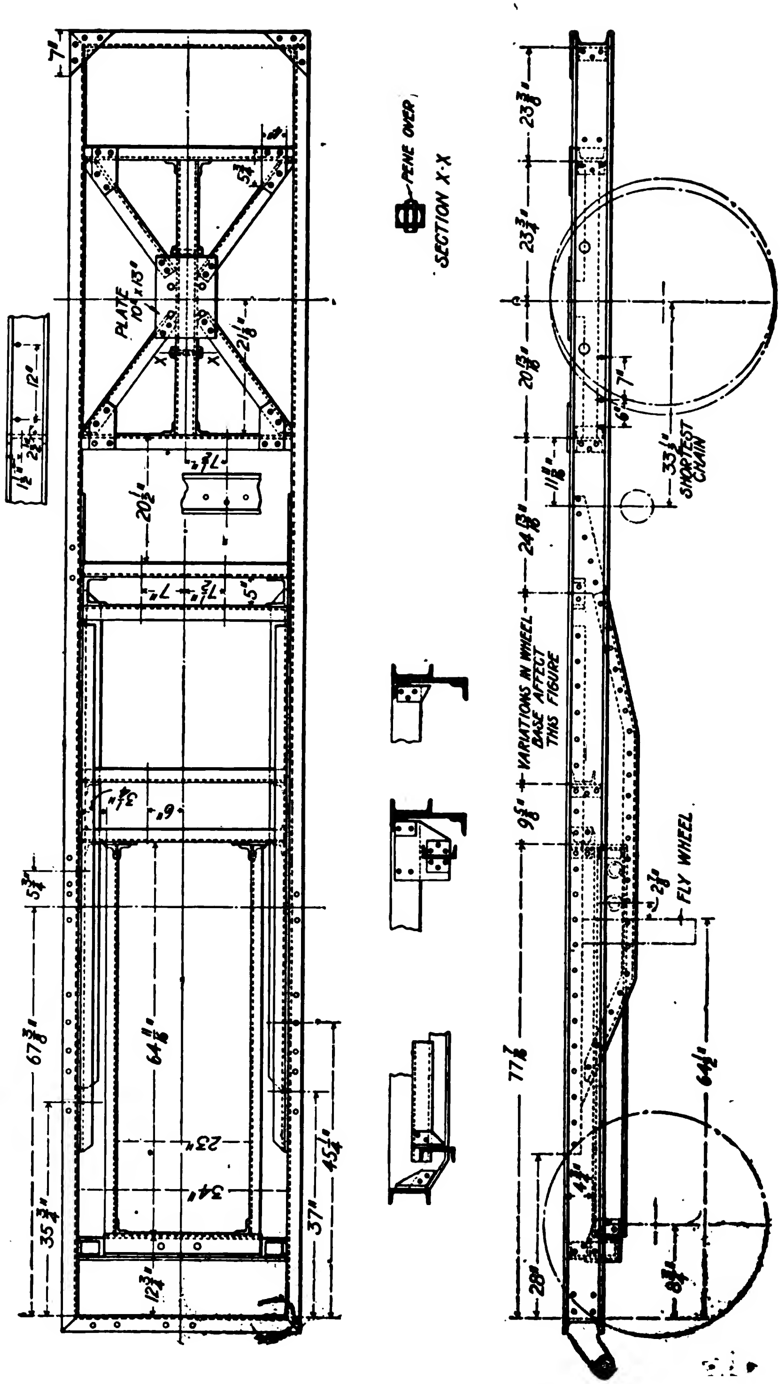


Fig. 385. Plan and Elevation of Frame of Heavy Truck

Commercial-Vehicle Construction. Commercial work, being rougher, harder, and cheaper work, changes the frame construction just as it does everything else about the car. In Fig. 385, a commercial-vehicle frame which brings out this point is shown. The main sills are 6-inch channels, while all of the other members are correspondingly large angles and channels. In one place the section consists of a box shape made up by bolting two large channels together, with the open sides in. The total overall length is not given, since this differs according to the variations in the wheel base; but, by a comparison of the figures given, it is seen that the frame shown is in

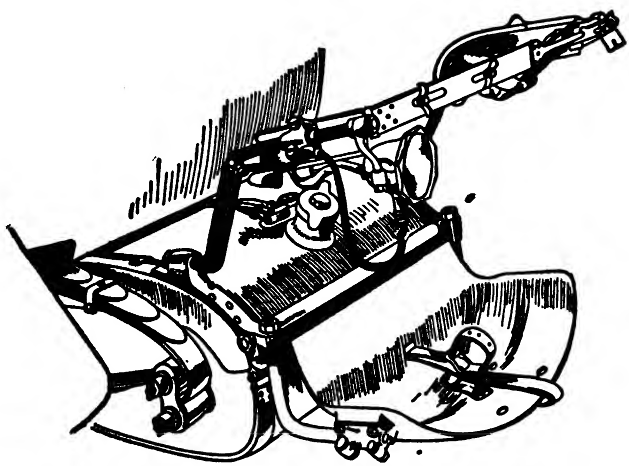


Fig. 386. Solid Rear Construction of Locomobile for Tires and Tanks
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

excess of 210 inches long by about 37 inches outside width. This is about twice the total length of the average small car.

In the bracing and arrangement of the different members, this frame shows other points of difference, the cross-members, for instance, being nine in number, not including the two diagonal cross-members. The longitudinal members, too, are eight in number, not counting the two diagonals.

Rear-End Changes. The locating of the fuel tank at the rear of the chassis—a practice that was brought into favor largely through the introduction of the vacuum system of fuel supply—has resulted in a number of changes to the rear ends of frames. The placing of the fuel tank at the rear is not new, and probably it would not have occasioned any change to the rear end of the frame were it not largely for the fact that the spare tires are now carried at the rear of the chassis. The tires themselves are not heavy enough to make it

Fig. 387. Sketch of Rear-End Construction of Reo Car

essential to strengthen the rear ends, but the very general use of carrying the spares inflated on demountable rims has added considerable weight to the rear of the chassis. This weight, coupled with

Fig. 388. Typical Rear-End Construction, Carrying Gasoline Tank

that of a large fuel tank, has compelled makers to give more attention to the rear construction.

Provision is made for carrying the spare tires on the Locomobile chassis by means of an apron conforming in shape to the shoe. The three-quarter elliptic springs of the scroll type have ends attached to the outside of the main frame, which is carried back and serves as an extension for attaching the fuel tank. A cross-member is also utilized; it serves as a point of attachment for the two rods supporting the lower apron and for two upper rods as well. This design has merits in that the tire carrier is firmly anchored and serves to protect the fuel tank from injury possible in operating in crowding traffic where rear-end collisions are not uncommon. As may be noted, Fig. 386 shows the method of using an upper cross-member to prevent theft of the tires.

A different type of rear construction is shown in Fig. 387, a Reo. Here the rear cross-member is gusseted, and a pair of substantial arms are riveted to the cross-member. These arms serve as an anchorage for the tire holders which, in turn, have a cross-rod for protection. Still another design is shown in Fig. 388. Here the side rail of the frame projects back of the rear cross-member of the frame for a distance of about 12 inches. The fuel tank is suspended from these two extended frame members by means of steel straps which pass around the tank.

FRAME TROUBLES AND REPAIRS

The more usual troubles which the repair man will encounter are sagging in the middle; fracture in the middle at some heavily loaded point or at some unusually large hole or series of holes; twisting or other distortion due to accidents; bending or fracture of a sub-frame or cross-member; bending or fracture at a point where the frame is turned sharply inward, outward, upward, or downward.

Sagging. A frame sags in the middle for one of two reasons, either the original frame was not strong enough to sustain the load or the frame was strong enough normally, but an abnormal load was carried, which broke it down. Sometimes a frame which was large enough originally and which has not been overloaded will fail through crystallization or, in more common terms, fatigue of the steel. This occurs so seldom, and then only on very old frames, that it cannot be classed as a "usual" trouble; moreover, it cannot be fixed.

When a frame sags in the middle, the amount of the sag determines the method of repair. For a moderate sag, say $\frac{1}{4}$ to $\frac{1}{2}$ inch, a good plan is to add truss rods, one on either side. These should be stout bars, well anchored near the ends of the frame and at points where the frame has not been weakened by excessive drilling. They should be given a flattened U-shape, with two (or more) uprights down from the frame between them. The material for them should be stiff enough and strong enough to withstand bending and should be firmly fastened to the under side of the frame. The truss rods should be made in two parts with a turnbuckle to unite them, the ends being threaded right and left to receive the turnbuckle. When truss rods are put on a sagged frame, it should be turned over and loaded on the under side; then the turnbuckles should be pulled up so as to force the middle or sagged part upward a fraction of an inch, say $\frac{1}{8}$ to $\frac{1}{4}$ inch, and then the frame turned back, the other parts added, and the whole returned to use. A job of this kind which takes out the sag so that it does not recur is a job to be proud of.

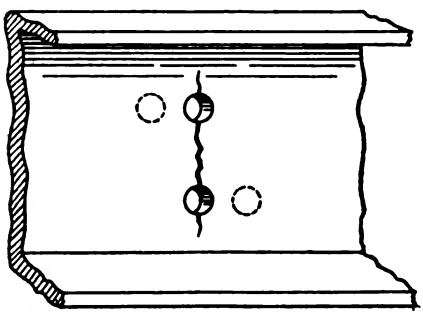


Fig. 389. Reboring Cracked Steel Channel

Fracture. Many frames break because too much metal was drilled out at one place. Fig. 389 shows a case of this kind. The two holes were drilled, one above the other, for the attachment of some part, and were made too large. They were so large that at this particular point there was not enough metal left to carry the load, and the frame broke, as indicated, between the two holes and also above and below. A break of this kind can be repaired in two good ways. The first and simplest, as well as the least expensive, is to take a piece of frame 10 to 12 inches long, of sufficiently small section to fit tightly inside this one. Drive it into the inside of the main frame at the break, rivet it in place firmly throughout its length, and then drill the desired holes through both thicknesses of metal.

This is not as good as welding. A break of this kind can be taken to a good autogenous welder who will widen out and clean the crack, fill it full of new metal, fuse that into intimate contact with the surrounding metal, and do so neat and clean a piece of work that one would never know it had been broken. When a welding job is done on a break like this, and no metal added besides that needed to fill the crack, subsequent drilling should be at an angle, to avoid a repetition of the overloading condition. In the figure, the dotted lines suggest the drilling. By staggering the holes in this way, there is a greater amount of metal to resist breakage than would be the case with one hole above the other—a method which might preferably have been used in the first place.

So much welding is done now, and so many people know of its advantages, that every repair shop of any size should have a welding outfit. A frame job is essentially an inside bench job, but a large number of cases of welding could be done directly on the car outside the building, particularly in summer when the outside air and cooling breezes are desirable. So, it is well to construct a small truck on which to keep the oxygen tank, acetylene cylinder, nozzle for working, and a fire extinguisher. One form of a truck is shown in Fig. 390. This truck is a simple rectangular platform with casters, a handle, and a rack to hold the tanks. It saves many steps and is particularly convenient in summer months. This outfit is essentially a home-made affair, but the gas-welding and electric-welding manufacturing companies have designed small outfits especially for automobile repair work, which would be preferable to the one in Fig. 390, especially where the amount of repair work warrants a reasonable expenditure for a welding outfit. A description of both gas and electric outfits and instructions for their use are given in the section on Oxy-acetylene Welding Practice.

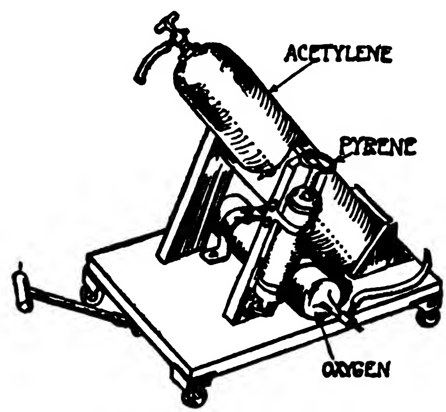


Fig. 390. Handy Oxy-Acetylene Outfit

Riveting Frames. *Tightening Rivets.* Rivets securing the corners of a frame or holding cross-members, gussets, and plates often work loose, particularly with the flexible type of frame previously alluded to. The location of the rivet and the accessibility of the part will determine how best to proceed with the work. The chief trouble experienced is that of placing a sufficiently solid article against the rivet while the other end is being hammered. As a rule, old axles, sledges, and hammers will serve under ordinary conditions, but these cannot always be used in a channel frame. One method is to employ an old anvil which is turned upside down and so placed in the frame that the flat end of the anvil is placed against the head of the rivet, while a rivet set is employed to set the rivet up snug. The horn of the anvil is allowed to rest on the other side of the frame. This method can be used for cutting off rivets as well as for tightening old ones. The anvil should be of sufficient length to rest on the frame as above described.

When an anvil is not available, the following method may be used with success. Take a ½-inch bolt and cut it off so that it will just go in the frame between the rivets. Slightly countersink the head of the bolt with a cold chisel. Put on the nut and slip in between the rivets and run the nut down until it expands tight in the frame. The depression in the head of the bolt, and the nut fitting around the opposite rivet head will keep it firmly in place while riveting. It is not always practical to attempt to tighten a rivet. The better method is to remove it, drill a larger hole and use a larger size rivet. Rivets are usually made of Norway iron. Heat to a red heat before using.

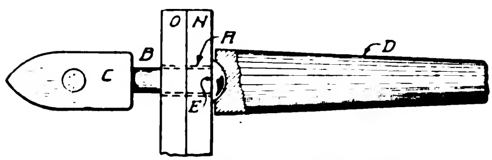


Fig. 391. Method of Riveting Frame

Riveting Methods. There are two methods of riveting, the driving in and the backing in. The latter method is shown in Fig. 391, and the two plates to be riveted are drilled in the usual manner, as shown at *A*, with the rivets a trifle smaller than the hole, placed as shown at *B*. With hot riveting, the hole should be about $\frac{1}{16}$ inch larger than the rivet, but with cold rivets, the opening should be such that the rivets will slide in. Instead of backing up the head of the rivet, a dolly is applied to the small end, as indicated at *C*, and the driving is done on the head of the rivet by a set *D* and a hammer. The energy of the hammer is applied through the set to the rivet, which is upset or enlarged, as it is unable to move because of the mass of metal in the dolly. The metal of the rivets expands sidewise at *A* and *B*, completely filling the space. A feature of this method is that a part of the hammer blow is expended in forcing the plate *N* into contact with the plate *O*. The metal at *B* is prevented from moving sidewise by a head formed at the dolly end of the rivet, and additional blows of the hammer tend to bring the plates closer and to hold them. The backing-in method is practical in making the various styles of rivet heads, particularly in making the thin, almost flush, head, and an advantage is that there are no reactionary stresses upon the thin head as would exist with the driven-in rivet.

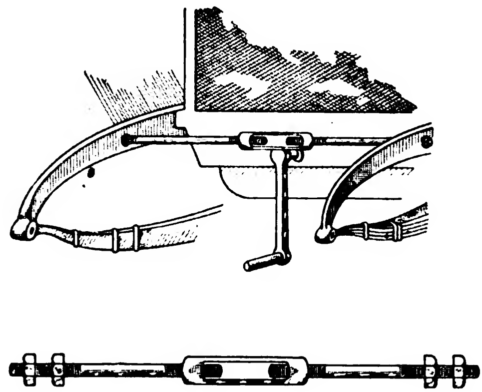


Fig. 392. Adding a Truss Rod to the Front of a Weak or Damaged Frame to Strengthen It and Preserve the Radiator

As there is more demanded of the rivet replacing the old member, it is important that the work be carefully performed. This applies to the holes in the plate. All sharp corners should be removed, as they afford an opportunity for the rivet to shear off by external stress or to fly off under internal strain. A reamer, drill, or countersink can be used in removing sharp corners. The face left need not be more than $\frac{1}{64}$ or $\frac{1}{32}$ inch wide, in order to greatly strengthen the rivet at its weakest point, or where the head joins the body. By slightly

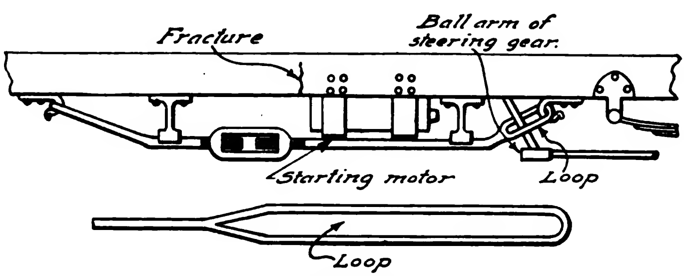


Fig. 393. Bracing Fractured Frame with Bar and Turnbuckle

chamfering the corner of the plate, the rivet is given a corresponding fillet, which not only increases its holding power but serves to draw the plates together.

Frame Bracing Methods. There are several methods whereby a frame that has been injured through collision or has sagged because of too light construction can be repaired. The front of the frame is the chief offender in this respect, and many times a leaking radiator is the result. When repairs to the radiator fail to cure the trouble, it may be assumed that the frame is at fault. A simple remedy is shown in Fig. 392 and consists in bracing the frame by means of a rod and turnbuckle. The rod should be about 2 inches longer than the width of the frame and threaded for about 3 inches on each end. The turnbuckle is not essential, but it simplifies the work. In installing the brace, the inside nuts are screwed on first and far enough to allow putting the rod in place. These nuts are next screwed out until they bear against the frame, and the latter is forced out until any pressure that may have existed on the radiator is eliminated. The outside nuts are then screwed up snug. The advantage of the turnbuckle is that adjustments may be made as required.

Fig. 393 shows a method of trussing a frame that was fractured by the stresses of the motor starter. Even after the fracture had been repaired, the driving gear of the starter would not mesh properly with the ring gear on the flywheel of the engine. As the movement was up and down on the frame, a truss was found necessary; while it was a simple matter to attach one end of the truss on the left-hand side of the chassis, the right-hand side was more difficult because of the proximity of the ball arm of the steering-gear lever. The problem was solved by forming a loop at one end of the truss of sufficient width and length to permit travel of the ball arm. By utilizing a turnbuckle the desired tension was obtained.

SPRINGS

Basis of Classification. The springs are important components of the chassis; for while the frame supports the power plant, clutch, and gearset, it is, in turn, supported upon the springs. The tendency at present is to design the frame and spring suspension so that the rear springs are placed very close to the rear wheels. In some cases, the frame is wide at the rear and is directly over the springs. Springs may be divided into seven general classes as follows: semi-elliptic, the full-elliptic, the three-quarter elliptic, the platform type, the cantilever, the quarter-elliptic, the coil, and combinations of these. The full-elliptic spring is made up of two sets of flat plates, slightly bowed away from each other at the center and attached together at the ends. When these are used, the centers of the springs are attached top and bottom, respectively, to the frame and axle. With half of the top of the spring cut away, and the cut, or thick, end attached to the frame, this spring becomes a three-quarter elliptic. When the whole top of the spring is cut away, so that the spring is but a series of flat plates, bowed to a long radius, this becomes a semi-elliptic spring. By turning the semi-elliptic spring over, it becomes a canti-

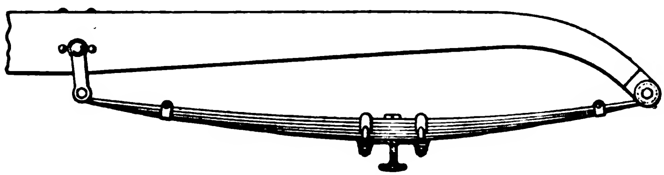


Fig. 394. Typical Semi-Elliptic Front Spring

lever when its center and one end are attached and the load applied to the other end. The quarter-elliptic is but a quarter of a spring, while the platform consists of three semi-ellipticsтАФtwo as side members in the regular position, while the third is used as a cross-spring, being inverted and attached at the center to the rear end of the frame and at its ends to the side members. The coil form requires no explanation and is not now used on cars. In addition, these forms are modified by scroll ends and various attachments.

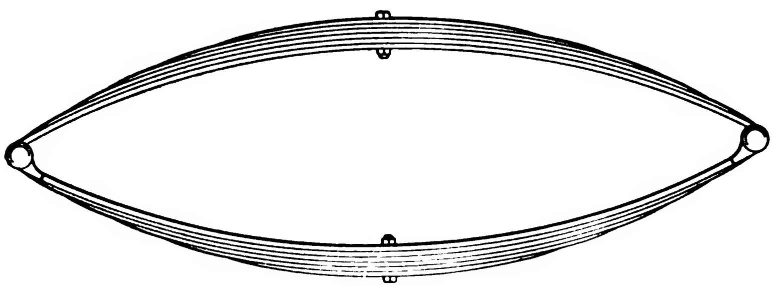


Fig. 395. Typical Full-Elliptic Front or Rear Spring

Semi-Elliptic. Fig. 394 shows a front spring of the semi-elliptic type, the form which is used now for almost every front spring. This is a working spring of the usual type, fixed at the front end, shackled at the rear end, attached to the axle in two places, and with two rebound clips in addition. The latter are put on the springs to prevent them from rebounding too far, in the case of a very deep drop. In some cases, as high as four, six, or eight of these clips may be used. Many other springs are made with ears, these being clipped over the next lower spring plate, the final result being the same as the use of many clips, but with improved appearance.

Full-Elliptic. Full-elliptic springs are the oldest form known. Fig. 395 shows the construction of this type, the upper and lower parts being pivotally connected at the ends. A slight modification of this form, known as the scroll-end full-elliptic type, is in more extensive

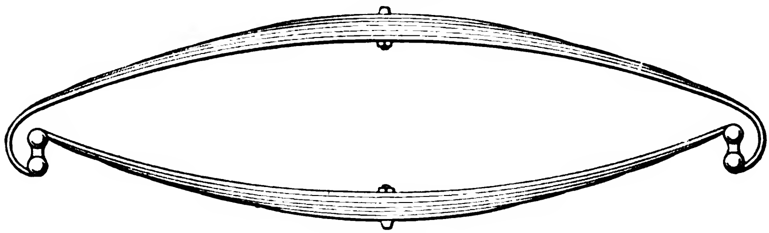


Fig. 396. Full-Elliptic Spring with Scroll Ends

use than the full-elliptic plain type. As Fig. 396 shows, the ends of the upper leaves are bent over. Each carries an eye, which is connected to the eye in the end of the upper leaves of the lower half of the spring by means of a shackle. This construction makes a very soft-riding spring.

Three-Quarter Elliptic. Very much like Fig. 396 is the form known as the three-quarter elliptic spring, the one having scroll ends being shown in Fig. 397. This form of spring is fastened at three

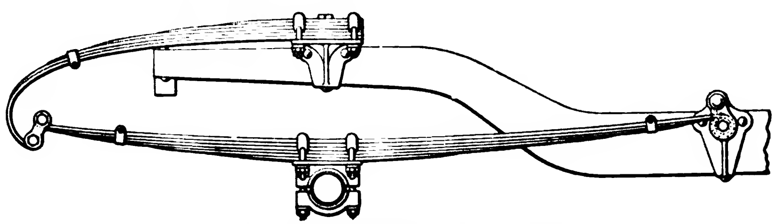


Fig. 397. Three-Quarter Elliptic Rear Spring with Scroll Ends

points. The lower part of the spring is shackled at the front end, fixed to the axle at the center, and shackled to the upper part of the spring at the rear. The upper part of the spring is fixed to the frame at the upper front end and shackled to the lower part at the rear. Fig. 407 shows another example of the three-quarter elliptic spring, which may differ in practice, as some three-quarter springs are not scroll ended.

This form of spring is growing in favor daily, a greater number being used this year than last, while designs for next year show a still greater increase. One reason for this increase is the great increase in the number of dropped frames, that is, frames unswept at the rear. To this form of frame, the three-quarter elliptic spring is very well adapted and makes a very natural, very good, and very easy-riding combination.

Platform. The platform type of spring is used a great deal on large cars, as well as on very heavy trucks, on account of its ability to carry heavy loads well, and also on account of its flexibility. As may be seen in Fig. 398, it consists of three semi-elliptic springs shackled together at the corners. The rear cross-spring is usually made shorter than the two side springs, while the latter are set off center, making the front of the spring, that is, the part forward of the point of attachment to the axle longer than the part to the rear. There are two reasons for this: First, the front end acts somewhat as a radius rod, the rear end of the frame rising in an arc of a circle whose radius is the front half of the spring; second, this plan dis-

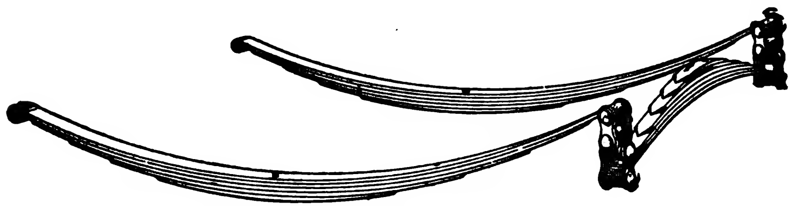


Fig. 398. Platform Springs, Showing How Side- and Cross-Springs Are Shackled Together

tributes the spring action equally in front of and back of the axle. Since the rear cross-spring is fastened to the frame in the center, each half of it is considered as a part of the side spring to which it is shackled. Thus, the total length of the side spring in front of the axle is the measured length of the side spring, while the total length of the side spring back of the axle is considered as the side length plus half of the cross-spring length. The center point, or point of axle attachment, is not moved so far forward as to make these two lengths equal, but in a proportion which may be derived thus: Assume a side spring 42 inches long and a cross-spring 35 inches long; then the spring would be set out of center some 4½ inches, making the front length about 25½ inches, while the rear length would be 16½ inches plus half of the rear spring, or 17½ inches, making a total of 34 inches. This would give a ratio of 25½ to 34, or 1 to 1.333. If the side members were 50 inches, the ratio would be about 1 to 1.25, and for side members shorter than 42, the ratio would be about 1 to 1.5.

Cantilever. The cantilever is, in appearance, a semi-elliptic spring turned over. It gets its name, however, from the method of suspension, which is quite different from that of any form of semi-elliptic spring. Moreover. as a part of this suspension, at least one

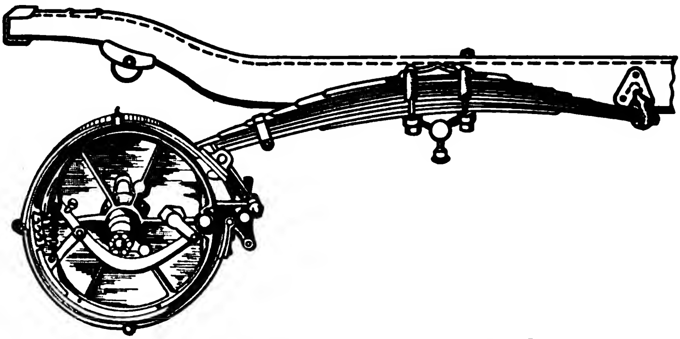


Fig. 399. Cantilever Rear Spring Used on King Cars
Courtesy of King Motor Car Company, Detroit, Michigan

end of the cantilever and sometimes two are finished up flat and square to slide back and forth in a groove provided for that purpose, a bolt through a central hole preventing the spring from coming out of its guide. One form, shown in Fig. 399, has a fixed attachment to the rear axle, a pivoted attachment to the frame at its center

Fig. 400. Front End of Cantilever Spring on Siddeley-Deasy (English) Car

(or slightly beyond the center), and a sliding attachment to the frame at its forward end to take care of the increase in length and of the forward movement necessary when the rear wheels rise.

Another form of cantilever is that shown in Fig. 400. This is the rear spring on the Siddeley-Deasy (English) car and, like that of the King, is pivotally mounted on the frame just forward of its center. Unlike the King, however, the forward end of the spring has a shackle which permits it to swing when the rear axle rises or falls. This shackle is a very interesting feature of this installation, having an adjustment which is most unusual for a shackle, Fig. 401. Note how the outsides of the shackle have a series of grooves, into which the head of the shackle bolt on one side and the washer on the other, fit. By setting these in the desired grooves and tightening the nut, the position is fixed. If this does not give the proper throw, it is a simple matter to remove the nut and make a new adjustment.

Fig. 401. Detail of the Adjustable Shackle on Siddeley Cantilever Spring

In France, a form of double cantilever has been tried out with success; this form consists of a pair of cantilevers, one above the other, separated at the center by a carefully sized spacing block, which is pivotally attached to the frame. The rear ends are attached above and below the axle, while the front ends are attached to two fixed points. Although the ends are made much thinner and more flexible than those just shown, it should be noted that both of them are fixed. The rise and fall of the wheels must be taken up by the springs themselves, the pivot in the center simply distributing the distortion over both the front and rear halves.

Advantages of Cantilever. The advantages of the cantilever spring are the smaller unsprung weight and the reduced manufacturing cost for a given amount of flexibility. Another advantage is the absence of sharp rebounds and a greater deflection for a given load and length of spring; it also obviates the cut in the body required with the three-quarter elliptic spring. When the cantilever takes the driving strain, the main leaf is usually stiffened and, being stronger sidewise, it eliminates a good deal of the side sway. With torque rods, the main lead may be made lighter, as the starting, the braking,

Fig. 403. Unique Rear Spring of Marmon Cars

and the torque act through the torque rods. Since there is more metal in the line to the thrust, they are especially suitable for taking the thrust, and not quite as efficient in taking the torque.

Hotchkiss Drive. The adoption in 1915 of the Hotchkiss drive, Fig. 402, in which the rear axle is connected with the frame through the chassis springs only, making the springs perform the functions of torque and thrust, is a radical departure from previous forms. The objection that it subjected the springs to unnecessary strains has not been sustained in practice, which has shown that a slight yielding of the rear axle when starting and braking, by a certain flexure in the springs, has reduced the stresses upon the transmission members.

In the Hotchkiss drive, the springs are rigidly attached to the rear axle, while the front end of the spring is secured to the frame with a proportionately large bolt through which the drive is transmitted. Users of the drive claim that it is quieter, that the car holds the road better, that it is more flexible, and that it avoids the road shocks which are transmitted through stiff torque members from the axle to the frame. Makers who drive through the springs and employ other torque members claim that they are not sacrificing flexibility in driving while eliminating a certain side sway and other strains preva-

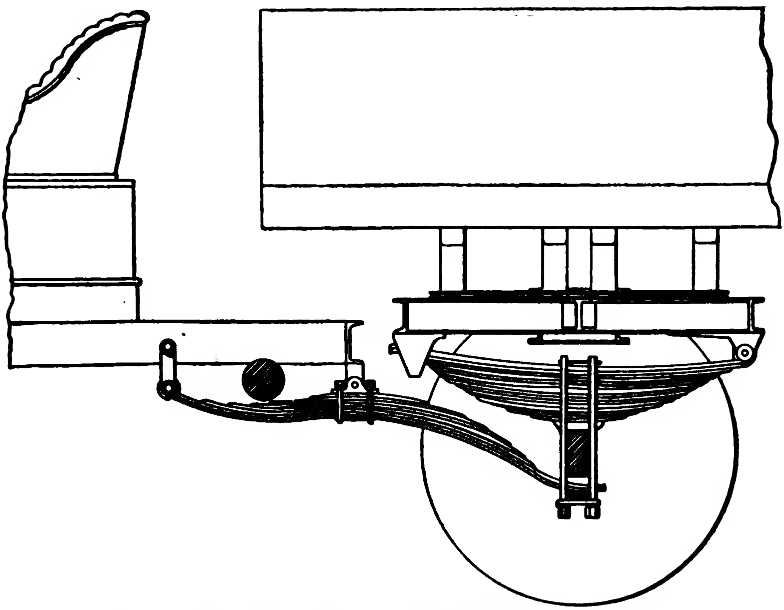


Fig. 404. Combination Cantilever and Semi-Elliptic Spring on Tractor

lent when the springs perform the functions of the torque. In the Hotchkiss drive, two universal joints in the drive shaft are used.

Unconventional Types. *Marmon.* A departure from conventional practice is the spring used on the Marmon car and shown in Fig. 403. It is a double-transverse construction, consisting of semi-elliptic springs bolted together at the center, with a curved block, or hard-maple cam, between them. This cam varies their stiffness, the spring automatically becoming stiffer as the load increases. Under normal load, the stiffness is about 170 pounds per inch, but as the springs are compressed the stiffness will reach 400 pounds. They are shackled at one side and fixed at the other, obtaining a perfectly parallel motion to the frame. There is said to be no roll as is sometimes found with transverse springs.

Knox Tractor. An unusual method of suspension is that employed on the Knox tractor, a combination of a cantilever and semi-elliptic spring at the rear end of the frame. The design shown in

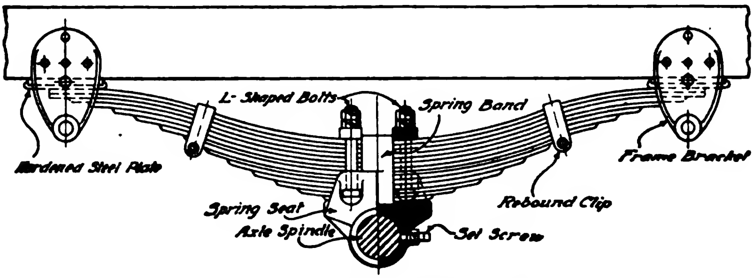


Fig. 405. Rear Spring of Six-Ton Truck

Fig. 404 includes heavy semi-elliptic springs, which are attached to the rear axle by long clips and carry the fifth wheel of the trailer. There is no connection between the springs and the tractor frame, so they carry the weight of the trailer and load only. The tractor frame is mounted on a cantilever spring having a pivot near its center and a shackle at the front end. The rear end bears on a seat clipped to the rear axle. This obtains a flexible mounting for the tractor and also permits the carrying of very heavy loads on the trailer.

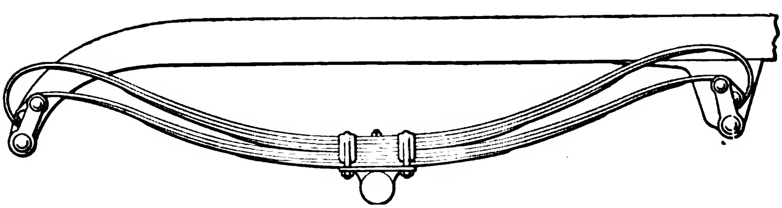


Fig. 406. Special Semi-Elliptic Rear Springs Formerly Made for Winton Cars
Courtesy of Perfection Spring Company, Cleveland, Ohio

Semi-Elliptic Truck Spring. The semi-elliptic spring is a favorite with makers of commercial vehicles. It is simple, and if the length, width, and other dimensions are proportioned correctly, it is a most satisfactory method for both front and rear suspension. Fig. 405 shows a rear spring for a 6-ton truck, the method of shackling, and how it is mounted on the axle by means of a spring seat.

Winton. Many makers use their own special form of springs. Fig. 406 shows the spring formerly used on the Winton cars, a type which might be described as a double-purpose spring. It was made in two parts, the lower part consisting of a regular semi-elliptic flat spring, while the upper part was a semi-elliptic flat spring with scroll ends. The central part of the spring was treated as one, being attached to the axle in the usual manner; the ends, however, had a peculiar appearance, because the upper and lower halves of the spring were of different shape. The scroll end of the upper part was supposed in itself to absorb many of the small road shocks. The spring was loosely attached to the frame at each end by means of a double shackle, made necessary by the double action of the spring; the tendency to flatten out increased its length, thus calling for a forward motion of the front and a backward motion of the rear ends, while the different lengthening action, owing to the difference in the lengths of the two parts of the spring itself, resulted in a turning about a different point.

For comparison with this earlier Winton spring, the latest form is shown in Fig. 407. It will be seen that the three-quarter elliptic form has been adopted, with a kick-up at the rear end of the frame. If the two types are compared somewhat closely, it will be seen that the only change in the frame part is the kick-up. The new springs show the scroll ends to which Winton has always been partial.

Ford. The form of the Ford spring has always been distinctly different. Fig. 408 shows the front and Fig. 409 the rear spring used on Ford cars, the distinction in the front spring being principally in the use of a single ordinary inverted front spring set across the frame on top of the axle, where most makers use a pair of side springs set parallel to the frame. This form is simple and cheap to make and assemble, the cost of the spring itself, and the work of putting

Fig. 408. Special Vanadium Front Springs for Ford Cars
Courtesy of Ford Motor Company, Detroit, Michigan

it on being just about half that of the spring attachment of the ordinary two-spring type. On the other hand, excellent riding qualities are claimed for it. A second distinction is that the spring is an inversion of the usual semi-elliptic type, the set of the spring being downward instead of upward. A third claim to distinction is in the use of vanadium steel, which, it is claimed, has a higher tensile and compressive strength than any other steel, and it is practically unbreakable in torsion. This steel is also being used in many other

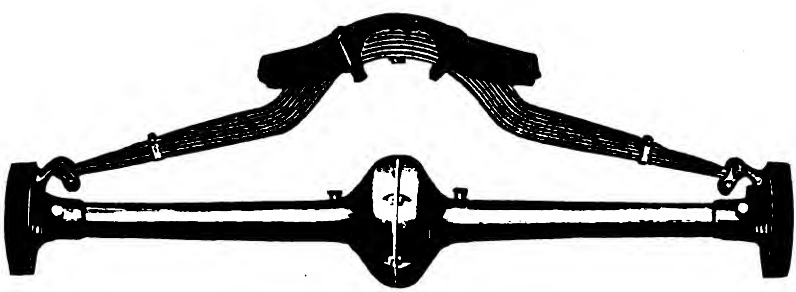


Fig. 409. Rear Springs of the Ford Car

parts, such as crankshafts, camshafts, fender irons, frames, drive-shafts, etc., resulting in a very light-weight car, since the greater strength of the material allows the use of smaller sections for equivalent strength.

The Ford rear spring has all the claims to distinction of the front spring, and, in addition, a hump at the center. Fig. 409 shows this hump clearly, the rear-frame cross-member being only partly shown. It will be noted that both ends of both springs are shackled, the construction necessitating it. These springs represent quite a radical departure, the success of which has been proved in actual practice.

Locomobile. Fig. 410 shows the three-quarter scroll elliptic rear spring used on the Locomobile, also the method of shackling both ends

Fig. 410. Three-Quarter Scroll Elliptic Spring Used on Locomobile Cars

of the spring, and the use of a considerable extension beyond the spring clip of the two upper leaves. Fig. 411 illustrates the Locomobile front springs, the upper spring being used on the 1916 model, and the lower one on the 1917 model. As may be noted, the later type is 2 inches longer and also flatter, and the distance between the spring

Fig. 411. Two Sets of Front-Axle Springs on Locomobile Cars

bolt and eye of the shackle is less in proportion to the 1916 design. It was found that the jerky action and fore-and-aft pitching of the axle were eliminated by this construction, greatly improving the riding qualities of the vehicle.

Electric Car Springs. The spring suspension of electric pleasure cars is similar to that of the gasoline vehicle, semi-elliptic suspension in front, and full-elliptic scroll-end suspension at the rear. The method of shackling is similar.

Varying Methods of Attaching Springs. Springs are attached in many ways. For example, the one shown in Fig. 398 might be shackled at the front end, fixed to the axle, and fixed to the center of the frame at the rear, the side and cross-springs being shackled together. Again, the front end might be fixed to the frame, Fig. 412, all other connections being unchanged. Or, with either method of fixing the front end, the spring might be swiveled on the axle, so as to be free to give sidewise without changing the other properties of the spring. Or, with either method of fixing the front end of the spring, and with or without the axle swivel, the cross-spring might be pivoted at the central point so as to be free to turn in any direction

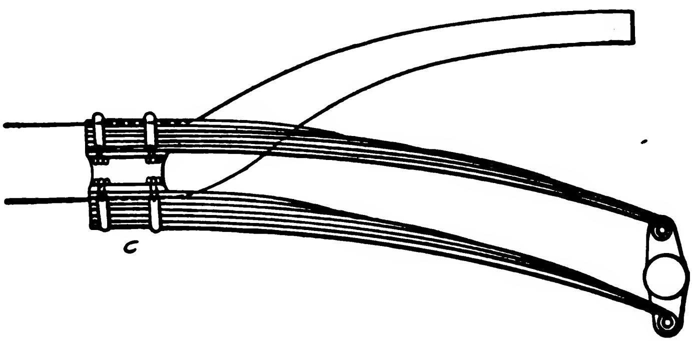


Fig. 412. Special Type of Double Quarter-Elliptic Rear Spring

about this central point. This latter method prevents binding and unequal spring action when one side of the frame is unduly raised or depressed, the solid method of fixing the rear end resulting in a double action on the part of one spring, owing partly to the tilting of the body and partly to spring action itself. With the pivot joint, the spring first swings about this point until a position of equilibrium is established, when the suppleness of the spring comes into action, the result being a deflection of half what it would be in the other case.

This form of spring also is used with the spiral spring, the latter taking the place of the shackle between the side and rear members. In this position it serves two purposes: (1) as a connector, taking the place of and doing the work of a shackle, thus acting as a universal and swinging joint between the two springs; (2) as a shock absorber, taking up road shocks within its length, that is, in the coils, without transferring any of them to the body proper or, in case of heavier shocks, sharing with the side and rear springs. This, of course, is the true function of the springs—to allow the road wheels to pass over the inequalities, rising and falling as may be necessary, while the body travels along in a straight line, level and parallel with the general course of the road.

Underslinging. Almost any of the spring forms shown and described may be underslung, that is, attached to the axle from below. This is a quite common practice for semi-elliptic springs when used in the rear, but it is very uncommon for front springs. Similarly, full elliptics, whether having scroll ends or not, are frequently under-

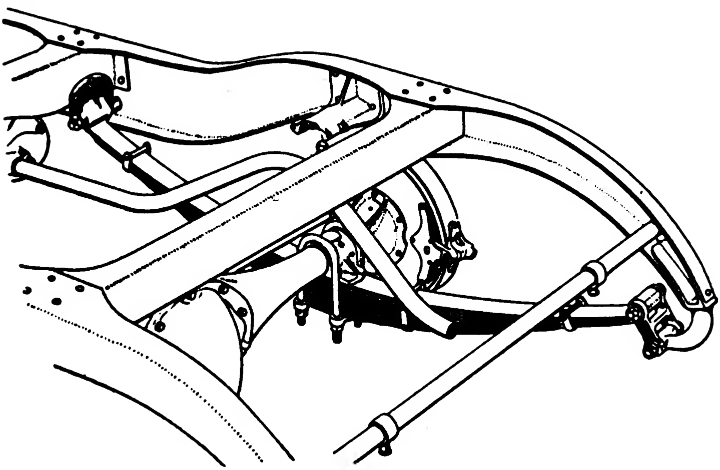


Fig. 413. Rear-Spring Arrangement on 1917 Premier

slung. The three-quarter elliptic form when used in the rear is usually underslung; the platform spring is not underslung so often. The cantilever and quarter-elliptic springs have been mentioned in connection with the underneath attachment. It should be pointed out that the position beneath the axle lowers the center of gravity by an amount equal to the thickness of the spring plus the diameter of the axle plus twice the thickness of the attaching means, and this, too, without interfering with the quality or quantity of the spring action. In the case of the cantilever, the effect of underslinging is to reduce the straightness of the spring, that is, the form when attached above the axle is almost straight, while the form when fastened below the axle is very much curved- has considerable "opening".

Shackles and Spring Horns. Considerable improvement has taken place in the method of shackling springs, and provision is now made with some types of springs for the adjustment of the shackles and hangers as well as for renewing bushings. Reference has been made to the tendency of design in rear-spring suspension and to the underslung types. Fig. 413 shows the design employed with the 1917 Premier, and, as may be noted, the springs are slightly diagonal, the front ends coming inside the frame line, while the rear ends are attached to goose necks of a rear extension of the frame pieces. Shackles are used for connecting the ends of the springs to the extensions.

A departure from the conventional shackle is the safety double shackle used on the Rainer 1000-pound capacity delivery car, shown in Fig. 414. In addition to the main eye on the main leaf of the rear spring, the second leaf is extended and formed into an elongated eye, allowance being made for deflection under load. The eye of the leaf is attached to the frame by the usual rigid spring bolt. Additional means of support are furnished by clamps on either side of the spring, one by a pin through the elongated eye, and the other by a pin through the lower end of the clamp which takes in the third and fourth leaves. It is pointed out that in case the main leaf breaks the eye of the second becomes the driving eye, and should this break, the spring will wedge between the under pin and the upper part of the clamp, thus obtaining rigidity which is essential with the Hotchkiss method of drive.

Fig. 414. Double Shackle Used on Rainer Delivery Car

Although the general practice is to shackle the semi-elliptic front spring at its rear, a departure which places the shackle at the spring horn or in front is noted in the Manly truck.

Adjusting Spring Hangers. The type of front-spring hanger, shown in Fig. 415, is adjustable. This adjustability is accomplished by relieving the body of the grease cup and screwing in the slotted bolt which eliminates side play. The grease cup body acts as a lock nut. The rear hanger of the front spring, Fig. 416, is adjusted by loosening the inside lock nut and the body of the grease cup. After removing the cap of the grease cup, the hanger bolt is turned out, or to the left, with a screwdriver, decreasing the distance between the links. The grease-cup body and lock nut are then set up tight.

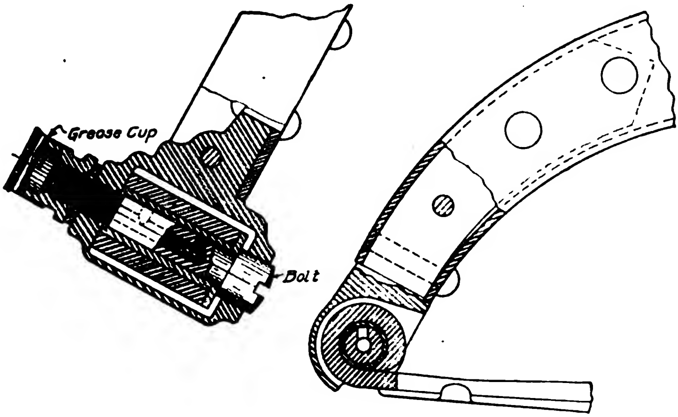


Fig. 415. Section of Adjustable Front-Spring Hanger

Provision is made with some types of rear springs for eliminating play when the rear ends are mounted on seats.

Spring Lubrication. All springs now are fairly well lubricated. All shackles are provided with grease cups, and other points of attachment to the frame are provided with oil holes. Where the springs are pivoted either on frame or axle, a big grease cup is usually furnished. In addition, it is now realized that the maker can prevent much of the noise formerly coming from dry and perhaps rusted steel spring plates working over each other. There are several ways in which oiling is accomplished. The springs are made with an internal lip, or groove, which is filled with lubricant when they are assembled; or between each pair of spring leaves is placed

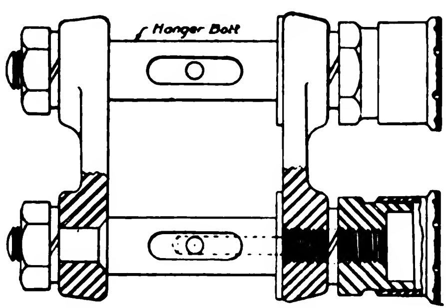


Fig. 416. Section of Rear-Spring Hanger

an insert having a series of oil pockets throughout its length, each filled with lubricant normally held in by means of a membrane cover; the movement of the spring plates and the heat generated thereby starts the lubricant flowing to all parts. An even later method is the attachment of external cups, provided with a wick which goes around the spring leaves and is pressed against their sides. The wick is kept wet with lubricant from the cups, and the motion of the spring leaves, together with the capillary action in the wick, draws the oil in between the leaves.

Spring Construction and Materials. A study of the illustrations used will show that practically all modern springs are clipped together, the number of these clips varying with the length of the spring and the use to which it will be subjected. Thus, Winton, Fig. 407, shows three clips and a band. Some springs show as many as five clips and two bands. But none indicate the use of spring ears—very small projections on the ends of the leaves—which are bent over the edge of the leaf next below it to assist in holding the spring together, but they are in quite general use. Altogether, there are about 14 or 15 forms of spring-leaf ends, but those in general use may be reduced to seven. These are: the oval; the round point; the short French point, a modification of the oval; the round end with slot and bead; the ribbed form, widely used on motor trucks; the square point tapered; and the diamond point.

In addition, sizes have been standardized in America to the extent that only five widths are used for pleasure cars and seven for motor trucks. Those for the former are: $1\frac{1}{2}$, $1\frac{3}{4}$, 2, $2\frac{1}{4}$, and $2\frac{1}{2}$ inches; for the latter: 2, $2\frac{1}{4}$, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, and $4\frac{1}{2}$ inches.

As the automobile business has called for better stand-up qualities under more severe conditions of use, the quality of steel used has been greatly improved, and other materials are better. The French make excellent springs, many of our best automobile manufacturers going abroad for their springs for this reason, but American springs are improving in quality so rapidly that this is becoming unnecessary. Formerly, all springs were of a plain carbon stock, but now a great deal of silicon, manganese, and vanadium steel are being used. Some chrome and chrome-nickel steel have also been tried.

SPRING TROUBLES AND REMEDIES

Usual Spring Troubles. *Lubrication.* The average repair man is likely to have more call to lubricate the leaves of a spring than any other one thing in connection with springs. True, they lose their temper; they sag and show signs of losing their set; plates break in the middle, at the bolt hole, and near the ends of the top plate; and inside plates break in odd places. But more frequently the springs make an annoying noise, a perceptible squeak, because the plates have become dry and need lubricating. When this happens, and the up or down movement of the car rubs the plates over each other, dry metal is forcibly drawn over other dry metal with which it is held in close contact; naturally, a noise occurs.

To lubricate the spring, it is well to construct a spring-leaf spreader. Of course, the job is best done by jacking up the frame, dismounting the spring entirely, taking it apart and greasing each side of each plate thoroughly with a good graphite grease, then

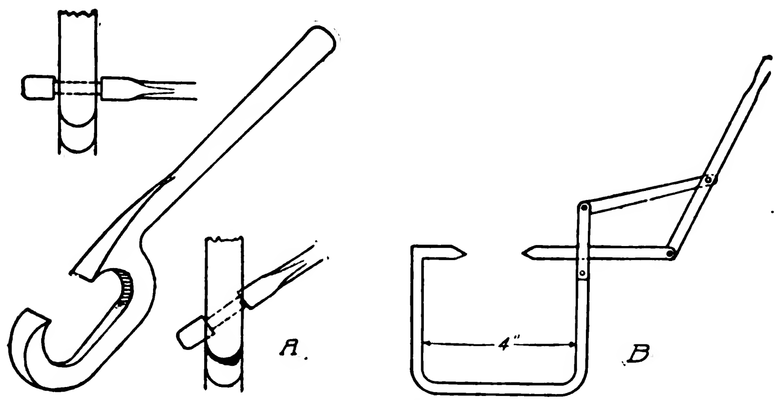


Fig. 417. Handy Tools for Spreading Spring Leaves to Insert Lubricant

reassembling it, and putting it back under the car. This is the best way, but it costs the most, and few people will have it done. Sometimes spring inserts are used; these are thin sheets of metal of the width and length of the spring plates, having holes filled with lubricant over which is a porous membrane.

For the ordinary spreading job, the plates must be pried apart and the grease inserted with a thin blade of steel, for instance, a long-bladed knife. To spread the leaves, jack up the frame so as to take off the load, then insert a thin point and force it between a pair of leaves. In Fig. 417, two forms of tools for making this forcible separation are shown. The first is a solid one-piece forging with the edges hardened. It is used by sliding the edges over the ends of the spring leaf, then giving it a twist to force it in between them, as shown in the figures. The second tool is intended to be forced between two plates by drawing back on the handle.

Tempering or Resetting Springs. When springs lose their temper or require resetting, it is better for the average repair man to take them to a spring maker. Tempering springs is a difficult job, as it requires more than ordinary knowledge of springs, their manufacture, hardening, annealing, etc. When springs are in this condition, they sag down under load and have no resiliency. If a great many springs are handled, a rack like that shown in Fig. 418 is well worth making.

Broken Springs. When springs break, there is but one shop remedy—a new plate or plates. But when they break on the road, it is necessary to get home. When the top plate breaks near the

Fig. 418. Simple and Well-Designed Spring Rack

shackled end, repair this sufficiently to get home by using a flat wide bar with a hole in one end big enough to take the shackle bolt; bolt this bar to the spring in place of the end of the leaf which is broken.

General Hints on Spring Repairs. As a rule, a break in a plate takes place where it does not prevent operating the vehicle, but it should be borne in mind that the damage to the plate subjects the other plates to extra work, and, unless the broken member be properly repaired or replaced, the others are likely to break. If one of the intermediate plates breaks in the center at the bolt, tighten the spring clips as much as possible. Very frequently the rebound clips will be found to be loose, and missing clips also contribute to spring breakage.

The removal of a plate from or addition to a set is very likely to upset the grading of the construction. It is not practical to replace a broken plate with a new one because it is of the same width and thickness, but an expert spring maker should be called in to see that the set, or fit, is correct. The fitting of a leaf requires the services of an expert spring man; while it appears to be a simple matter, the lack of knowledge by some claiming to be spring experts is responsible for breakage after the spring has been repaired. The spring clips and the nut of the center bolt should be kept tight. The importance of preventing the accumulation of rust on the leaves and of lubrication has been commented upon.

SHOCK ABSORBERS

Function. The ordinary flat-leaf springs of any of the types previously described are inadequate for automobile suspensions. When the springs are made sufficiently stiff to carry the load properly over the small inequalities of ordinary roads, they are too stiff to respond readily to the larger bumps. The result is a shock, or jounce, to the passengers. When the springs are made lighter and more flexible in order to minimize the larger shocks, the smaller ones have too large an influence, thus keeping the body and its passengers in motion all the time. These two contradictory conditions have created the field for the shock absorber.

The shock absorber is generally a form of auxiliary spring, the function of which is to absorb the larger shocks, leaving the main springs to carry the ordinary small recoils in the usual manner; in short, to lengthen the period of shock. This is done in a variety of ways, and, as might be expected, by a great variety of devices.

General Classes of Absorbers. The simplest forms of absorbers are the ordinary bumper, or buffer, of rubber and the simple endless belt, or strap, encircling the axle and some part of the frame and acting as the rubber pad does—simply as a buffer. There are the following classes of the more complicated shock-preventing and shock-absorbing devices: (1) frictional-plate or cam, in which the rotation of a pair of flat plates pressed together tightly—one attached to the frame, the other to the axle—opposes any quick movement of the two or of either one relative to the other; (2) a coil spring used alone and in combination—alone it is used in the plane of the coil, or at right angles to it, and parallel to the center line about which the coil is wound, while in combination it is found joined with the simple leather strap or with another coil spring of equal or sometimes of less strength, in the latter case the weaker one acting with the main springs; (3) the flat-leaf spring, a more simple description of which would be a small duplicate of the main semi-elliptic spring set on it so as to oppose its action; (4) the air cushion; and (5) the liquid device, in simple form and in combination with some one or more of the coil-spring forms.

Frictional-Plate Type. A frictional-plate type of shock absorber is shown in Fig. 419. This absorber consists of an upper arm attached to the frame, having at its outer end a frictional plate in contact with a similar plate at the upper and outer end of the other arm pivoted to the axle. The two plates are pressed together by means of the nut shown in the center; this nut is resisted by the spring beneath it and the slightly arched surfaces of the plates. When a sudden bump raises the axle, it must turn the two faces of metal across each other to the limit before it can lift the body. As will be seen, this means a considerable distance, and it can be made relatively greater by clamping the nut up tighter, thus increasing the friction between the surfaces, and, therefore, requiring greater force to turn them. Because of this adjustable quantity of friction, this type is called the governed friction type.

Fig. 419. Hartford Governed Friction Type of Shock Absorber
Courtesy of Hartford Suspension Company, Jersey City, New Jersey

When cams are used, practically the same result is obtained, except that the device is necessarily more complicated. The cam action usually generates some heat, and, for this reason, this form of shock absorber is most always enclosed, and the interior, where the cam works, is filled with grease or very heavy oil.

A modification of the plain frictional-plate form is seen in Fig. 420, which is called a passive range absorber, because, for ordinary movements of the springs to which it is attached, it does not come into action. When the usual spring action is exceeded, however, as in a sharp jounce, the device becomes effective. It appears much like the Hartford just shown, but the construction is decidedly different. The upper, or frame, arm is threaded to receive an Acme-threaded screw, which is carried by the lower, or axle, arm. The action of screwing this out tends to force the plate on the lower arm, which must move outward with the screw against a rubber washer held firmly by the outside nut and cover plate. Thus, the scissors action of the two arms on a sudden movement is resisted by the compression of the rubber washer. This compression can be increased or decreased by tightening or loosening the slotted outside nut, so that the screw is given less or more movement. The rubber washer is made with a series of holes in it to allow of compression.

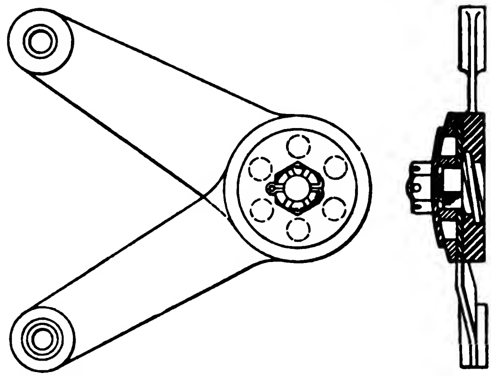


Fig. 420. Laporte Passive Range Friction Type of Shock Absorber
Courtesy of Charles Laporte, Detroit, Michigan

Coil Springs, Alone and in Combinations. *Springs Alone.* The coil-spring absorber is probably the most widely used form, primarily because it is both good and cheap; furthermore, it is simple and adds little weight. In most instances, the coil is so placed as to compress along the direction of its center line. One device, however, the Acme, shown in Fig. 421, works at right angles to this. It consists of a pair of coils, the two ends of each being so constructed as to go on the ends of the shackle bolts in place of the usual shackle. When the shackle is removed, one pair of ends is fastened to the spring in place of the shackle, while the other pair of ends is fixed to the frame

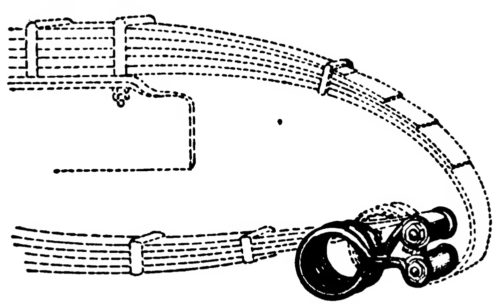


Fig. 421. Acme Torison Spring Fitted to Three-Quarter Elliptic Gears
Courtesy of Acme Torsion Spring Company, Boston, Massachusetts

or the other part of the spring, as the case may be. Note that this arrangement brings one of the coils on either side of the main spring end, extending away from it in a horizontal plane. In this position, the torsion spring acts as a spring shackle, absorbing the jounces and bounces so that they do not reach either the body, the attaching point, or the other half of the spring, as the case may be.

Fig. 422. Sager Equalizing Springs Are Very Simple in Construction
Courtesy of J. H. Sager Company, Rochester, New York

Fig. 422 is a simple coil spring of barrel shape, that is, the end coils are smaller than those in the center and are set between frame and axle in such a way that they absorb the jounces directly. This is probably the simplest possible shock-preventing device, consisting only of the spring and its top frame and bottom axle connections. These are made in four sizes of wire, varying from $\frac{5}{16}$ inch up to $\frac{13}{32}$ inch.

In the K-W road smoother, shown in Fig. 423, the action of the spring is opposed by an air chamber at the top, creating a balance. A shock which causes the spring to move is opposed by the spring itself, while the rebound, or reaction, is opposed by the air compressed in the air chamber.

Fig. 423. K-W Spring Type of Road Smoother

Combinations. Probably exceeded in simplicity only by the two forms just shown is the type in which a coil spring and leather band, or strap, are combined. One of these, the Hoover, is shown in Fig. 424. It will be seen that the spring end is fastened to the body, while the strap is attached to the lower end of the spring and encircles the axle. Hence, this will not interfere with upward movements of the axle, but only with the downward ones, that is, the axle is free to rise, but as soon as the car body starts to rise, the strap-spring combination acts to prevent it. This is particularly true if the axle has reached the limit of its motion and has started downward before the body starts upward. In that case, the body can move upward only the amount of slack in the strap plus the give of the spring, but minus the amount the axle has already moved downward. This inexpensive arrangement has found great favor on small cars.

Fig. 424. Hoover Shock Absorber, a Spring and Strap Combination
Courtesy of H. W. Hoover Company, New Berlin, Ohio

Double-Coil Spring Types. In principle, the use of two springs is not different from the use of one. For structural reasons, however, it is easier to attach the two-spring form, while dividing the load up into two parts allows of the use of smaller diameters and smaller sizes of wire, thus making the device appear more compact. One of the two-spring forms, the J.H.S., is shown in Fig. 425. It consists of a pair of cylinders with coil springs within. The tops of the two cylinders are joined by a pin, and this joining pin is attached to the lower leaf of the spring. Inside the cylinders, pistons are set above each spring, and these are connected, this connection being used for the other half of the spring. At the bottom, the external bands on each of the two cylinders are connected, so as to keep them parallel at all times. Thus any movement upward of the lower part of the

Fig. 425. J.H.S. Shock Absorber Has Twin Springs Encased

main-leaf spring tends to draw the enclosure for both shock-absorbing springs upward. The springs themselves resist this and absorb a large part of the movement both in force and distance.

Flat-Plate Recoil Springs. The third class, or flat-leaf spring, is a semi-elliptic unit in miniature. It is placed upon the top of the ordinary semi-elliptic spring, but it is reversed and has a spacing plate between the two. The object of this plate is to prevent recoil and to eliminate the rebound of the car body without restricting the flexibility of the main springs. As shown in Fig. 426, the Ames equalizing spring is constructed along these lines. As will be noted, this allows all downward movement of the spring, having no influence thereupon; but when the recoil, the upward equal and opposite reaction, comes, the smaller upper spring opposes this reaction and

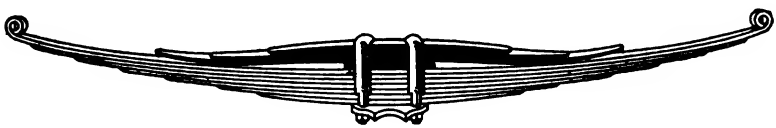


Fig. 426. Ames Equalizing Spring Is a Simple Small Inverted Semi-Elliptic
Courtesy of Clarence N. Peacock and Company, New York City

minimizes it, so that little or none of it reaches the body or the passengers.

Air Cushion. Perhaps the most complicated form of shock absorber—certainly the most expensive and at the same time the most efficient—is the air cushion. This form consists of a pair of telescoping cylinders one being attached to the frame and the other to the spring. When road obstructions cause the spring to rise, it pushes its cylinder upward, but this movement is resisted by the air inside of the cylinders. With the amount of air properly proportioned to the size and weight of the car and its load, all this upward movement will be absorbed and none will reach the body and its occupants.

This rough outline describes the Westinghouse air spring, shown in cross-section in Fig. 427. In order to handle the air pressure and keep the cylinders within the commercial limits, oil also is used in the cylinders. This reduces the volume of contained air; but, for each inch the device is compressed, the air is reduced by a greater percentage of its original volume, consequently the resistance to compression is greater than it would be without the oil.

In the drawing, *A* is the upper section of the cushion chamber, telescoping into the lower section made up of tube *B* and crosshead *E*. The outer tube *C* is simply a guard. A steel casting *D* is bored out to form a guide for the outer tube and crosshead, and has a rectangular pad *F* machined for bolting the whole device to the bracket attached to the frame of the car. A shackle *G* is fastened to the end of the car spring *I* and is pivoted to the crosshead *E*. Packing ring *H* is used to make the inner cylinder a tight fit in the outer casing. A breather *J* is placed on the side, through which air is drawn by the upward movement of tube *B* through the medium of the tightness of packing ring *H*, just mentioned, and this air, on the downward movement, is forced through the passage *K* to a port partly surrounding the tube *B*. There is no packing ring between this tube and its guide *D*, so the air blows out and keeps the contacting surfaces clean. A further protection is afforded by the felt-wiper ring *L*,

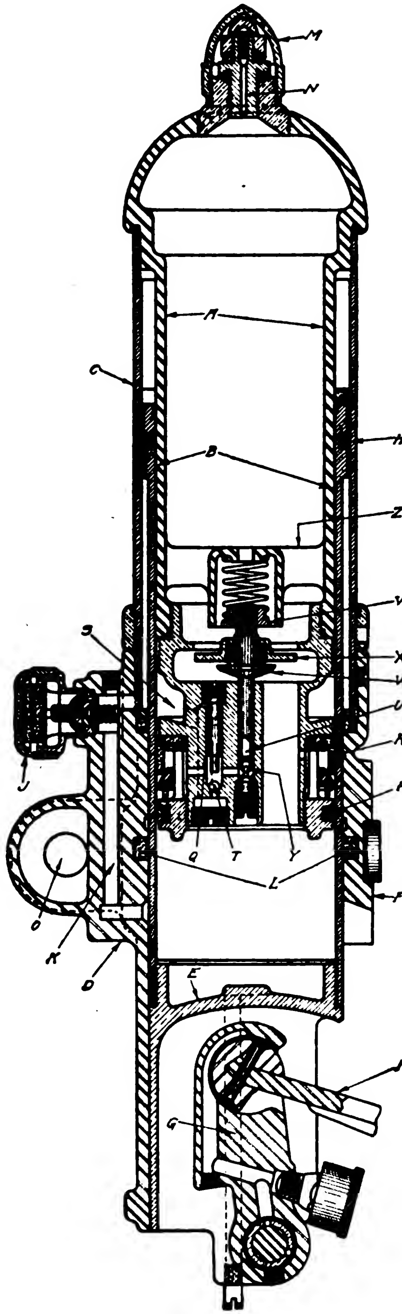


Fig. 427. Section through the Westinghouse Air Spring, Showing Construction and Operation
Courtesy of Westinghouse Air Spring Company, Pittsburgh, Pennsylvania

which retains the grease in the groove just above it. *O* is a rod connecting the two front or rear springs. At the top is the screw cap *M*, covering the air valve *N*, which is designed to be used just as the air valve in a tire.

The lower part of the device is filled with oil up to a level which approximates the line *Z*, all above this level being air under pressure. Consequently, the device actually compresses the air through the medium of the oil, which is incompressible. This oil forms a seal for the air chamber and prevents its leakage, although the oil itself is allowed to leak through, this leakage being pumped back automatically by the action of the springs. This works out as follows:

Fig. 428. Westinghouse Air Springs Applied to the Rear of Pierce Limousine

In what might be called the piston, although it is not, because it does not move—the other parts moving relative to it—there is the plain leather packing ring *P* and the cup leather *R* held out against the sides of the cylinder by the conical ring and spring.

The small amount of oil which does leak past the packing rings *P* and *R* is caught in the annular chamber *S*, whence it flows down through the vertical (dotted) passage *Q* into the chamber just below the ball valve *T*. In the center is a hollow plunger *U* of a single-acting pump. This has two collars on its upper end *V* and *W* and between them a disc *X*. This almost fills the passage just above it. The plunger is held down by the light spiral spring shown pressing on the collar *V*.

When a road obstruction is met and the spring rises, crosshead E rises and the upward movement of the oil takes the disc X upward until it strikes and carries with it collar V, which lifts the plunger and draws in a charge of oil. When the air compressed in the upper chamber of the device expands, and the car spring I and crosshead E go down again, the oil flows in the opposite direction, carries disc X down against collar W, and forces the plunger downward. Then the oil passes the ball check Y, goes through the hollow plunger, and is discharged back into the upper, or air, chamber. In the first place, the oil is put in by taking off cap M and taking out the air valve N. Then a special single-acting oil gun is used to force it in, a long nozzle being necessary to reach down into the interior, with a stop to limit this downward distance. The maker recommends that an excess be put in and then slowly drawn off to the right level.

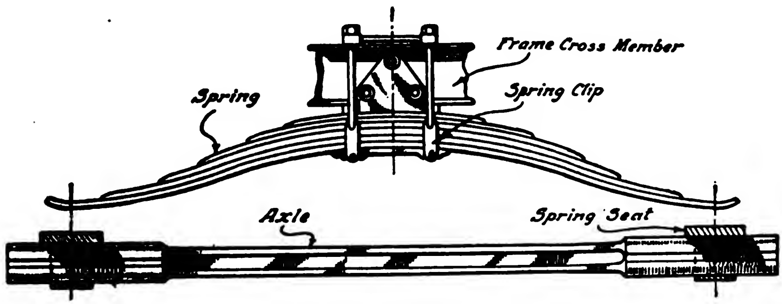


Fig. 429. Typical Semi-Elliptic Overload Spring

As will be seen from the foregoing, this device is essentially an air spring, and the air cushion does the work; but it is the oil below it, with its permissible leakage and with a pump to return this leaking oil, which makes this device practicable. To show the exterior, the part which most persons would see and remember, Fig. 428 is presented. This figure shows the rear end of a Pierce limousine equipped with a pair of the Westinghouse air springs. Note the breather, tie rod, cap at the top, cast guide at the bottom, and other parts previously shown and described.

Hydraulic Suspensions. The majority of the hydraulic devices developed as shock absorbers consist of turning vanes connected to the axle or spring, enclosed in a liquid-tight case filled with some heavy oil. There is a hole of small diameter in the case which connects the two sides of the vane, its motion forcing the fluid through this hole.

Thus the spring action simply pumps the oil from one side of the vane to the other and back again, the resistance to the flow of the liquid past the vanes and through the small hole absorbing all of the shocks.

Overload Springs. Overload springs are utilized with commercial vehicles and may be of either the leaf or coil type, and so arranged as to act only when the load on the main springs reaches a certain weight. The wear plate may be a separate platform, as shown in Fig. 429, or it may be formed integral with the pressure block. Where coil springs are used, they are made of square section, attached either to the frame cross-member or to the axle. Two such springs are used, one on each side. The design in Fig. 429 is a semi-elliptic. It is attached to a frame cross-member, and the ends are free so that they may make connection with a separate spring seat or a pad on the pressure block of the side spring when a predetermined load has been applied. With some trucks the front springs are mounted on a seat forged integral with the axle and are retained by box clips; a coil spring is attached to the pressure block, which acts as a bumper. Under excessive deflections these springs strike the bottom flange of the frame and arrest the rebound motion of the vehicle spring. The Jeffery Quad employs a spring bumper which is made of flat metal and is termed a volute spring. It is attached to a bracket fastened to the pressure block.

SUMMARY OF INSTRUCTIONS

STEERING

Q. Which wheel travels farther on curves and why?

A. The outer wheel must travel much farther on any curve, or turn, because it is turning through an equal angle on a curve of much longer radius. On very short turns, the distance the outer wheel must travel can be more than 50 per cent greater, or longer, than that of the inner.

Q. What general condition exists which makes the problem of steering so complicated to lay out?

A. The answer to the previous question gives an idea of the demands on the steering gear. The difference in the distances which the two wheels must travel on all curves—some differences being as high as 50 per cent, and with the difference shifting from one side to the other—is the general difficulty.

Q. How does the usual steering arrangement care for this?

A. By having the linkage which connects and steers the front wheels arranged so that a prolongation of the center lines of the two steering arms will pass through the center of the rear axle.

Q. How does this solve the difficulty?

A. When this arrangement is used, any swing or turn given to the steering system, say a turn to the right, will swing the left-hand knuckle through a larger angle than the right, although the two are connected together by linkage. This means that the inner, or left, wheel will swing about a shorter radius than the outer, or right, wheel, since if the two were turned through equal angles, the two radii would be equal.

Q. What other items complicate this steering problem?

A. The fact that the wheels themselves must toe in slightly at the front in order to steer easily and hold a straight line when set straight. Furthermore, the wheels must be set with their tops wider apart than their bottoms so that the line through the center of the plane of the wheel strikes the cambered, or raised, road surface at a right angle; this makes the whole situation even worse.

Q. Is the ordinary front axle of such a design that it gives perfect steering?

A. No. But it represents a working approximation which could not be improved upon without many needless complications. On a sharp turn, probably one wheel is dragged around the curve for a small portion of its length, but the distance is so small that it would never be noticed by the eye nor discovered in any difference of life in the tires.

Q. How is the turning of the steering knuckles about their pivots obtained?

A. The swinging movement of the steering knuckles is obtained through a fore-and-aft movement of the steering rod connected up to one of the steering-knuckle arms by a ball joint.

Q. How is this longitudinal movement of the steering rod obtained?

A. By a fore-and-aft swinging of the steering arm attached to the steering gear.

Q. How is this fore-and-aft movement of the steering arm produced?

A. By the partial rotation of the gear within the steering gear itself.

Q. And how is this partial rotation of the gear developed?

A. By the turning of the hand wheel, which turns the worm. The hand wheel is fastened to the upper end of the steering post proper (as distinguished by its stationary brass cover), while the worm is fixed to the lower end of it. Consequently, whenever the hand wheel is turned, the worm must turn also.

Q. Why are the worm and the gear used for steering gears?

A. The worm is used to secure irreversibility, as it is one of the few forms of mechanism which will not transmit power back through the entire group in the reverse direction, that is, it will not allow a movement of the wheels to be transmitted back to the steering wheel against the driver's wishes. In addition, it is compact, noiseless, easy to care for, wears little, and is highly efficient.

Q. What other forms of mechanism are used for steering gears?

A. Bevel gear, screw-and-nut, double screw, worm gear and full gear as distinguished from worm gear and partial gear, spur gear, simple bent lever, and other forms.

Q. What are the disadvantages of these forms?

A. With the exception of the worm and full gear, all are wholly or partially reversible, so if the front wheels strike an obstacle, the shock is transmitted back to the driver's hands.

Q. How are steering wheels made?

A. In various ways. Some are rings of glued-up wood, to the underside of which the arms of the steering-wheel spider are fastened. Others have the arms cast integral with the aluminum rim; still others are of bronze with a molded rubber surface applied to the bronze ring.

Q. Is the wood form, with spider fastened to it, popular?

A. It was, but it is rapidly going out in favor of something better. This construction is now used only on the cheapest cars and not on all of those.

Q. What are the advantages of the hinged, or folding, steering wheel?

A. Folding up the wheel out of the way allows the driver to get out on the lever side of the car, which might be practically impossible otherwise. It allows stout drivers more comfort in getting in and out. It is also an advantage when working in the front compartment of the car.

Q. What is the importance of the cross-rod at the front axle?

A. It is the only member tying the two steering knuckles together. If this rod is bent, the wheels cannot be steered accurately; if it is broken, they cannot be steered at all. In fact, the car cannot be moved forward when the rod is broken.

Q. Why is the rod usually placed behind the front axle?

A. As a protection against damage from high spots in the road. If it is back of the axle, it is well protected; but if the design places the rod in front of the axle, it has no protection, and trouble is likely to ensue on rough roads.

Q. Where is the front end of the steering rod carried?

A. As a similar means of protection, the steering rod is frequently carried over or above the front axle, so that the axle will protect it. Even when the design of axle, steering knuckle, and other parts necessitates this rod being below, it is placed as close as possible to the axle level, so as to get the maximum protection.

Q. What is the function of the steering knuckle?

A. It forms a pivot, or bearing, upon which the front wheel rotates; but, in addition, it forms the basis of steering, being capable of turning about a vertical (or nearly vertical) axis.

Questions for Home Study

1. Describe the complete steering mechanism of the Pierce-Arrow car.
2. Why is it better to steer with the front wheels than with the rear wheels?
3. Tell in detail how a worm and sector mechanism works.
4. Describe the working of a worm and nut device. Is it better than a worm and gear and if so, why?
5. How is the Gemmer steering gear adjusted (a) for wear of the worms; (b) for looseness of the steering wheel? How is it lubricated?
6. Describe the Hindley worm. What are its advantages; disadvantages?
7. Select and describe one form of steering-wheel construction.
8. How would you adjust a steering rod for (a) length; (b) wear?
9. Tell the advantages and disadvantages of the various possible positions for the cross-rod; for the steering rod.

FRONT AXLES

Q. What are the usual front-axle classes?

A. Eliminating freak forms, axles are generally divided into five classes: Elliott; inverted or reversed Elliott; Lemoine; front drive; and fixed axle, or fifth wheel, form.

Q. What is the nature of the Elliott front axle?

A. The Elliott form has the end of the axle in the form of a jaw, or Y, with a bearing above and one below the steering knuckle. The latter fits in between the two parts of the jaw, or Y, and consequently has a single central bearing.

Q. How does the inverted Elliott differ?

A. In the inverted, or reversed, Elliott form, the axle end is made with a single central bearing, while the knuckle takes the form of a jaw, or Y, and has the two bearings, one above and one below the axle end.

Q. Which of these two forms is the better?

A. There is little choice, but what there is seems to favor the Elliott form because it gives a stiffer and better bearing in the axle end, which is generally a good size rigid member. In fact, the axle ends can be made large enough in this form to have ball, roller, or other anti-friction bearings. This is not true with the reversed form.

Q. How is the Lemoine axle constructed?

A. The steering knuckle and its pivot are integral and form a letter **L**. The axle end is plain and forms a single bearing on the upper end of the steering pivot. In the regular Lemoine form, the **L** has its vertical leg extending upwards, and the axle is on top of the knuckle, so to speak. As constructed in United States the vertical leg of the **L** is turned downward, so that the axle is below the knuckle

Q. What are the advantages of this form of construction?

A. Both axle end and knuckle are simplified and can be constructed more cheaply. Moreover, the complete axle can be assembled or disassembled more readily and quickly. Some consider that this type has a nicer, cleaner appearance and thus improves the front of the car.

Q. What is the disadvantage of the Lemoine type?

A. The principal disadvantage of the Lemoine axle, ascom pared with other forms, is the difficulty of suitably handling the bearing loads. The ordinary axle has separate radial-load bearings and thrust washers or thrust bearings. In the Lemoine the axle-end bearing must handle both radial and thrust loads, as well as road shocks.

Q. What are the usual axle materials?

A. Modern practice restricts front axles to hand- and drop-forged steel, to tubular centers with forged ends, and to pressed steel. The latter is little used, however. Cast steel and manganese bronze as well as wood, have been used.

Q. What are the usual axle bearings?

A. Ball, roller, and plain bearings are widely used. For the sake of simplicity and compactness, the steering-pivot bearings are often plain, while the wheel bearings on the knuckle end are about evenly divided between ball and roller. Thrust bearings are about evenly divided between plain steel bearings with bronze washers, on the one hand, and with ball bearings, on the other.

Questions for Home Study

1. Describe a good method of truing front wheels.
2. How would you determine that front wheels were out of alignment?
3. Describe in detail the (a) Overland front-axle; (b) the Christie; (c) the Marmon.
4. How are axles lubricated, with reference to (a) wheel bearings; (b) steering pivots; (c) thrust washers or thrust bearings?
5. What are the disadvantages of cast front axles?
6. Are ball bearings better than roller bearings for front-axle pivots and if so, why?
7. Describe in detail the process of straightening a bent front axle. Would you use a template and if so, why?

FRAMES

Q. What is the need for a frame in an automobile?

A. Every automobile needs a frame, stiff and strong enough to support all the units for power development and use, down to the springs.

Q. Is there any radical difference between pleasure-car and motor-truck frames?

A. None, except that the truck frame must carry a much heavier load and, therefore, needs to be stiffer and stronger and that it must cost less relatively, thus necessitating a form or shape which is cheaper to construct.

Q. What materials are used for frames?

A. Principally steel and wood. Steel is divided into rolled, used mainly for trucks; and pressed, used for pleasure cars and for the smaller trucks, or delivery wagons. Wood is divided into plain straight wood, laminated wood, and wood used as a filler for steel.

Q. Is wood used at all widely?

A. No. With the exception of Franklin, using laminated wood, and of a few light cars and light trucks which have a wood filler inside of a pressed-steel frame, wood is used very little.

Q. Is steel tubing used for frames?

A. Frames are no longer constructed entirely of tubing, although this has been tried, but some designers use tubular cross-members for the support of the engine, the transmission, and other units.

Q. Is structural steel widely used?

A. For pleasure cars very little, if at all; for trucks quite freely, but in gradually decreasing quantity. Frame makers are producing better and cheaper frames of pressed steel each year, gradually eliminating any and all arguments in favor of rolled or structural steel.

Q. What is a frame "kick-up"?

A. When the rear end of a frame otherwise fairly straight and level is bent sharply upwards from two or three to as much as ten inches, beginning just forward of the rear axle and carried out to the rear end of the frame on this higher level, this whole raised rear end is called a kick-up.

Q. What is the purpose of a kick-up?

A. It lowers the central part of the chassis relatively, thus giving a lower step, incidentally lowering the center of gravity and making the car safer. It raises the rear end to give adequate rear springing.

Q. What is the shape of the modern frame, in plan?

A. It is gradually assuming a considerable taper. Originally, the frame formed a rectangle, with straight side members. Then it was found advantageous to narrow the front end to give more room for the front wheels to turn and thus allow a shorter turning radius. As this had the additional effect of shortening the engine-supporting arms, the makers were able to eliminate the sub-frame, with a saving of expense and weight. Finally, the width needed for modern touring car rear seats gradually widened out the rear ends of the frame, while the narrowing at the front became so great as to put a weak spot in the frame where its greater load had to be carried. It then became a logical step to make the frame taper from front to rear continuously, with straight sides. This is the form which all frames are assuming now.

Q. In what other ways do modern frames differ?

A. The rear cross-member is being eliminated very widely, as is also the front cross-member, so the triangular-shaped frame is not closed at either end. Formerly, the depth of the frame was pretty much the same from front to rear, but now this tapers very materially from the front up to the middle and then down again at the rear. A good stiff typical frame would be perhaps $2\frac{1}{2}$ inches to 3 inches deep at the front, 6 inches deep in the middle, and perhaps $2\frac{1}{4}$ inches to $2\frac{3}{4}$ inches deep at the rear. In short, except for perhaps 20 to 24 inches of length right in the middle, the frame depth would differ continuously.

Q. What is the advantage of varying the depth so much?

A. It eliminates every pound of excess weight, putting much metal where there is heavy load and severe stresses and little metal where the load and the stresses are light.

Q. Is this form of construction more expensive?

A. No. The art of pressing the frame out of sheet steel has been developed through large quantity production to such an extent that a frame of this type, with a constantly varying depth, costs no more than a straight frame cost four years ago.

Q. Does this form give the repair man more to do?

A. No. On the contrary, frames give less trouble in the way of sagging, breaking, or cracking than ever before. The frame troubles of today are mainly due to poor or light design, in an effort to lower weight too far, or to accidents.

Q. What has been the effect of cantilever springs on frames?

A. One effect of cantilever springs for rear use has been to eliminate the rear cross-member, as spoken of previously. Another effect has been to continue the deepest section back quite a few inches to the point of support of the front end of the cantilever.

Q. Is the trussed, or latticed, frame widely used?

A. No. Only by one or two makers, although a few heavy cars have a truss rod below the main frame to add stiffness and strength. The trussed, or latticed, frame is a new departure in frame design.

Q. What are the noticeable tendencies in frame construction, other than those already mentioned?

A. The use of heavier frames, that is, heavier sections of metal, deeper side members, and general stiffening is being accomplished without much gain in weight, owing to the better distribution of the metal. The combination of other units, as steps, step supports, and fenders with the frame is being worked out, this being one of the tendencies in construction. The general carrying of spare tires at the rear is having an influence, but there seems quite a tendency to construct the body so as to enclose the tires, which, if carried out, would change this.

Questions for Home Study

1. How would you repair a sagged frame, if sagged at (a) front end; (b) center; (c) rear end; (d) cross-member?
2. Describe the method of welding a cracked frame by the oxy-acetylene process.
3. Describe the following frames in detail (a) Stearns-Knight; (b) Marmon; (c) Fergus.
4. How is the Franklin wood frame built up?
5. How is what is called an "armored frame" made?
6. Tell how to remove and replace an underpan.
7. What material is usually used (a) for a truck frame; (b) for a light pleasure car; (c) for a heavy touring car?
8. Give the advantages and disadvantages of pressed steel for frames.

SPRINGS AND SHOCK ABSORBERS

Q. What is the need for vehicle springs?

A. To support the load in a flexible manner so that the jolts and jars of the road will not be transmitted to the passengers or load. In addition, a flexible connection between the power plant and the road wheels is needed.

Q. How many recognized different types of spring are in use?

A. Seven; all of which are made and used in all sizes and qualities for all kinds of load.

Q. What are these seven types?

A. The semi-elliptic, the full elliptic, the three-quarter elliptic, the platform, the cantilever, the quarter elliptic (or half semi-elliptic, as it is sometimes called), and the coil. All but the last three also are made with scroll ends, which alters the general appearance without altering the type of action.

Q. What is the shape of the semi-elliptic?

A. This form has a slight bow upwards, the two ends being slightly higher than the middle. The middle is attached to the axle and the ends to the frame, and when load is applied, these ends come down, flattening the spring so that it approaches a straight line.

Q. Describe the full-elliptic spring.

A. This form has the shape of two semi-elliptics, one inverted and set on top of the other. This gives it the appearance of an elongated letter **O** with points at the ends. The lower half is attached to the axle and the upper half to the frame, and loading tends to bring the two halves closer together, flattening the **O** still farther.

Q. What is the form of the three-quarter elliptic spring?

A. This consists of a flat lower semi-elliptic member and a highly curved quarter-elliptic upper member, the two being joined by means of a shackle. With the exception of the difference in curvature of the two parts and the use of the shackle to join them, this has the appearance of a full elliptic with the upper forward quarter cut away. When loaded, both members give slightly, the upper quarter more than the lower half. · The shackle gives a considerable difference in this action from that of the full-elliptic.

Q. What is the platform spring like?

A. This spring consists of three semi-elliptics joined together at the ends so as to form three sides of a rectangle. The two sides are fastened, respectively, to the axle at the middle of each, to the frame at their front ends, and to the third spring at the rear ends. The rear spring is inverted and its center is fastened to the center of the rear end of the frame, while its ends are shackled to the rear ends of the two side springs. This makes a combination in which the normal semi-elliptic spring action is modified somewhat by the inversion of the rear cross-member and by the use of shackles at the ends of all three. While popular three or four years ago, it is now going out in favor of the three-quarter elliptic.

Q. What is the cantilever spring like?

A. It consists of an inverted semi-elliptic fixed or shackled to the outside of the frame at the front end, hinged or pivoted slightly forward of its center to the outside of the frame, and having its rear end attached to the upper or lower surface of the rear axle. It is used in greater lengths than any other form of spring and is very popular.

It is the most simple spring now in use and is said to give the easier riding of all.

Q. What is the quarter-elliptic spring like?

A. This is simply what its name indicates, one-half of a semi-elliptic or one-quarter of a full-elliptic. Its front end is fixed to the frame outside, and the rear end is shackled or allowed to slide on the rear axle. It is generally inverted. In reality, it is a cheap substitute for the cantilever or inverted semi-elliptic, this use being allowable because of the light weight of both car and load.

Q. Is this used in any different way?

A. Sometimes a pair of these is used, one above the other, with the idea of doubling the resistance or rather of giving equal resilience with but half the movement.

Q. What is meant by underslinging?

A. When this refers to frame, the entire frame is placed below the springs. This has gone out of use. When referring to springs, this means placing the spring below its support, as below the rear axle. This construction lowers the frame and center of gravity by the thickness of the spring plus its seat plus the diameter of the rear axle, sometimes amounting to a total of five inches. It is growing rapidly in popularity.

Q. What is the purpose of a shock absorber?

A. To absorb the small vibrations while the spring cares for the large ones. It generally takes the form of any auxiliary spring or friction device.

Q. What are the general classes of shock absorber?

A. Coil spring, flat-plate spring, friction plates, compressed air, and a few hydraulic (or liquid) forms.

Questions for Home Study

1. How are springs lubricated (a) as to leaves; (b) as to shackles?
2. How are the spring leaves separated for lubrication?
3. Describe a method of getting home with a broken rear spring.
4. Why do racing cars have their springs wound with rope or cloth?
5. Describe the following car springs in detail: King; Winton; Ford.
6. How do electric car springs differ from those of gasoline cars?
7. What are the standard spring-plate widths?

SECTIONAL VIEW OF PACKARD "TWIN SIX", SHOWING POWER UNIT AND TRANSMISSION TO REAR AXLE

Courtesy of Packard Motor Car Company, Detroit, Michigan

GASOLINE AUTOMOBILES

PART VI

FINAL-DRIVE GROUP

REAR AXLES

TRANSMISSION

Units in the Final Drive. Generally speaking, the transmission is located in the middle or forward end of the chassis. When this is the case, the final drive begins right at the rear end of the transmission. The units back of the transmission, then, would be a universal joint; a driving shaft; possibly another universal joint; the final gear reduction; rear-axle shafts and enclosure; the differential; the torque rod, or tube, or substitute for it; the wheels; the brakes; the tires; and other smaller units.

Even when the transmission is placed on the rear axle, this general layout is changed little, and the transmission, which has been covered in detail previously, is not considered again. In the case of a chain drive, which is still used on one pleasure car or perhaps two, on a number of small trucks, and on a large number of large trucks, this layout is changed considerably. In the large trucks, the transmission in perhaps 90 per cent of all cases would be in a unit with the jack-shaft, which means that for consideration in the final-drive group there would be only the driving shaft to the transmission; the joint or joints in it, if any; the chains and the method of adjusting them; the rear axle and wheels; the brakes; the differential, of necessity becoming a part of the transmission; and the jackshafts.

To make this clear and point out the various units, it will be noted in Fig. 430 that it is a unit power plant. Directly back of the transmission is the first universal joint, driving through the hollow propeller shaft to the rear axle, in front of which is the second universal joint. The rear-axle group includes the axle shafts, differential gears, final gear reduction, gear housing, and the wheels. The torque reaction of the drive, to be explained later, is taken by the torque rod, marked in the drawing, which connects the rear axle to the under

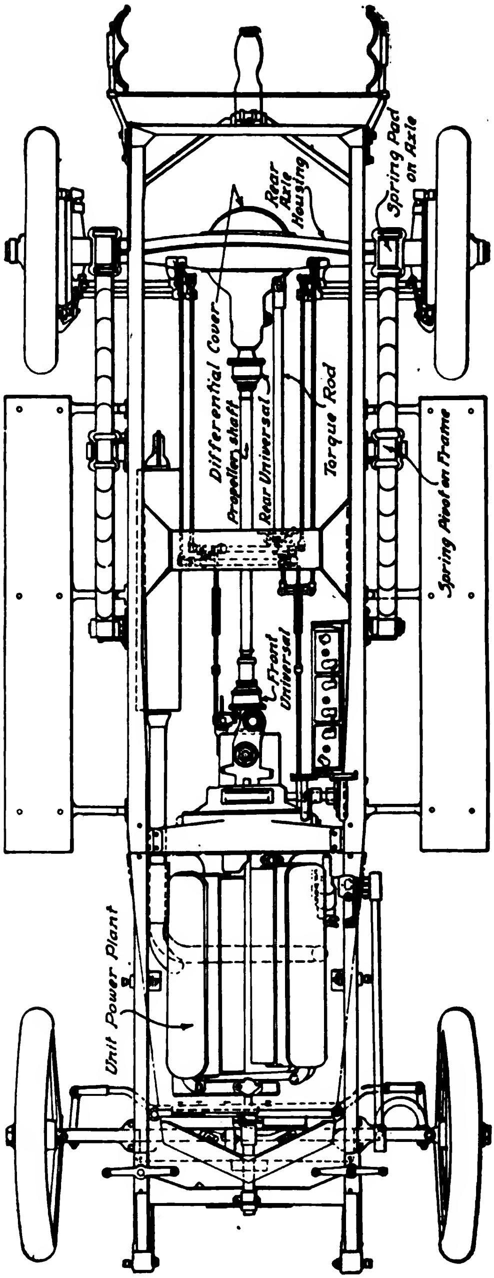


Fig. 430. Layout of Units in Final-Drive Group
Courtesy of Federated Motors Company, Indianapolis, Indiana

side of the stout frame cross-member in front of the axle.

Universal Joints. The purpose of taking up the universal joints—it can be seen from the drawing—is to show how the rear axle rises and falls or moves sidewise in either direction without making any difference in the transmission of power to the axle. When joints are used at other points, the purpose is generally to take care of any lack of alignment, but here the purpose is to transmit power at an angle.

The transmission of power at an angle is effected by constructing the joint so that it can work at any angle. Usually, this is done by constructing the central member in the shape of a cross, with four projecting arms or pins, all in the same plane. The ends of the two shafts are made in the form of forks, or Y's, and are set at right angles to each other, that is, the forks are laid in planes which are at right angles. The fork on one shaft is fastened to a pair of diametrically opposite pins, while the fork on the other shaft is fastened to the other pair of diametrically opposite pins. Each shaft is able to turn on its pins about a line through the center of both. As these two lines are in planes which are at right angles to one another, but intersect at a common center, movement is possible in either plane, or by combination movements of both, in any direction.

Slip Joints. In many situations, a real universal joint is not needed, since the parts are not actually free to move in all directions; but what is needed is slight freedom up and down or sidewise combined with possible fore-and-aft movement. In such cases a slip is used, the name giving the idea of a joint which allows one shaft to slip, or slide, inside the other. The general construction of slip joints varies. Sometimes a round gear is fastened to the end of one shaft; this gear has a fairly large diameter and many teeth, with the teeth chamfered to an unusual extent—almost rounded, in fact. An internal gear of the same size and number of teeth with similarly rounded profiles is meshed with the hollow gear of the other shaft. Both gears have unusually wide faces. This combination gives an action that is almost universal, and also allows lateral sliding of perhaps ½ inch.

The second form of slip joint consists of a squared shaft and square enclosure. The end of the shaft has a member split along a central line attached to it; the exterior approximates a round of large diameter, but the interior is machined to a perfect square, one-half in each part of the split member. Attached to the end of the other shaft is a member machined to an exact square, but slightly rounded in a fore-and-aft direction. The square will drive, no matter in what part of the housing it is located, so that considerable fore-and-aft sliding is possible. In addition, the rounded surface of the square gives an approximate universal effect. The split housing is used to make assembling and disassembling easier and much quicker. Sometimes such a housing is put on the end of each shaft, the connecting member being made in the form of a dumb bell, but with two square ends—one to work in each squared-out housing. In this way the effect of a full universal joint with the fore-and-aft sliding is obtained at less cost, and with easier assembling and disassembling as extra advantages.

Occasionally a square joint is constructed as simple and small as possible, in which case the housing is not split and the shaft end is not rounded. This gives a simple square which drives through a simple squared-out hole. In this case there is no universal action, but simply lateral or sliding freedom.

Other Flexible Joints. To get away from the complication of the universal joint and yet give practically the same results, many other forms have been produced. A very thin disc of tempered steel, with the two shafts bolted to the two opposite sides of it, has been used. The metal will bend and give enough to allow considerable angle of drive. Later forms of the same joint use leather in several thicknesses, the leather being bolted up to the two shafts in the same way. A joint of this kind, consisting of several layers of fabric which have been fastened together in laminations until a disc of fair thickness, say ½ to ¾ inch, has been built up, is shown in Fig. 431. Then the leather is cut round and drilled for the bolts. In this form, six bolts is the preferred number, three for each shaft end; they are in a three-armed spider fastened to the end of each shaft, as the figure shows. These newer forms are usually convenient for the repair man, for they allow breaking into the main shaft by the simple removal of the three bolts (or two as the case may be). By taking out the bolts at each end of such a shaft, the shaft itself can be removed, leaving the other units in the chassis ready for immediate removal, according to the needs of the repair job.

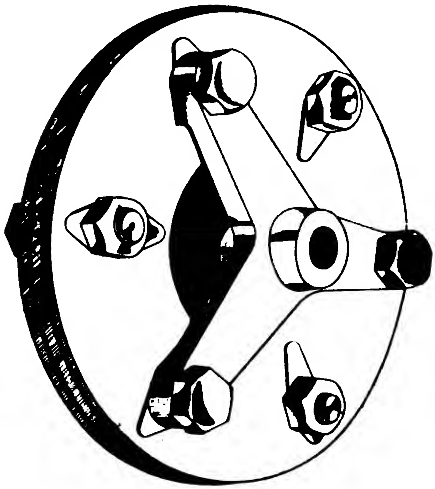


Fig. 431. Laminated Discs Forming Flexible Shaft Coupling
Courtesy of Thermoid Rubber Company, Trenton, New Jersey

Types. Possible types of final drive, from the gear box to the rear axle and the driving wheels or from the motor to the gear box—in case this is mounted on the rear axle, as is not uncommon practice—are practically limited, in cars of sound design, to shaft and double-chain constructions.

Shaft Drive. In its usual form, shaft driving in an automobile involves simply a propeller shaft interposed between the rear axle and a revolving shaft in the car above the spring action. There is some provision for taking the torque of the shaft and of the axle so that they shall maintain their proper relative positions.

In Fig. 432, a typical short driving shaft with its two universal joints is shown. This is such a shaft as would be used in the car shown in Fig. 430, except that the latter is a long wheel-base car with its transmission in a unit with the motor and clutch and thus, far forward. This combination necessitates a very long propeller shaft. The one shown is actually from a car having a short wheel base, with the transmission located amidships. This is a combination which calls for a fairly short propeller shaft.

The short shaft, shown in the figure, is a solid shaft. The modern tendency toward lighter weights is being worked out in the case of

Fig. 432. Ordinary Driving Shaft of Solid Form with Two Universal Joints

propeller shafts, and many are now made hollow. By making the diameter slightly larger and having a large central hole, unusually light weight is obtained with all the strength of the solid form. In addition, the larger diameter hollow shaft has more rigidity than the small diameter solid form, and in many of the modern cars without torque or radius rods, unusual rigidity of the driving shaft is necessary. Other forms have been used for the driving shaft, but they come more or less in the freak class. About two years ago, a car was brought out with a spring, or flexible, shaft, which consisted of a rectangular member of considerable height, but fairly thin. The idea was not only to transmit the power of the engine, but to do it in a flexible manner, that is, the shaft was supposed to absorb all the sudden changes, such as quick acceleration or quick braking. At the same time, one of the electric-car makers brought out a chassis with a square driving shaft of very small size. This served the same purpose as the flexible shaft only in a different way; its two ends, setting in square holes. formed two sliding joints without further machining.

Fig. 433. Ford Final Drive, Differential, and Axles

Fig. 434. Worm and Gear for Rear Axle, Showing Upper Position of Worm
Courtesy of Timken-Detroit Axle Company, Detroit, Michigan

An objection to the shaft type of drive is that the reaction of the revolving shaft tends to tilt the whole car on its springs in a direction opposite to that in which the shaft is turning. In some cars, this is counteracted by the use of slightly heavier springs on one side. The advantages of the shaft drive are the complete enclosure of all working elements, with their consequent protection from dirt and the assurance of their proper lubrication.

The final drive of the Ford automobile, in which the end of the propeller shaft is shown at *A*, together with the bearings in which it revolves, the pinion by which it drives the car, the axle, the differential, and the bearings of the floating inner elements of the axle is illustrated in Fig. 433.

The shaft drive does not necessarily include the use of bevel gears for the final reduction at the rear axle; in fact, almost any form of gears may be used. In one well-known shaft-driven commercial car, the final gears consist of a pair of plain spur gears, while on the shaft of the second of these gears is a pair of bevels.

Fig. 435. Spiral Bevel Gears—a New Noiseless Type for Rear Axles
Courtesy of Timken-Detroit Axle Company, Detroit, Michigan

As soon as the bevel gear final reduction disclosed its limitations and disadvantages, designers started to displace it. One of the earliest forms of gear used for this purpose was the worm, an example of which can be seen in Fig. 434. This figure shows the worm placed above the wheel, but the lower position, which is also used, has the advantage of copious lubrication. In the form shown, the wheel must come directly beneath the worm so that the differential may be set inside of it.

The worm is usually more suitable for slower moving vehicles which have a large reduction of speed between engine and rear wheels, that is to say, it is peculiarly fitted to electrics and motor trucks of all sizes, on which it is finding wider and wider use. On pleasure cars of the average size and type where a speed as high as 50 m.p.h. or higher is expected by all concerned, it has not been found suitable and consequently is not being used.

A later form, which is designed to replace the straight bevel, is the spiral bevel. This is primarily a bevel gear with spiral teeth, the

Fig. 436. Typical Roller Chain

idea being to incorporate in the bevel gear the advantages of the spirally shaped worm tooth, without its disadvantages. As Fig. 435 shows, this makes a very compact and neat arrangement, the differential fitting within the larger gear in the same manner as with the worm.

Double-Chain Drive. The use of double chains, by which the driving wheels of an automobile are driven from a countershaft across the frame of the machine, is a practice possessing a number of advantages. But because of the noise and quick wear with badly

Fig. 437. Typical Silent Chain

designed chain drives and the difficulties of completely enclosing the driving mechanism, chains are not now as popular as formerly. Nevertheless, the elimination of universal joints working through large angles and under heavy loads, the avoidance of heavy weights carried on rear axles without spring support, the lowering of the clearance by the differential housings, etc., are very real objections that the double chain avoids.

For trucking and other heavy service, chains are still commonly in use, and it is the belief of many that a better understanding of their merits and the means of securing these merits in positive and permanent form will result in their more general use.

A typical roller chain of the type most used for automobile drives is illustrated in Fig. 436.

Silent chains, of the types illustrated in Figs. 437 and 438, possess certain points of superiority over roller chains and are therefore coming increasingly into use for camshaft drives, in gear boxes, etc., and there is some possibility that they will find more extensive application to final drives than at present.

The action of a silent chain is illustrated in Fig. 438, in which it is seen that as the chain links enter the sprocket teeth the chain teeth at the same time close together and settle in the sprocket with

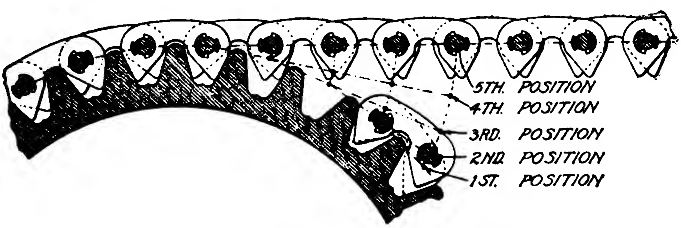


Fig. 438. Action of Silent Chain and Sprockets

a wedging action that causes them to be absolutely tight, but without any more binding than there is backlash.

To keep silent chains from coming off sidewise from the sprockets over which they run, it is customary to make the side links of deeper section than the center links, as is illustrated in Fig. 437. Another successful scheme is grooving the sprocket to receive a row of special center links in the chain, which are made deeper than the standard links.

At present, only one American pleasure car, the Metz, has final drive by means of silent chains. This is a small car with a friction transmission, the drive from the ends of the cross-shaft being by enclosed silent chain to each rear wheel.

Torque Bar and Its Function. It is a well-known fact that action and reaction are equal and opposite in direction, so that if a gear is turned forcibly in one direction, say clockwise, there is a reaction in the opposite direction, or counter-clockwise. This is the simple basic reason for a torque bar, or torque rod, on an automobile. It is needed with any form of final drive, but it takes different forms, according to the type of gear used. The bevel and spiral bevel used on 88 per cent of the 1917 cars are explained in detail as follows: Fig. 439 shows the rear end of a typical pleasure-car chassis. The engine is rotating clockwise, and so is the driving shaft *A*, as shown by the arrow. The shaft turns the pinion *B* in a clockwise direction, which rotates the large bevel *C* so that its top turns toward the front of the car. The bevel *C* turns the rear axle *D* and the rear wheels (not shown) in the same direction; so the car moves forward.

In addition to the gear *C* and shaft *D* turning easily in the axle housing *E*, there is an equal and opposite reaction which tends to keep them stationary, while the bevel pinion *B* and driving shaft *A* tend to rotate around the rear axle as a center in a counter-clockwise direc-

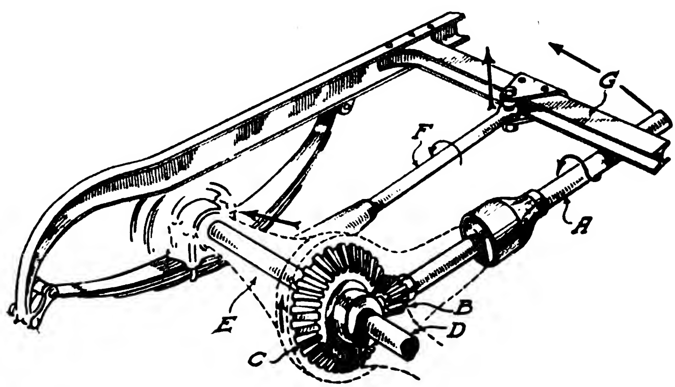


Fig. 439. Diagram to Show What Torque Is and Why Torque Rods are Necessary

tion, as shown by the diagram. If the rear axle were held firmly so it could not rotate, and there was nothing to restrain the bevel pinion and shaft, this could easily happen. However, since we do not wish this to happen, a means is provided to oppose this action and prevent it from happening. Since the turning force which makes the shaft rotate is called the torque, this rod, bar, or tube, whatever its form, is called the torque member.

In the sketch, the torque member is marked *F* and is attached to the frame cross-member *G*, between a pair of springs, so as to cushion the shocks of sudden car or shaft movements. The force on this is the force which tends to rotate the driving shaft and pinion counter-clockwise, so that it works upward, as shown by the arrow. The frame prevents this and absorbs the force.

Driving Reaction. As has been stated, the power, or torque, of the motor is used to rotate the rear wheels. These stick to the pavement or road surface, so the car is really pushed forward. Since it is this pushing action which really moves the car forward, it is very interesting to note how this push is transmitted from the wheels and rear axle to which they are attached to the frame which carries the body and passenger load.

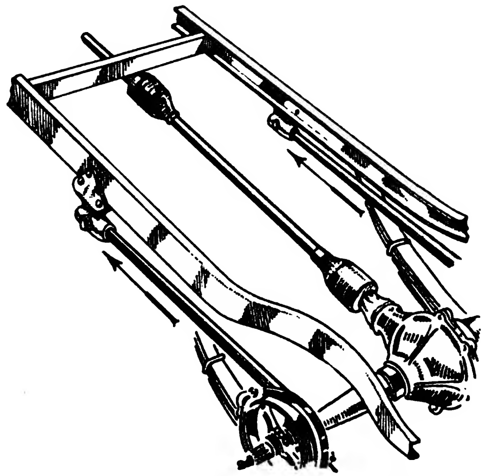


Fig. 440. Diagram to Explain Driving Reactions Using Radius Rods

The transmission of the drive to the body is accomplished in one of three ways. The first form was the so-called radius, or distance, rod, which the shaft-driven car inherited from the chain-driven form. In the chain drive, these rods were a necessity and served a double purpose; they kept the driving and driven sprockets the proper "distance" apart for correct chain driving (hence their name "distance" rods), and they also transmitted the drive back to the frame. On the shaft-driven car, the distance function is not needed, so they are called radius rods. As shown in Fig. 440, they transmit the drive forward to the frame, thus propelling the car in the direction of the arrow, and they also keep the rear axle in its correct position.

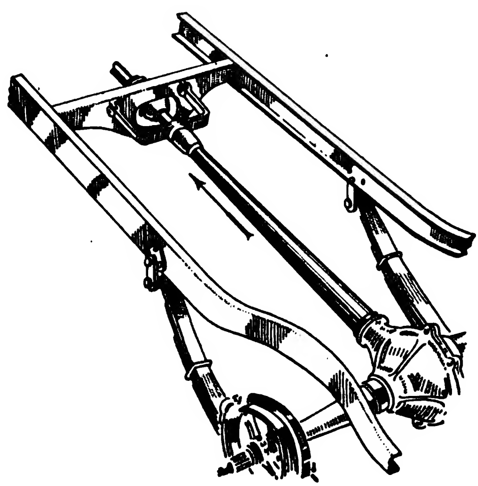


Fig. 441. Layout of Driving Reaction Using Torque Tube around Shaft

In lightening and simplifying the shaft-driven car, designers figured that three members for the torque and driving reactions were too many; so a design was worked out in which all three were combined into one, which is a form of tube surrounding the shaft. This made the member light but strong, and simplified the whole rear end. As shown in Fig. 441, the tube has forked ends at the front, which are connected to the frame cross-member in such a way as to absorb the torque reaction and also to transmit the drive. The method has the further advantage of needing but one universal joint, and that at the front end. Furthermore, it gives a correct radius of rise and fall for the rear axle, since the center of the combined torque and drive member is also the center of the universal joint in the driving shaft. In the form shown in Fig. 339 (radius rods not shown), the two different centers will be noted, the torque rod giving a greater radius than the shaft. Similarly, in Fig. 440 (where the torque rod is omitted for clearness), the rods give a longer radius of rear-axle movement than the shaft, which has a joint close to the axle.

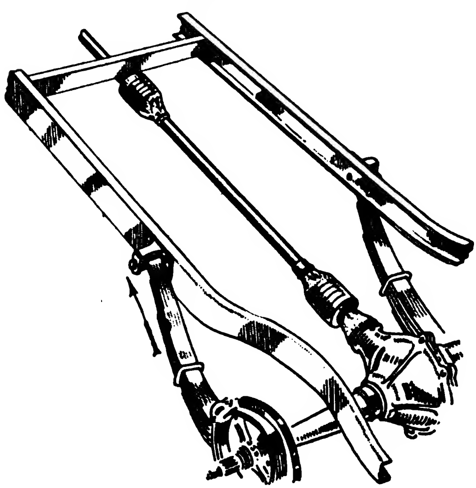


Fig. 442. Arrangement of Driving Reaction When Hotchkiss Drive is Used

It will be noted that both these methods allow complete freedom of the rear springs, which may be of any form, and shackled at the front end if desired by the designer. In its newest and simplest form, the so-called Hotchkiss, or spring, drive has both the radius and torque rods omitted, the springs being forced to transmit both forces, as shown in Fig 442. In this case, the forward end of the rear spring must act as a rod, or lever, instead of as a spring, and must be fairly straight and stiff without a shackle, but firmly pivoted on the frame. In addition, the shaft must have two universal joints, as shown.

It must be stated, as a simple fact, that this last form is increasing rapidly and at the expense of the other two. On smaller lighter cars it is gradually replacing all other forms. It has the advantages of minimum weight and fewer parts, and applies the driving force in a direct line to the frame, the same as the two radius rods do. On the other hand, it makes the springs serve a triple purpose, the demands on these for torque and drive transmission and absorption being such that the spring flexibility must be negligible, which makes the car ride hard. In addition, making the springs handle the three widely different actions puts additional stresses upon them, so that they are more likely to break. On the medium size and larger heavier cars, this construction is not gaining so rapidly.

TYPES OF REAR AXLES

Classification. Rear axles may be divided into the following classes, distinguished according to the method of carrying the load and taking the drive: the form in which the axle carries both load and drive; the semi-floating form, carrying the drive and a small part of the load, the axle shafts not being removable without removing the wheels; three-quarter floating form, carrying the drive and a small part of the load, the latter being divided between the shaft and its housing, but with the shafts removable; seven-eighths floating form, carrying the drive but not the load, the arrangement of bearings to take the load being such that the wheel hubs do not rest wholly and solely upon the axle-casing end; the full floating form, in which the shaft does nothing but drive, and is removable at will without disturbing the wheel and wheel weight resting on the axle-casing end, which is prolonged for this purpose.

The seven-eighths floating type has been developed to meet the need which arose for a floating construction, in which the axle casing did not pass entirely through the wheel hubs. With the full floating form, any accident to the wheel, in which it was struck from the side, also damaged the casing, or tube, end. The result of this in nine cases out of ten was to make the removal of the wheel impossible, because the tube end, which projected through, was bent over. Moreover, repairing in such a situation called for a new axle casing —a very expensive proposition. Consequently, the seven-eighths floating form was developed to present all the advantages of the full floating form, with this serious drawback eliminated by a rearrangement of the parts which did not necessitate prolonging the axle through the wheel hubs. Despite the facts, it did not gain as rapidly as the other floating forms, and now is almost out of use.

The three diagrams in Fig. 443 explain the types as well as words can. At the top is shown the full floating axle, the best but most expensive form. In the middle, the semi-floating axle, which makes the axle shaft do all the work—carrying load as well as transmitting power—is shown. At the bottom is the three-quarter floating form, which is really a combination of the other two forms and possesses a maximum of advantages with a minimum cost. The car weight is carried on the tubing, while the shaft drives and carries a portion of the side stresses to which the wheels are subjected, the quantity depending upon the construction of the bearings.

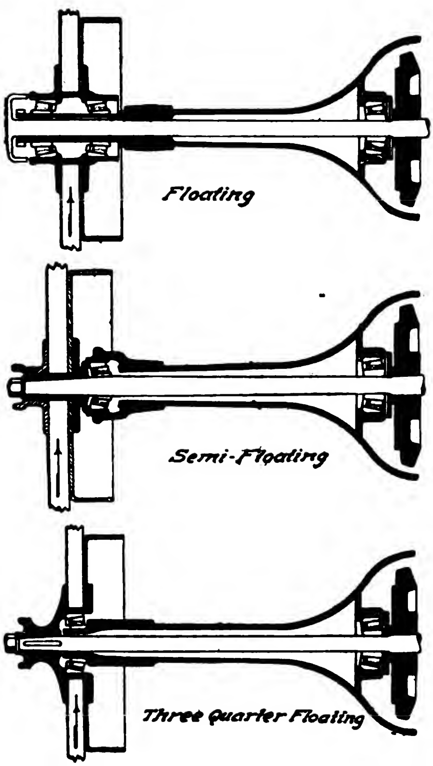


Fig. 443. Arrangement of Axle Bearings and Housing in Three Principal Forms of Rear Axle

Of the 1917 cars, practically 30 per cent (29.5) have the three-quarter floating rear axle, 25.5 per cent the semi-floating form, and 43.5 per cent the full floating form. In 1916, however, the three-quarter form was used in but 22.8 per cent, and in 1915 in only 18.5 per cent of the cars. These figures show how the three-quarter floating axle has been gaining constantly at the expense mostly of the floating form, the semi-floating form practically standing still for three years.

Axle Carrying Load and Drive. The type in which the axle carried both load and drive was a peculiar one and did not last long. In this form, the rear-axle shafts were exposed and carried the weight of the load at the spring seats, which were bushed to allow the shafts to turn within them. This made a place which was hard to lubricate, and yet which was down in the dust and dirt, so that lubrication was a great necessity. All these causes, coupled with the fact that the axle carried both load and drive, caused its disuse.

Dropped Rear Axle of Full Floating Type. The dropped type of axle is not much used at present for cars of the shaft-driven type, the dropped part of the axle bed being used to hold the rearward-placed transmission. Fig. 444 shows a former American type, in

Fig. 444. Rear Construction Embodying Dropped Type of Rear Axle

which the weight of the car as well as the weight of the load is carried on the I-section drop-forged rear axle, while the drive is transmitted from the transmission by the usual shafts, which carry no load. The cut shows the complete assembly above and the dropped axle below. The round ends of the I-beam axle are hollow, carrying the driving shaft through the central hole and the wheels on bearings which fit over the outside. The wheels will revolve on the bearings, even if the inner shafts and transmission be removed from the chassis.

Despite its manifold advantages, the expense of constructing an axle of this type—it is practically the same as that of two ordinary axles, making the total cost double that of any other form—has worked to prevent its general use. In fact, it is not now in use in this country, as the maker has gone out of business.

A prominent French constructor, De Dion, utilizes a dropped rear axle, but, in this, the differential casing and gearing are suspended from the frame and drive down to the axle shaft by means of a pair of short inclined shafts with two universal joints in each, that is, the drive from the differential to the two wheels contains four universal joints. The inevitable loss due to the necessarily short inclined shafts and to the two joints in each has deterred other manufacturers from

Fig. 445. Typical Ball-Bearing Differential

using this form, although a few makers—notably the Peerless Company—have inserted a pair of joints in the rear axle in order to give the rear wheels the same camber as the front wheels. As this necessitates inclined shafts, the joints are needed to connect the horizontal center part with the inclined ends.

Clutch Forms in Semi-, Three-Quarter, and Full Floating Types. The main point of difference in the various semi-, three-quarter, and full floating axles, aside from the principle of design which makes them decidedly different, is the clutch, by means of which the wheel is driven. In some cases, this clutch takes the form of a gear, with straight sides and external notches, or jaws, to correspond with the teeth, but usually it is more of a claw type, the driving ends projecting inward from the point of attachment to the axle shaft. Another notable point of difference—and one which makes a huge difference in the cost —lies in the machining of these jaws, whether they are attached to the axle or machined up with it in one piece. The latter is considered better and stronger in every way, but, as it is much more expensive, it is used only on the best cars.

The driving clutch takes various forms, one of which is shown in the Studebaker axle, Fig. 445. In this type, the axle is a square rod acting within a square hole in the hubs. In the small detail at the upper left-hand corner the letter *A* shows the square upon which the driving clutch is slipped. The spaces at the inner ends of this indicate the clutches, or jaws, which mesh with corresponding slots on the wheel hub and thus do the driving.

Fig. 446. Rear Axle, Showing Wheels Driven by Spur Gears

The dropped type of axles are neither all shaft-driven nor all chain driven. Fig. 446 shows one that is of the spur-gear driven type. The dropped axle bed *C* is of tubular form, and the differential case is dropped down on and slightly back of the rear axle, as at *B*. From this case, two shafts *A A* extend out to the sides, driving the wheels through the medium of the spur gear *D*, which meshes with internal gears within the wheel hubs (not shown). This type of rear axle and drive is used on a number of the Fifth Avenue stages in New York City.

Internal-Gear Drive for Trucks. The spur-gear driven type just described is gaining rapidly for motor-truck use, because it has a number of important advantages. Besides carrying the heavy load on a member able to withstand any amount of overload, it materially lightens the power-transmitting portion of the axle, which is enclosed and therefore quiet. It is simple and inexpensive to construct and repair. Fig. 447 shows a section through one of these axles, which is used on a very light truck of ¾-ton capacity. In this figure, it will be noted that the load-carrying axle is behind the power-transmitting shafts, consequently the former is straight. In Fig. 446, the load carrying axle is in front and consequently must be bent down at the center. This bend is a source of weakness.

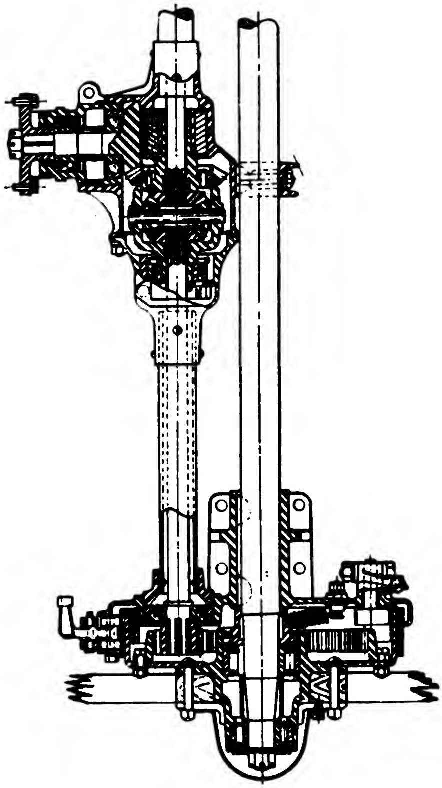


Fig. 447. Sectional Drawing through Internal-Gear Drive Axle of Three-Quarter Ton Capacity
Courtesy of Russell Motor Axle Company, Detroit, Michigan

Full Floating Axle. Fig. 448 shows a full floating axle, with the ends of the driving shafts projecting beyond the housing and carrying five jaws which mesh with five similar ones in the wheel hubs and thus drive the wheels. Unless the jaw end is welded on to the shaft, this makes a very expensive axle despite its many good points. Fig. 449 shows the rear construction of a car with full floating axle, with the brace below it for the purpose of strengthening the whole construction. The large diameter brake drums, shown close to the wheels, are made of pressed steel and are united to the axle tubing, which is also united to the differential housing, so that the whole forms one large and continuous piece, except where the differential unit bolts on one side and the cover on the other. Note that the shaft has the driving clutches machined as an integral part, and that removing the two shafts for a few inches makes it possible to unbolt

Fig. 448. Example of Full Floating Type of Axle

Fig. 449. Timken Full Floating Rear Axle, Showing Differential Removed
Courtesy of Timken-Detroit Axle Company, Detroit, Michigan

Fig. 450. Timken Full Floating Rear Axle with Spiral Bevel Gears

and remove the entire differential unit. For the sake of comparison, Fig. 450 shows an axle which differs from Fig. 449 only in having spiral bevels substituted for the ordinary straight-tooth bevels. In

Fig. 450, the differential unit is removable in the same manner as in Fig. 449. One of the axle shafts, with its integral driving clutches, and the differential cover are shown below. Note the two plugs in the cover; the upper one is for filling the case with lubricant, while the lower plug acts as a level indicator. When it is opened, heavy oil or oil and grease combinations are put in the filling plug above until the lubricant begins to flow out of the lower opening.

Three-Quarter Floating Axle. An interesting study in rear axle design is seen in Fig. 451. This axle has a number of points in which

Fig. 451. Partial Section through Rear Axle of Case Car, Showing Construction
Courtesy of J. I. Case T. M. Company, Racine, Wisconsin

it differs from previously described forms. It is of the three-quarter floating type. Note the enclosure of the driving shaft and the splines at its forward end for the universal joint, also the housing for the joint forming the torque member. The small roller bearing for the spigot end of the driving shaft beyond the bevel pinion is unusual; so are the diagonal distance rods, the spherical seat for the springs, the combination of drawn-steel tubes, steel castings, and pressed-steel cover for the axle housing. The wire wheel and its method of attachment will be seen, also the double set of brakes, internal and external on the same drum, with operating shafts for both supported from the central part and ends of the axle housing.

Rear-Axle Housings. Rear-axle housings are usually of pressed steel, although castings play a very important part and are sometimes used alone and sometimes in combination with other castings or in combination with pressed steel. Aluminum, although not a dependable metal, is used quite a good deal for the purpose of saving weight, as excess weight upon the rear axle is anything but desirable. In one unusual but effective combination, the axle housing consists of two malleable-iron castings joined together by means of bolts at the centers, the brake drums being cast as a part of the tubes. While not usual, this is safe practice, for malleable iron is tough and will not break or splinter. It seldom is the case, however, that the axle casing is reduced to as few parts as are shown here.

Welding Resorted To. Where the differential housing or brake drums are of malleable iron, cast steel, or even of pressed steel, and it is desired to unite them with the steel tubing forming the main part of the shaft housing, welding is now universally used. Formerly, it was good practice to make the casing a drive fit on the tube, riveting it in place, or else soldering it in place, making doubly sure by using rivets. Now, however, welding is resorted to, either the oxy-acetylene, electric, or some other process being used.

In the axles shown in Figs. 449 and 450, it will be noted that the axle shell is of pressed steel, to which the spring seats are bolted, the remainder of the construction being formed by drawing. In Fig. 448, however, the construction is such as to necessitate making the two halves longitudinally and then bolting or spot-welding them together. Being machined after they are fastened together, it makes as accurate a construction as the one-piece jobs, Figs. 449 and 450.

Effect of Differentials on Rear Axles. A differential gear, sometimes called a balance, or compensating, gear, is a mechanism which allows one wheel to travel faster than the other and which at the same time gives a positive drive from the engine. This device is a necessity in order to allow the car to go around a curve properly, for in doing so the outer wheel must travel a greater distance than the inner one during the same interval of time.

There are two forms of differential, the bevel type and the all-spur type, the latter differing from the former only in the use of spur gears instead of bevel gears. The principle used in both is that a set of gears are so held together that when a resistance comes upon one part of the train of gears the whole train will stop revolving around on a stationary axis and revolve around another gear as an axis, the first gear, in the meantime, standing stationary, or practically so, according to the amount of the resistance encountered. In the bevel type, a pair of bevels are set horizontally. Between the bevels is a spider with three or four arms, with a small bevel on the end of each. These small bevels mesh with the larger bevels at the sides and ordinarily stand still, rotating around on the arm of the spider as an axis by virtue of the continued rotation of the two side gears in opposite directions. When one wheel meets greater obstructions on the road than the other, thus holding it back, the shaft which drives that wheel lags behind the shaft driving the other wheel and thus holds back the horizontal gear attached to the shaft. This retarding movement allows the other horizontal gear more freedom to rotate. The result is that the spider carrying the smaller bevels rotates around on its axis, thus imparting to the free gear attached to the free wheel an additional motion, and to the free wheel a doubled speed, while the retarded wheel has a lessened speed. This takes the car around the corner without breaking the rear axle, as would be the case without some such contrivance. The description of the bevel differential action applies equally well to the spur type, except that all gears are spurs.

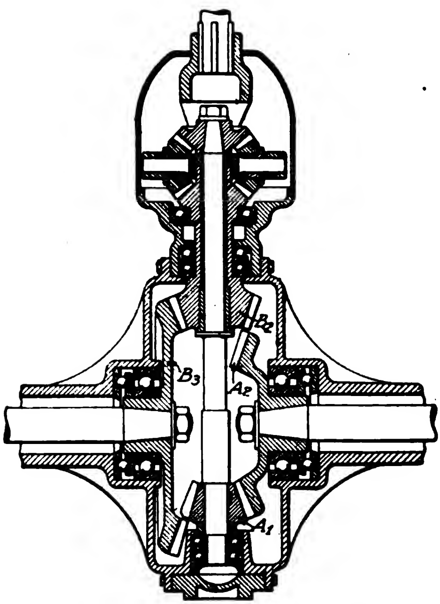


Fig. 452. Peculiar Differential Construction

The dividing of the rear axle is, of course, done to make a place for the differential gear to work, and much time and thought have been given to this subject in an endeavor to work out a substitute which would permit the differential action and still allow the strengthening of the rear axle. Fig. 452 shows one solution of the problem, which has been worked out in such a way that the differential is moved forward into the driving shaft. The rear axle shafts are thus greatly strengthened, the designer being unhampered by the presence of the differential in the rear axle. In this design, one side gear of the bevel-gear differential is carried upon a shaft, and the other upon a tube around the shaft. Then, at the rear axle, two sets of bevel gears B_2B_3 and A_1A_2 are used, A_1 being driven by the main shaft, and driving the right-hand shaft through the gear A_2; while the other B_2 is driven by the tube, and drives the left-hand shaft through the gear B_3. In this case the axle shafts are made much larger than in the ordinary case, while the differential action is just the same.

Improved Forms of Differential. Lately, much work has been done upon differentials to cause them to act as differentials should. The present form of differential acts according to the amount of resistance offered, but should act according to the distance traveled. When no resistance is offered, all the power is transmitted to that wheel, leaving the other stationary. This is just the opposite of the desired effect. If a differential were constructed to work for distance only, then, in the case of a wheel on ice or other slippery surface which offered little or no resistance, both wheels would still be driven equally, and the power transmitted to the one not on the ice would pull the vehicle over it.

One way in which the differential action might be corrected is by the use of helical gears and pinions instead of the usual bevel or spur gears. In the M & S forms, this construction is used, Fig. 453, showing the form constructed by Brown-Lipe-Chapin. In this form, each axle shaft carries a helical gear, and the differential spider carries two helical pinions with radial axes and four additional pinions, each of which meshes with one of the radial pinions and one of the gears on the axle shafts. On a turn, the outer wheel tends to run ahead of the inner and thus causes the nest of helical gears to revolve. All gears and pinions have a right-hand 45-degree tooth, so that one wheel may revolve the housing if the other is locked or held, but it is impossible to turn the free road wheel by pulling on the housing. The principle is the same as a worm steering gear in which the turning of the hand wheel may be transmitted to the front wheels, but the gear cannot be operated from the wheel end, because the worm is irreversible. This differential is used to advantage to prevent spinning on slippery ground and also to eliminate the skidding which the ordinary differential gives.

Another somewhat similar device has but two pairs of helical pinions in addition to the two helical gears on the shafts, the axes of each pair being set at an angle to the others. Thus, each helical gear and its pinion form an irreversible gear combination, so that movement cannot be transmitted through either in the reverse direction. This form fulfills the same conditions as the Brown-Lipe-Chapin M & S form, as the construction is such that no motion can be

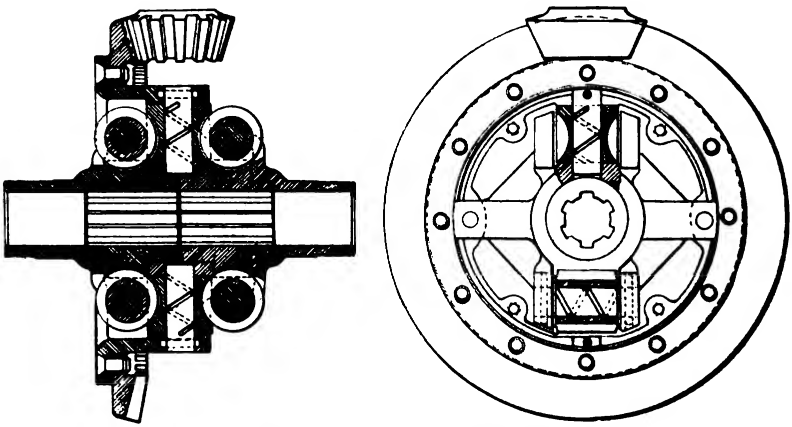


Fig. 453. The M & S Helical Gear Differential in Sections
Courtesy of Brown-Lipe-Chapin Company, Syracuse, New York

transmitted from the differential spider or housing to one of the wheels alone.

The above principle is back of the gearless form, shown in Fig. 454, in which the result is achieved through ratchets instead of helical gears, the lack of gears giving it its name. In this form there are two ratchets *Y* and *Y1*, which are keyed to the two axle shafts and free to rotate independent of the housing. The round members marked *B* are the interlocking pawls; the upper one is in a tooth of the right-hand ratchet at the right and is driven by the contact face of the driving sector *X* at the left. Thus, the right-hand ratchet is being driven positively forward. The lower pawl is engaged at the other end; so the left-hand ratchet is also being driven positively forward. On a turn, one wheel revolves faster than the other, say the right, and causes the right-hand ratchet to move faster than the differential housing, which can only go as fast as the other, or slow-moving, wheel. Then, the right-hand ratchet pushes the end of its pawl out of the tooth and gives it a free movement forward. As soon as the wheels revolve at equal speeds, the spring pushes it back. In the figure, the right-hand portion shows the original form in perspective.

Possible Elimination of Differential. The whole modern tendency is toward differential elimination. In the cyclecars and small cars brought out in recent years, designers have been forced to get

Fig. 454. Sketches Showing Construction and Operation of Gearless Differential

along without it because of the demand for simplicity, light weight, and low price. This effect has been obtained by the use of a pair of driving belts, letting one slip more than the other; by the use of friction transmissions; by simply dividing the rear axle and letting one side lag when there was resistance; by not dividing it and letting one wheel drag; and in other ways. The evident success of these small vehicles without a differential or any real substitute for one has set designers to thinking about this subject again, and some big cars without a differential, or with a more simple and less expensive substitute for it, may appear in the near future.

Rear-Wheel Bearings. The bearings used on rear axles differ very little from those used on front axles. All forms are used—plain bearings, ball bearings, ball thrusts, roller bearings in both cylindrical and tapered types, and all combinations of these. Thus, Figs. 445 and 452 show the exclusive and liberal use of ball bearings, while Fig. 451 shows all rollers of two kinds and ball bearings for thrust bearings only. The two kinds of roller bearings are the tapered roller and the flexible roller. Similarly, in Fig. 447, it will be noted that balls are used with two kinds of rollers, straight solid rollers in the wheels and flexible rollers in the differential case. Figs. 449 and 450 show the exclusive use of the tapered roller type, a construction which is gaining ground very rapidly, the same as in front axles, although, formerly, ball bearings were most widely used. The materials employed are similar to those used for front axles, which have been previously described. Cases are made of all kinds of steel and iron—pressed, drawn, cast, etc.—not to speak of crucible steel, malleable iron, manganese bronze, phosphor bronze, aluminum, aluminum alloys, and many combinations of these materials in twos and threes.

Rear-Axle Lubrication. Rear-axle lubrication is generally automatic in so far as the central bevel or other gears and the differential housing are concerned. The housing usually has a form of filling plug, or standpipe, which is used to fill the case with a form of heavy grease every 5000 miles, or once each season. The case is generally arranged so the filling plug works through and lubricates the outer bearings on the axle shafts as well, with suitable provision against this reaching the brake drums or other brake parts. The wheel bearings either are cared for in this way or have a central space which is filled with heavy grease once a season, being self-lubricating from then on. Such other rear axle parts as need occasional lubrication, as torque-rod pivots, brake-band supports, brake-operating shafts, etc., are generally provided with external grease cups, which are given a turn once a week on the average. It is highly important that the braking system be as well lubricated as the lubricating means provided will allow.

REAR-AXLE TROUBLES AND REPAIRS

Jacking-Up Troubles. Much rear-axle work—practically all, in fact—calls for the use of the jack. True, the full floating type of axle can have its shaft removed without jacking, but, aside from differential removal, there is little rear-axle trouble in which it is necessary to remove the shaft alone. In almost all cases, the axle must be jacked up. Many axles have a truss rod under the center, and this is in the way when jacking; however, this can be overcome. Make from heavy bar iron a U-shaped piece like that shown on top of the jack in Fig. 455, making the width of the slot just enough to admit the truss rod. The height, too, should be as little as will give contact with the under side of the axle housing.

Substitute for Jack. A good substitute for a jack is a form of hoist, Fig. 456, which will pick up the whole rear end of the car at once. This not only saves time and work, but holds the car level, while jacking one wheel does not. Moreover, with a rig of this kind, the car can be easily lifted so high that work underneath it may be easily done. The usual hoisting blocks are very expensive, but the above hoist can be easily made by the ingenious repair man. This one was made from an old whiffletree with a chain attached at each end. For the lower ends of the chains, a pair of hooks are made sufficiently large to hook under and around the biggest frame to be handled. With the center of the whiffletree fastened to the hook of a block and tackle, the hoist is complete. By slinging the hooks under the side members of the frame at the rear, it is an easy matter to quickly lift that end of the chassis any distance desired.

Workstand Equipment. Next to raising the rear axle, the most important thing is to support it in its elevated position. To leave it on jacks is not satisfactory, for they will not raise the frame high enough, and, furthermore, they are shaky and may easily let the whole rear end fall over, doing considerable damage. With the overhead hoist, the chains or ropes are in the way; so a stand is both a necessity and a convenience. In Fig. 457, several types of stands are shown. *A* is essentially a workstand, intended to hold the axle and part of the propeller shaft while repair work is being done thereon. It consists of a floor unit, or base, built in the form of an *A*, with six uprights let into it, preferably mortised and tenoned for greater strength and stiffness. Then, the four rear uprights are joined together for additional stiffness and rigidity. If casters are added on the ends, the stand can be more conveniently handled around the shop.

The forms *B* are for more temporary work and consequently need not be so well or so elaborately made. The little stand *C* is a very handy type for all-around work. Stands of this kind with the top surface grooved for the axle are excellent to place under cars which have been put in storage for the winter.

The stand *D* is, like *A*, a workstand pure and simple. In this, however, the dropped-end members allow supporting the axle at

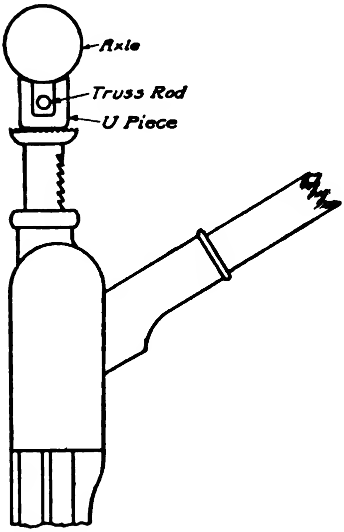


Fig. 455. Simple Arrangement for Avoiding Rear-Axle Truss Rod

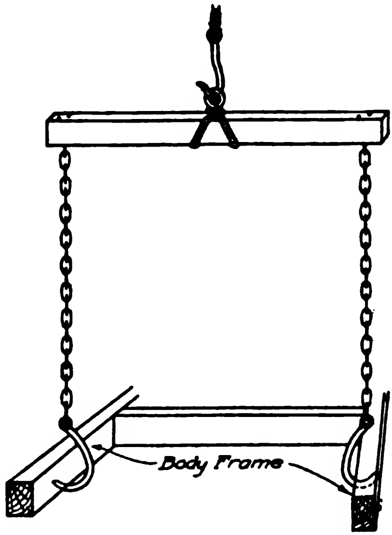


Fig. 456. Simple Automobile Frame Hoist

those points, while the elimination of central supports gives plenty of room for truss rods. This type of stand would preferably be made from metal, pressed steel or small angle irons being very good. Every

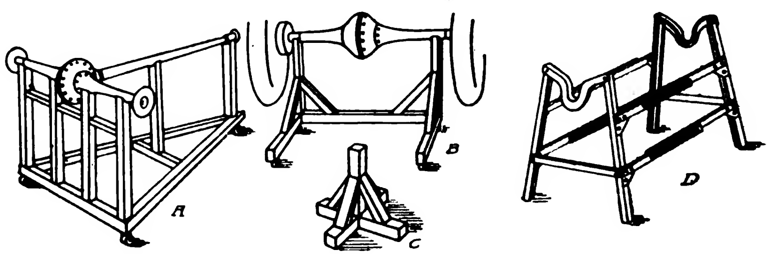


Fig. 457. Types of Handy Stands for Rear-Axle Repair Work

repair shop should have a considerable number and variety of stands, made as the work demands them, to fit this particular class of work.

Universal-Joint Housings. Universal joints usually are covered with leather casings which are packed with grease. These keep out the dirt and, consequently, lessen the wear, and also lubricate the moving parts of the joints. A secondary function of the casings is to render these joints noiseless. If a car is not equipped with them, it is advisable for the owner to purchase them.

The shape of these casings, when opened out flat, would be not unlike that of two bottles with their flat bottoms set together, that is, narrow at the top and bottom and wider at the middle. All along both edges are eyelets for the lacing. The enlarged center fits around the joint, while the small ends encircle the respective shafts. To apply the casing, one end is placed around the shaft on one side of the joint, and the lace started; then the lacing proceeds, gradually drawing the ends together and around the joint. When this has been completed, and before the last end is closed, the whole is shoved back along the first shaft a little way, and the center portion half filled with a heavy grade of transmission grease. This done, the glove is pulled back into place, and the work of lacing completed around the second shaft. Both ends should be laced as tightly as possible, while the middle part should be loose. Sometimes these housings will become worn and make a very annoying chatter on the road, even when they are not sufficiently worn to warrant replacements. Under such circumstances, the offending member may be wound with tire tape held firmly in place in addition to its adhesive power by means of a hose clamp, as shown in Fig. 458. The coupling is held tightly enough to prevent the rattle and chatter, but not enough to interfere with its action. While not a handsome job, it does the business, stopping the noise effectively.

Rear Axle. Rear axles do such hard work and must stand up under such a large portion of the load carried in the machine that they offer many chances for wear, adjustment, or replacement.

Truss Rods. Truss rods hold the wheels in their correct vertical relation to the road surface and to one another. If, through wear or excessive loading, the axle sags so that the wheels tip in at the top, presenting a knock-kneed appearance, the truss rods must be tightened up. Usually, they are made with a turnbuckle set near one end, a locknut on each side preventing movement. The turnbuckle is threaded internally with a right-hand thread on one end and a left-hand thread on the other, so that a movement of the turnbuckle draws the two ends in toward one another, shortens the length of the rod, and thus pulls the lower parts of the wheels toward one another, correcting the tipping at the top.

To adjust a sagging axle, loosen both locknuts, remembering that one is right-handed and the other left. Then, with the wheels jacked clear of the ground, tighten the turnbuckle. A long square should be procured or made so that the wheel inclinations may be measured before and after. Placing the square on the ground or floor, which should be selected so as to be perfectly level, the turnbuckle should be moved until the tops appear to lean outward about ½ inch—some makers advise more.

It should be borne in mind that even if the wheels and axle do not show the need of truss rod adjustment, if this rod be loose, it will become very noisy and rattle a great deal, as the rear axle sustains a great amount of jouncing. Moreover, this noise and rattle, if not taken up, will cause wear, which cannot be taken up.

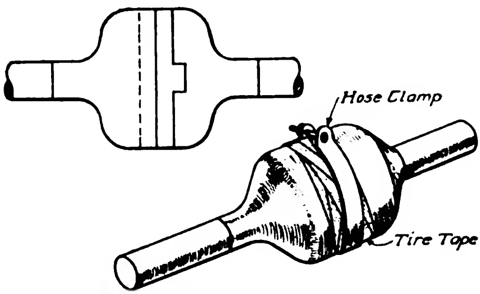


Fig. 458. Easy Method of Quieting Noisy Universal-Joint Housings
Courtesy of "Motor World"

Disassembling Rear Construction. In disassembling the rear construction for purposes of adjustment or repair, the repair man should be careful to mark all parts. Those parts which have been running together for several thousand miles act better and with less friction than would those which have never run together, despite the fact that the duplicate parts are supposed to be alike and interchangeable. It is therefore suggested that separate boxes be provided for the parts taken from the two ends or sides. The method of disassembling is about as follows: Jack up the axle, replacing the jack with small horses or blocks of wood if possible. Take off the hub caps, then free the wheels and take them off. Disconnect the brake-operating rods and levers and remove them from the car, marking them carefully. Spread the brake shoes apart, loosen the springs at one side, take out the springs, and then loosen and take out the brake shoes themselves. Remove the brake operating shaft with the cams;

then disconnect the spring bolts and jack up the chassis, using the spring for a support. Disconnect all torsion or radius rods and take off the grease boot around the universal joint in the driving shaft. Open this joint and disconnect the shaft. Take this off, and if the spring bolts have been removed, the rear axle will be free. Pull it out from under the chassis, and, if desired, further disassembling may be done more easily with the member clamped in a vice or laid on a bench.

Assembling. In assembling, almost the reverse of this process is followed, the parts going together in the opposite manner from that in which they were taken down.

Noisy Bevel Gears. If the bevel gears in the rear axle are noisy, the time to fix them is when the axle is disassembled, as this is quite a job. In general, bevel gears make a noise because they are poorly cut, because they are not set correctly with relation to each other, or because the teeth have become cut, or chipped, by some foreign material which has been forced between them.

In the first case, there is little the amateur can do beyond making the best possible adjustment and smoothing off any visible roughness. In the second case, it is simply a matter of setting one gear closer to or farther from the other by means of the adjustment provided. When the axle is disassembled, and all parts are readily accessible, it will be found that there is a notched nut on either side of each of the bevels; there should be a wrench in the tool kit to fit this. It is then a simple matter to move one outward and the other inward in either pair, according to which needs the adjustment. In case the teeth have become chipped, the projections should be smoothed down with a fine file, while the sharp edges of the cuts should be dressed in the same manner.

Packard Bevel Adjustment. Although strictly a transmission trouble, the older Packard cars have the transmission located on the rear axle, and this position made the adjustment of the bevel pinion difficult. For another thing, the shaft is very short and hard to hold. If the sliding gear on the shaft is meshed with the internal gear attached to the other end of the bevel-pinion unit, the latter will hold firmly, but there will still be a little play between the teeth. It is necessary to take this up, as otherwise the repair man would mistake this play for play in the bevel driving gear. It can be taken up as follows: Take an old sliding-gear unit from one of these transmissions, remove one of the teeth and slide the gear into position for meshing with the space at the top between two teeth on the good gear. Drive a pin in where the tooth has been removed, and this will fix the two firmly together without a particle of play. Then, by removing the cover from the differential housing, the bevels can be tested for play. Fig. 459 shows the transmission, bevel gears, and axle parts, also the gear with the tooth removed and replaced by a pin, so that the whole process will be clear.

Repair for Broken Spring Clips. The springs are held down on the axles by means of spring clips, which are simply U-shaped bolts

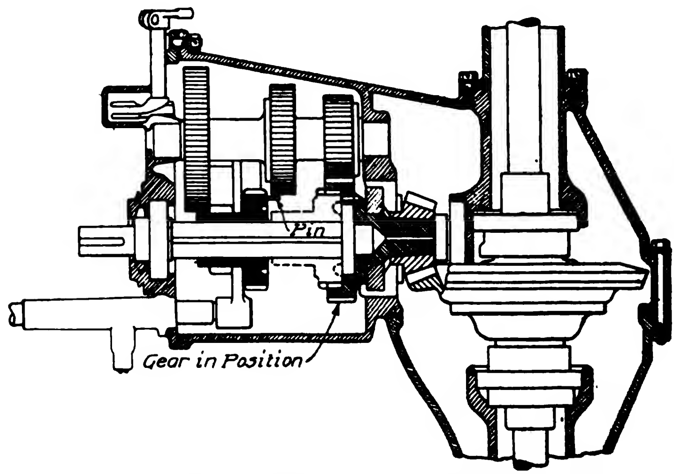


Fig. 459. Diagram of Packard Axle and Transmission to Show Adjustment of Bevel Pinion
Courtesy of "Motor World"

with the inside width of the U equal to the width of the spring. Occasionally, these will break when they cannot be replaced or new ones forged. Under such circumstances, a repair such as used by one man, shown in Fig. 460, will always get the car home or to a garage where a better one can be made. This method of repair consists of a pair of flat plates, one above the spring, the other below the axle, with holes drilled in the corners to take four long carriage bolts, which happened to be handy. The plates were put on, bolts put in and tightened up, and the car was ready to run. Although an I-section axle is shown, this method of repair would work just as well on a round axle or on one of any other shape.

Lining Up Axles. In such a repair, however, the main thing is to get the rear axle lined up correctly, which is not an easy job. This may be done in the following manner: Get the car standing level on a nice clean smooth floor; hold a large metal square with a plumb bob hanging down over its short edge against the side of the frame. Move the square forward until the line just touches the rear axle at some set distance out from the frame, say 3 inches, as shown in Fig. 461. Then notice the distance this line is forward from the rear end of the frame. In the sketch it is 16 inches. Transfer the square and plumb bob to the other side and repeat. Here it will be found that the distance from the rear end of the frame is either more or less. In the sketch it is shown at 18 inches; so the difference, 2 inches, shows that the axle is out of alignment that much or half that, 1 inch at each end.

This axle is straightened by loosening the spring bolts and pushing one side back the distance apparently needed, then fastening tightly and checking up. If not correct, try again, using judgment as to which side should be moved. When finally satisfied that the rear axle is square with the frame, it is well to check this against the center-to-center distance of the wheels on each side. This is done by setting the front wheels exactly straight and then measuring from the center of the right front to the center of the right rear wheel. Then go over to the other side and measure the center-to-center distance of the left wheels. The two axles should agree exactly. If they do not, the rear axle prusumably needs more adjustment for squareness.

Fig. 460. How Spring Clips Are Replaced in Emergency
Courtesy of "Motor World"

Taking Out Bend in Axle. A simple method of repairing an axle which has been bent, but a method which is only temporary in that it is not accurate enough to give a job which could be called final, is that indicated in Fig. 462. The axle was bent when the hub struck an obstruction in the road, and it had to be straightened immediately.

A short length of 2 x 4 timber was cut to be a tight fit between the upper side of the hub cap and the roof beam. Then a jack under the

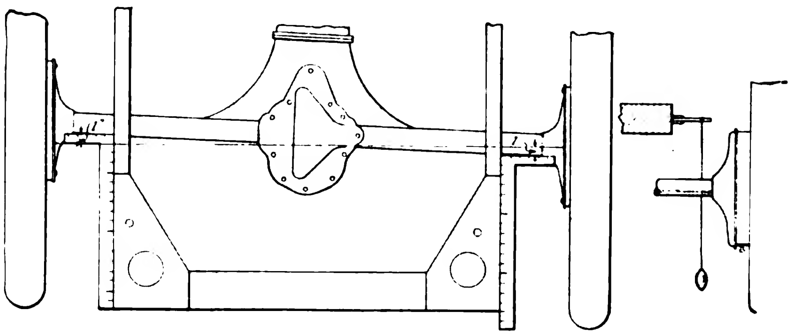


Fig. 461. Method of Checking up Rear-Axle Alignment with Square and Plumb Bob

axle at the point of the bend was raised. As the jack raised the axle, and the wood beam held the hub down, enough pressure was exerted to force the axle to give at the bend and return as nearly as possible to its original straightness. It was a quick and easy repair of the rough and ready order, which served when time was worth more than anything else; but it is a method which would not be advised or recommended when there was sufficient time to properly straighten the axle.

Fig. 462. One Way of Straightening Rear Axle Quickly

Locating Trouble. Many times, a car may be brought in for rear-axle repair on which the repair man cannot find any trouble. Many axles often develop an elusive hum, or grinding noise, which not only defies location, but is not continuous. The writer had such a case brought to him at one time, and was sure that the bevel gears were out of alignment and were cutting each other. It was a low-pitched whine which was not apparent at low speeds, but began to be heard around 18 to 20 miles an hour, and at times was very apparent. The noise was very annoying, but tearing down the rear construction showed absolutely no trouble; so the noise could not be at that point. Sometime later the noise was definitely located in a pair of worn speedometer gears on the right end of the front axle.

A good way to listen to rear axle hums out on the road is to lay back over the rear end of the car, Fig. 463, with the head against the top of the seat and projecting over slightly, and with the hands cupped in front of the ears, so as to catch every noise that arises. The larger sketch shows the general scheme, the small inset giving the method of holding the hands. When the sound arising from the axle is a steady hum, the gears are in good condition and well adjusted. If this sound is interrupted occasionally by a sharper, harsher note, it may be assumed that there is a point in one of the gears or on one of the shafts where things are not as they should be. By trying the car at starting, slowing down, running at various speeds, and coasting, this noise can be tied to something more definite, some fixed method of happening. In advance of actual repair work, including tearing down the whole axle, the gears can be adjusted. This can generally be done from outside the axle casing and without a great deal of work. If the adjustment makes matters worse, it can be reversed, or if it improves the situation, the adjusting can be continued, a little at a time, until the noise gradually disappears.

Fig. 463. Listening for Rear-Axle Noises

Checking Up Ford Axles. Many cases of Ford bent rear axles can be fixed without taking down the whole construction. The principal point is to find out how much and which way the axle is bent.

By removing the wheel on the bent side and placing the rig shown in Fig. 464 on the axle end, the extent of the trouble can be indicated by the axle itself. The iron rod is long and stiff, with its outer end pointed, and is fastened permanently to an old Ford hub. The rig is placed on the axle and held by the axle nut, but without the key, as the axle must be free to turn inside the hub. With the pointed end of the rod resting on the floor and with high gear engaged, have some one turn the engine over slowly, so as to turn the axle shaft around. As it revolves, the hub will be moved, and the pointed end on the floor will indicate the extent of the bend. By marking the two extreme points and dividing the distance between them, the center is found. Then a rod can be used as a bar to bend the axle, until the pointed rod end is exactly on the center mark. A little practice with this rig will enable a workman to straighten out a Ford rear axle in about the time it takes to tell it.

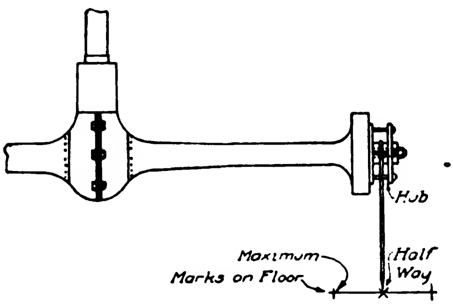


Fig. 464. Diagram Showing Method of Checking Up Ford Axles

BRAKES

Function of Brake. Next to power, applied through the correct form of gearing, and its final suitable drive to the road wheels, nothing is of more importance than the ability to stop the vehicle at will. One medium through which this is done, and which ordinarily suffices, is the shutting off of the source of power—in this case, the gasoline and the spark which is used to ignite its vapor. This will not always suffice, however, for the ordinary car possesses the ability to run at a speed of 40 miles per hour or upward, and weighs from 2000 pounds (one ton) upward to 4000 pounds (two tons). This combination makes for a large force of inertia, which will result in the car running for many yards, even hundreds of yards, after the power is shut off. It is for this reason that we must have a mechanical means of absorbing this inertia, or of snubbing the forward movement of the car. This is the function of the brakes, as fitted to the modern car.

Engine as a Brake. Although disregarded in any summary of brakes, the engine is the best brake possible, granting that the driver knows how to get the best results without doing any damage. The ordinary engine has a compression of from 60 pounds to 70 pounds per square inch, which is practically the pressure available when it is used as a brake. Since this is more pressure than any other type, or form, of brake will yield, its usefulness is self-evident.

Classification. Brakes are usually divided into two classes, differing mainly in location—the internal expanding and the external contracting. To these a third class should be added, because it partakes of the nature of both, yet differs from each one. This is the railway type of brake with removable shoes of metal, differing from the band type in that no attempt is made to cover the whole or even the greater part of the circular surface, but simply a small portion of it, against which a shoe is forced with a very high pressure. Both the other types are subject to division into other classes, the first into three subdivisions according to operating means, viz, cam, toggle, and scissors action.

Brakes are generally divided according to their location, as shaft and rear axle. The shaft brake at one time virtually went out of use, but it is now being revived. The marked swing toward the unit power plant, together with its simplification, lightening, and elimination tendencies, has produced a situation where a brake drum just back of the power and gear unit can be operated by the hand lever and a very short rod. In this way much weight and many parts are saved. An indirect advantage is that the brake is more accessible. With the worm drive, there is a marked tendency back to the shaft brake, particularly on motor trucks. Again, in the last few years, some work has been done with pneumatic, hydraulic, and electric forms of brake. With air under pressure for starting, and with water or electricity as needed for starting or for other purposes, it is a simple matter to utilize the same agency for braking, providing such use does not add too much complication and, at the same time, that it will give a superior method of snubbing the forward movement of the car. In case none of these advantages are realized, there will be no particular advantage in adding new forms of brake.

External-Contracting Brakes. This class of brakes is divided nto but two types, viz, single- and double-acting. In the first, an end of a simple band is anchored at some external point, while the other, or free end, is pulled. This results in the anchorage sustaining as much pull as is given to the operating end, that is, all pull is transmitted directly to the anchorage. This disadvantage has resulted in this form becoming nearly obsolete.

Any brake of the true double-acting type will work equally well acting forward or backward. The differential brake, Fig. 465, shows this clearly. The external band is hung from the main frame by means of a stout link which is free to turn. The band itself is of very thin sheet steel, lined with some form of non-burnable belting. The ends carry drop forgings, to which the operating levers are attached. These are so shaped that the pull is evenly divided between the two sides of the band. This will be made apparent by considering that a pull on the lever *H* will result in two motions, neither one complete, since each depends upon the other. First, there will be a motion of the upper band end *B* about the extremity of the lower one as a pivot, followed by a movement of the lower end, pivot and all, about *B* as a second pivot point. These two motions result in a double clamping action which is supposed to distribute evenly over the surface. In order to insure even distribution, the lining is grooved, or divided, into sections.

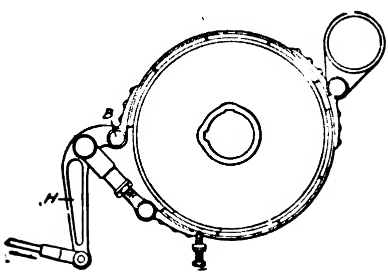


Fig. 465. Brake on Main Shaft of Benz (German) Car

Usually, chain-driven cars have a different brake location from a car with shaft drive. The chain-driven cars have three sets of brakes: one on the main shaft, one pair on the countershaft, and another pair on the rear wheels, as shown in Fig. 466.

Internal-Expanding Brakes. While the contracting-band brake is well thought of, the internal-expanding form is rapidly displacing it, for the reason that experienced drivers think more of it. In Fig. 467 will be seen a modern form of the internal brake, namely, the use of both brakes as internal, but placed side by side in the same drum. This is a tendency which seems to be gaining in favor. The car is the Owen Magnetic, one of the most expensive and luxurious; so the use of side-by-side internal brakes here must be attributed to superiority rather than to a desire to save in money or in parts.

A considerable number of foreign cars, which are used in mountainous countries, show a method of cooling the brake drums by means of external cooling flanges. In some makes, even a water drip is provided for extremely hilly country.

More modern practice shows no tendency to place all of the eggs in one basket, both forms of brake being employed together and upon the same car, usually also upon the same brake drum, one set working

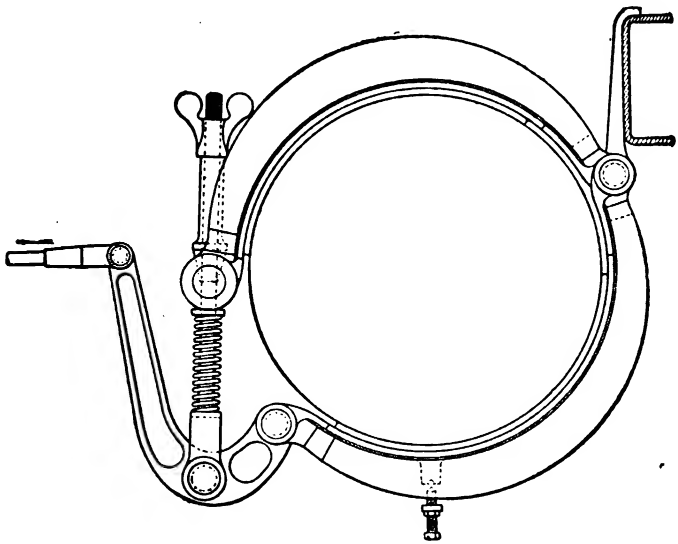


Fig. 466. Benz Countershaft Brakes for Chain-Driven Car

upon the exterior, while the other works upon the inside. In Fig. 468, which shows the rear-axle brakes of the larger cars made by the Peerless Motor Car Company, this mechanism is plainly illustrated, both the brakes being shown, although the drum upon which they work has been removed. The parts are all named so as to be self-explanatory. In this construction, the inner, or expanding, band is operated by a cam. In the brake sets put out by the Timken Roller Bearing Company, of Detroit, Michigan, in connection with their bearings and axles, the toggle action is used, Fig. 469. The constructional drawings, Figs. 470 and 471, showing the brakes used on the Reo car, manufactured by the Reo Motor Car Company, of Lansing,

In general, however, when both brakes are placed on the rear wheels, one external and of the contracting-band type, and the other internal and of the expanding-shoe form, modern practice calls for a cam to operate the latter, operating directly upon the ends of the two halves of the shoe, while levers operate the band so as to get a double contracting motion.

Some modern brakes may be seen in Figs. 472, 473, and 474. The first shows a system such as just described; the second shows a stiff metal shoe in both types; and the last a pair of shoes set side by side. In addition, the last-named includes a new thought in

Fig. 469. Timken Double Rear-Axle Brake

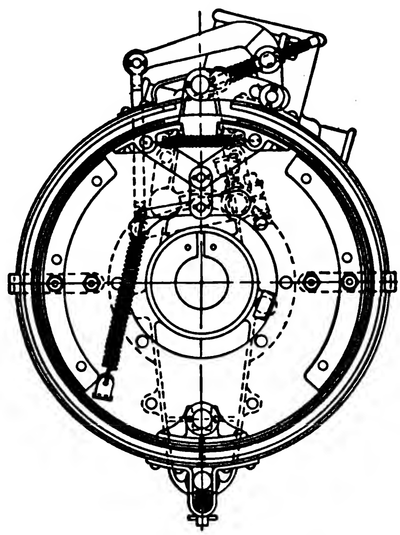


Fig. 470. Section Showing Construction of Reo Brakes

Fig. 471. Drawing Showing Method of Operating Reo Brakes

Courtesy of Reo Motor Car Company, Lansing, Michigan

that the brake shoes are floated on their supporting pins, as shown. This makes the bearing of the shoes certain when expanded against every portion of the drum, as the shoes can "float" until they fit exactly.

Double Brake Drum for Safety. A very important feature is pointed out in Fig. 472, namely, that of safety. Where both brakes work on a common drum, one inside and the other outside, the continuous use of the service brake (whether internal or external) heats up the drum to such an extent that when an emergency arises calling for the application of the other brake it will not grip on the hot drum, being thoroughly heated itself. The double drum allows air circulation and constant cooling.

Methods of Brake Operation. While it is generally thought that round iron rods are the universal means of brake operation, such is not the case. Many brakes on excellent cars are worked, as the illustrations show, by means of cables. This idea is even carried so far

Fig. 472. Double Brake Drum Used on Locomobile Cars

that brakes have been fitted to operate through the medium of ropes. Chains of small diameter have also been used, as well as combinations of rods, chains, cables, and ropes.

A lever-operated braking system of a well-known medium-priced car is shown in the outline sketch, Fig. 475. In this system the forward part of each half is worked by rods moved by means of pedals, but the rear part of each half is actuated by means of cables. Cables have one advantage over rods in a situation like this—the diagonal pull with a stiff rod might, in time, act to pull the brakes side-

Fig. 473. Brakes and Rear Construction of Pierce Cars
Courtesy of Pierce-Arrow Motor Car Company, Buffalo, New York

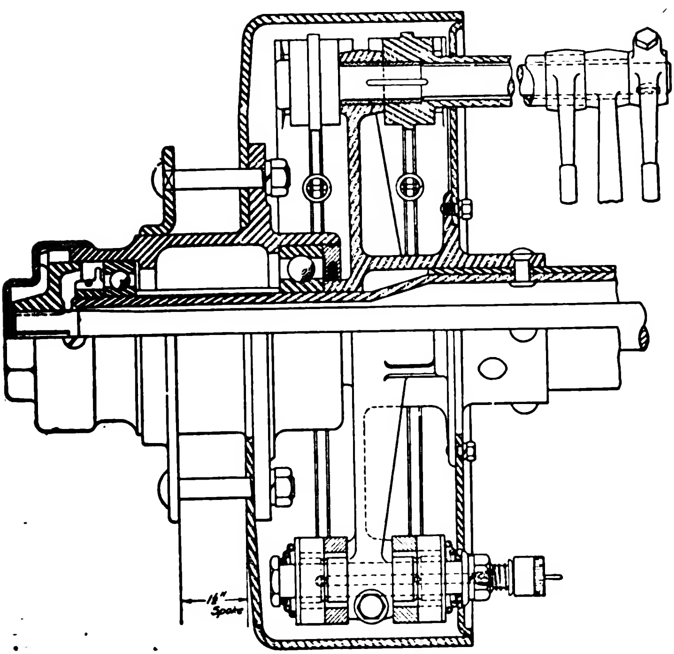


Fig. 474. Side-by-Side Arrangement of Brakes on American Rear Axle
Courtesy of American Ball Bearing Company, Cleveland, Ohio

wise off their respective brake drums, the cable, being more flexible, gives less danger of this.

This method of operation seems to be gaining favor because of its simplicity, which eliminates parts that add weight and gives immediate results when the parts are properly adjusted. The recent New York show revealed a surprising number of small and medium size cars with cable-operated brakes. An inspection of these cars showed a mechanical cleanliness which was lacking in many others of the same class on which an attempt was made to reduce braking rods

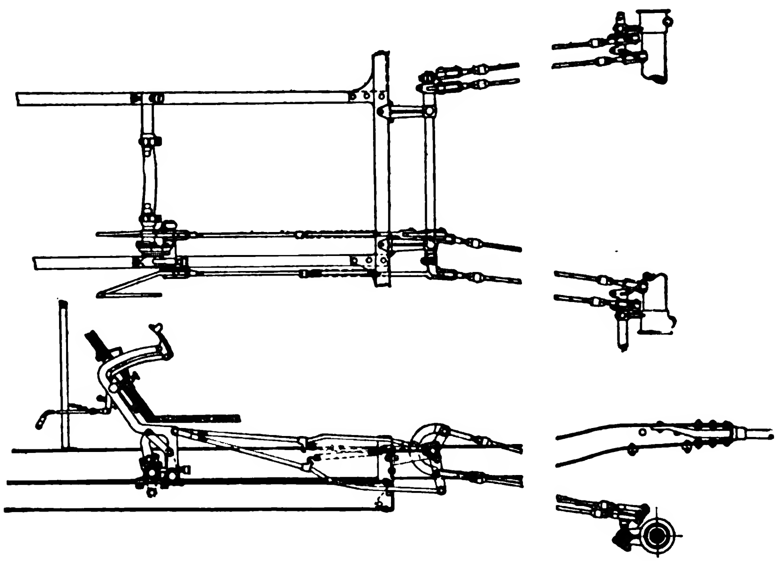


Fig. 475. Layout of Brake-Operating System Using Cables

and levers to a minimum, with consequent bent levers, bent or crooked rods, brakes worked from an angle, and other unmechanical ideas.

Fully as important as the operating means is the matter of equalizing the pull so that the same force is exerted upon both wheels at once. This action is influential in causing side-slip or skidding, which may result fatally. To equalize the force was one reason for the use of cables, although the more up-to-date way is to attach the operating lever to the center of a long bar, to the extremities of which the brakes themselves are fastened. A pull on the bar is then divided into two different pulls on the brakes, the division being made automatically and according to their respective needs. This is an important point, and one that should be looked after in the purchase of a new car.

Brake Adjustments. In recent years much of the brake improvement has been that of making adjustments easier and of making the adjusting parts more accessible. This can be noted in such a case as the Locomobile, Fig. 472, where the special adjusting handle on the brake is carried to such a height as to make the turning of it an easy matter. Similarly, on the Pierce, Fig. 473, it will be noted that there is provision for increasing or decreasing the closeness of the shoes to the drum, which is easily accessible.

Brake Lubrication. As for the actual brake surfaces, there is no such thing as lubrication. The surfaces should be kept as dry and clean as possible. If grease or oil gets out from the axle or other lubricated parts onto them, there is sure to be trouble. The operating rods and levers, however, should have fairly careful lubrication, for which purpose the best makers provide grease or oil cups at all vital points. If these be neglected, a connection may stick, so that when an emergency arises the brake will not act properly and an accident may result.

Recent Developments. In the last few years, the only new ideas advanced in the way of brakes concern front-wheel braking and electric brakes. The former were used quite extensively abroad in 1913, but in 1914 they seemed to drop back; this, too, despite the fact that the Grand Prix race of the latter year showed in a marked manner the need for and special application of front-wheel brakes to racing and high-speed cars.

Electric Brakes. A very efficient and compact brake, applicable with a small amount of work to any chassis having a storage battery, is the Hartford, shown in Fig. 476, while Fig. 477 shows the operating lever as it is placed beneath the steering wheel, and Fig. 478 shows the wiring system. This brake consists, in substance, of a small reversible electric motor, to which a 100 to 1 worm reduction is attached. Attached to the drum is a cable, which is fastened to the usual brake equalizer. Turning the current into the motor from the storage battery rotates the drum, winds up the cable, and applies the brake. The complete outfit weighs but 35 pounds. The motor has a slipping clutch set to operate at 1000 pounds pull, at which it draws 40 amperes of current from the battery for two-fifths of a second.

Fig. 476. Exterior of Motor Which Forms Central Unit of Hartford Electric Brake
Courtesy of Hartford Suspension Company, Jersey City, New Jersey

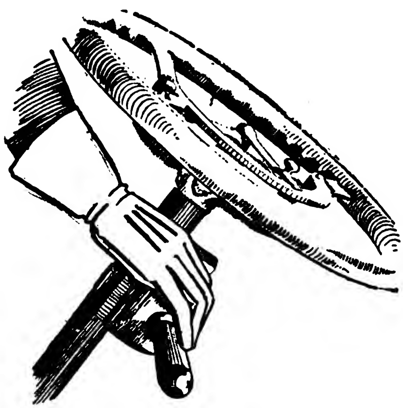


Fig. 477. Hand Lever on Steering Post for Operating Hartford Electric Brake

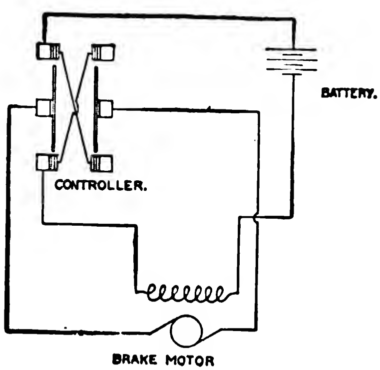


Fig. 478. Wiring Diagram for Hartford Electric Brake

In use, it replaces the emergency hand-operating lever, and is said to be able to pull a heavy car going 50 miles an hour down to less than 15 in a distance of less than 35 feet. The pull is so great that the brake drums are oiled to prevent heating and possible seizing.

Hydraulic Brakes. On the newer Knox tractors, a brake of very large size is made even more powerful by hydraulic operation. This brake is shown in Fig. 479. At the left will be seen the usual brake lever attached to a small piston in a chamber full of liquid. This chamber communicates through the medium of a valve normally held closed by a spring, with a passage above, and that, in turn, communicates with the pipes leading to the brake-operating cylinder. This cylinder has a stout rod attached to a good size plunger, back of which the liquid (oil) is introduced. When liquid is forced in, the plunger moves forward, forcing the rod out and, through connecting rods and levers, applying the brakes. As will be seen in the drawing at the right, these brakes, which are of the internal-expanding type, are exceptional in size and work against steel drums attached directly to the wheel spokes.

When the lever is drawn back in the usual manner, liquid is forced upward through the top passage to and through the pipes into the other cylinder, forcing the plunger to move, and, through the movement of the plunger, the brakes are applied. The return of the fluid is not shown, but it is assumed that this is through a simple pipe connection from the plunger cylinder to the hand-operated piston with a check valve. Should the initial movement of the lever fail to apply the brakes sufficiently, the driver can let the lever come forward and then pull it back again; in so doing he will take into his lever cylinder

Fig. 479. Layout of Hydraulic Brakes Used on Knox Tractor
Courtesy of Knox Motors Company, Springfield, Massachusetts

more liquid from below without releasing the brakes. Then, when this extra quantity is forced through, the plunger is moved even farther forward, and the brakes applied more forcibly. The brakes are 20 inches in diameter by 6½ inches wide.

Vacuum Brakes. The latest development in the line of braking systems is the Prest-O-Lite vacuum brake. This brake consists of a controlling valve, a vacuum chamber, piping from the inlet manifold to the valve and thence to vacuum chamber, and a foot button or finger lever on the steering post to operate the valve and thus put the system into use. The rod in the vacuum chamber is connected up to the service brakes, the system thus taking the place of the usual pedal and foot operation. The chassis sketch, Fig. 480, shows this in plan, *A* being the controlling valve, *BB* the tubing from the inlet manifold to the controlling valve and from it to the vacuum chamber *C*. The rod *D* from the chamber will be seen connected to the service-brake rods and levers.

In Fig. 480 the method of operating the system is not shown, but in Fig. 481 the foot lever can be seen with its connections. When this is pressed, the controller valve is opened and the engine, as it runs, draws air out of the chamber *C* in back of the plunger, gradually creating a vacuum, so that the plunger is forced to move forward to compensate for this. As the plunger carries a tail rod projecting through the end of the cylinder, and as this rod is connected up to the braking system, but with a big leverage, the movement of the plunger

Fig. 480. Chassis Plan Showing Application of Prest-O-Lite Vacuum Brake
Courtesy of Prest-O-Lite Company, Indianapolis, Indiana

applies the brakes. The amount of brake application depends upon the amount of suction, and that is governed by the amount the valve is opened by the finger lever or foot button. Consequently, with this new brake, the bucking effort can be varied to suit the conditions.

It is said that the leverage arrangement is such that 10 pounds per square inch in the intake manifold will produce 1000 pounds braking effort at the rear wheels. This means that the brakes could be used with the engine running very slowly. The system is applied to the service brakes because a brake is sometimes needed when the engine is not running, as when coasting down a hill with the engine shut off and clutch out, or with the car standing and engine shut off, etc.; also because it is the most used system, and it is felt that the simple finger pressure and gradual or instantaneous application possibilities of the new form make it more desirable as a service or running brake.

Whatever advantages may develop in the use of these special types, it is certain that the next few years will see considerable improvement in braking, so that a greater force may be applied more quickly, and thus act to prevent a large part of the accidents for which automobile owners and drivers are now unjustly blamed.

BRAKE TROUBLES AND REPAIRS

Dragging Brakes. Probably the first trouble in the way of brakes is that of dragging, that is, braking surface constantly in

Fig. 481. Foot Button for Operating Vacuum Brake

contact with the brake drum. This should not be the case, as springs are usually provided to hold the brake bands off the drums. Look for these springs and see if they are in good condition. One or both of the brake bands may be bent so that the band touches the drum at a single point.

Another kind of dragging is that in which the brakes are adjusted too tightly—so tightly, in fact, that they are working all the time. In operating the car, there will be a noticeable lack of power and speed, while the rear axle will heat constantly. This can be detected by raising either rear wheel or both by means of a jack, a quick lifting arrangement, or a crane, and then spinning the wheels. If the brakes are dragging, they will not turn freely.

All that is needed to remedy this trouble is a better adjustment. For the new man, however, it is a nice little trick to adjust a pair of brakes so that they will take hold the instant the foot touches the pedal, that they will apply exactly the same pressure on the two wheels, and yet will not run so loose as to rattle nor so tight as to drag.

Dummy Brake Drum Useful. Where a great deal of brake work is to be done, particularly in a shop where the greater part of the cars are of one make, and the brakes all of one size, a great deal of time and trouble can be saved by having a set of test drums. An ordinary brake drum with a section cut out so that the action inside may be observed is all that is necessary, except that it should be mounted suitably. As shown in Fig. 482, it is well to fit a pair of handles to the brake drum to assist in turning the drum when the adjustment is being made. The real saving consists of the work which is saved in putting on and taking off the heavy and bulky wheel each time when the adjustment is changed. The test drum is put on instead, and being small and light and equipped with handles, it is easily and quickly lifted on and off. This enables the workman to make a better and more accurate adjustment than he would when the heavy wheel had to be handled, while the cut-out section enables him to see the inside working also and thus correct any defects or troubles at this point.

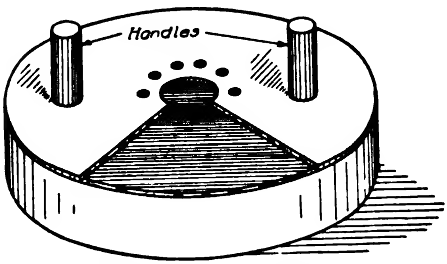


Fig. 482. Dummy Brake Drum for Adjustment Work

To Stop Brake Chattering. It is claimed that the chattering of brakes is caused by having the brake lining, particularly of internal hand brakes, extend over too large a portion of the circumference of the drum. The result is that with a well-adjusted system, as soon as force is applied, the lining close to the operating cam and that on the opposite side close to the pin on which the brake shoes are pivoted jumps against the drum and then away from it. This jumping of the brake shoe, which is the result of too much lining, is what causes the chattering. If the lining is cut away for about 30 degrees on either side of a line drawn from cam to pivot pin, as shown in Fig. 483, it is said that this chattering will stop immediately. If further trouble of the same kind results, bevel off the outside ends of the lining at the two 30-degree points.

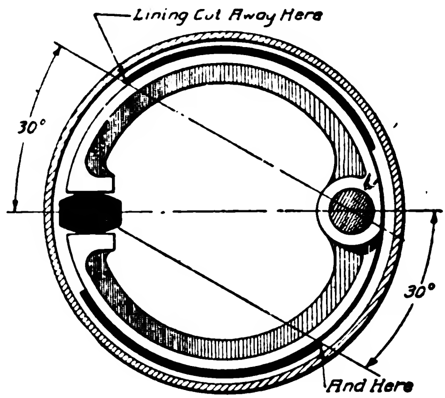


Fig. 483. Method of Eliminating Brake Chattering on Internal-Expanding Brakes

A number of suggestions in the way of possible brake troubles, particularly on the side-by-side form of internal-expanding brakes, are indicated in Fig. 484. This shows a semi-floating form of rear axle with the two sets of brakes and operating shaft and levers. A number of suggestions are offered for this form, the most important of which is: "Renew worn brake lining and broken or loose rivets."

When a brake lining is worn, the proceeding is much the same as with a clutch leather, with the exception that whereas the latter

Clean & refill cams

Fig. 484. Brake Troubles Illustrated

must have a curved shape, the former can be perfectly straight and flat. This simplifies the cutting; but most brake linings are made of special heatproof asbestos composition which is made in standard widths to fit all brakes, so the cutting of leather brake bands is not often necessary.

Eliminating Noises. Many times the brake rods and levers wear just enough to rattle and make a noise when running over rough roads or cobblestone pavements, but hardly enough to warrant replacing them. The replacement depends on the accuracy with which they work, the age and value of the car, and the attitude of the owner. In a case where the owner does not desire to replace rattling rods, the noise can be prevented by means of springs, winding with tape, string, etc.

If the rod crosses a frame cross-member or is near any other metal part, and its length or looseness at the ends is such that it can be shaken into contact there, a rattle will result at that point. This can be remedied or rather deadened by wrapping one part or the other. For this purpose, string or twine can be used as on a baseball bat or tennis racket handle, winding it together closely so as to make a continuous covering. Tire or similar tape may also be utilized. When this is done, it is necessary to lap one layer partly over the next in order to keep the whole tight and neat. It has the additional advantage of giving a greater thickness and thus greater resistance to wear. If none of these remedies are available or sufficient, burlap in strips or other cloth may be used, putting this on in overlapping layers the same as the tape.

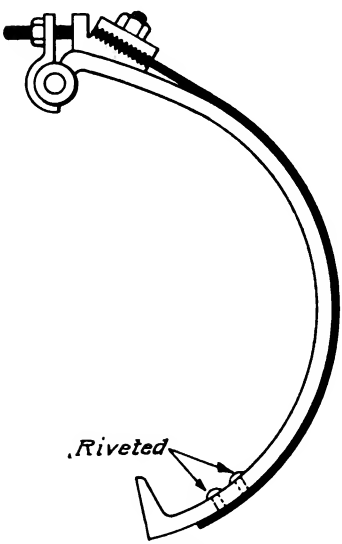


Fig. 485. Sketch Showing Method of Stretching Brake Linings before Attachment
Courtesy of "Motor World"

The springs should be put on in such a way as to take up the lost motion and hold the worn parts closer together. The rattle occurs when the movement of the car alternately separates and pulls together the two parts, a noise occurring at each motion. The spring should be put on so as to oppose this motion, acting really as a new bushing or pin, the pull coming first upon the spring and then upon the bushing or pin.

Stretching Brake Lining. Brake lining should be put on as tightly as possible, and the knowledge of this, combined with the difficulty of doing it by hand, makes the stretching device shown in Fig. 485 particularly valuable when much brake relining is to be done. This is a simple pulling clamp, which is attached to one end of the lining after the first end has been riveted in place. Then it is attached to the end of the shoe, and the nut tightened so as to stretch it. When it has been stretched sufficiently, the other rivets can be put in, or the shoe and band with the stretches in place can be laid aside for a while to stretch it fully before fastening. Obviously, this is applicable only to the internal-expanding form, but the hook and clamp can be used on any size or type of expanding brake.

Truing Brake Drums. When both inside and outside surfaces of the brake drum are used, it is highly important that both be true. Since they do not stay that way long, the repair shop should be equipped to true them up quickly. A truing device is shown in Fig. 486, with the wheel and brake drum in place on it. One feature of the device is that brake drums need not be removed from the wheel. The device consists of a metal base having a strong and stiff wooden pier with a horizontal arm the exact size of the axle end mounted on it. The wheels are placed on the arm and rest on it the same as on the axle when on the car. The tool is double, with two ends, one of which cuts the inside surface of the drum, while the other cuts the outer surface. At the center this tool is attached to a heavy casting, bored out to slide over the shaft and with a key fitted into a keyway in the shaft to prevent the tool from rotating. The end of the arm is threaded, and a large nut with two long arms is screwed up against the tool at the start, and then it is used to feed the latter across the work.

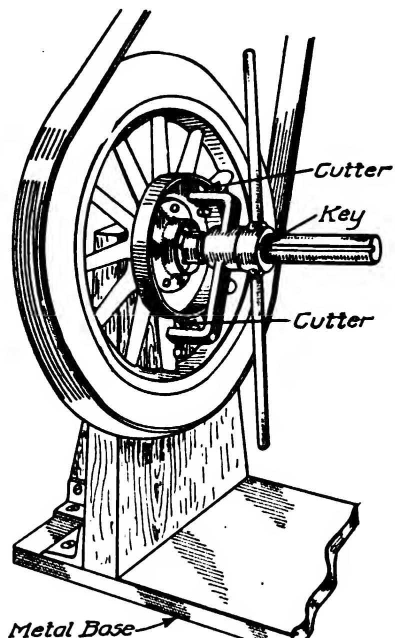


Fig. 486. Apparatus for Truing Inside and Outside of Brake Drum in Place on Wheel
Courtesy of "Motor World"

This is subject to a number of modifications to fit it to the various sizes and shapes of brake drum. Another method is to use the lathe, provided the shop is equipped with a lathe large enough. By making a mandrel the same as the axle spindle and having a pair of dummy bearings to place on it, the brake drum can be slipped on to the mandrel, and the whole put right into the lathe. The surface, either internal or external or both, can then be trued up exactly as if the drum were on the axle.

WHEELS

Broadly speaking, there are but two kinds of wheels according to the service each is to render, pleasure-car wheels and commercial-car wheels. The former may be further subdivided into wood, wire, and spring wheels; while the latter may be divided into wood, steel, and spring wheels. Some of the commercial vehicle wheels are further divisible, as steel wheels into sheet steel and cast steel; wood into spoked and solid; and spring wheels into various types.

Wheel Sizes. Wheels are used on automobiles, in combination with the tires, to afford a resilient and yielding contact with the surface of the road, so that people may ride with comfort. Therefore a wheel whose size is such as to yield the most comfort to the car occupants with due regard to its cost relative to the cost of the vehicle is the wheel to use. The cost of the wheels themselves, however, is so small in comparison with the cost of the pneumatic tires which are used on them as to be completely overshadowed by the latter.

Where comfort is sought as the prime requisite, cost becomes an accessory. The larger the wheel used the better the car will ride, and the greater will be the comfort of the occupants. This statement can be proved, although the gradually increasing sizes of wheels and tires as used on the best cars, both here and abroad—advancing from the early 26 and 28×3-inch tires, to as high as 38×5½-inch tires, and freaks up to 48×12-inch—should be sufficiently convincing.

Advantages of Large Wheels. A graphical demonstration of the difference between the action of the large and small wheel to the advantage of the former is shown in two drawings, Figs. 487 and 488. Fig. 487 presents the case of wheels passing over a common brick 4 inches wide by 2 inches high, and Fig. 488 shows the action in passing across a small rut in the surface of the road, 8 inches wide by 1¼ inches deep. In both cases, *A* shows the 28-inch wheel and *B* shows the 40-inch wheel. Both instances, too, have been selected at random, and not so chosen as to favor either wheel. It would have been possible to so select the sizes of both obstruction and depression as to make out a stronger case.

The height of the brick being 2 inches the wheel must rise that distance, whatever its diameter, but in the case of the 28-inch wheel, this rise of 2 inches is largely relative to the wheel diameter being one-fourteenth, or 7 per cent. In the case of the larger wheel of 40-inch diameter, the rise is again 2 inches, but it is now one-twentieth of the wheel diameter, or 5 per cent. In the case of the

Fig. 487. Diagram Showing Advantage of Large Wheels in Passing over Obstruction

smaller wheel, the rise is distributed over a length of about 18.43 inches from the moment when the forward edge strikes the obstacle to the moment when the last part of the tire leaves the last edge of the brick. If this rise were evenly distributed over this distance, rising as an arc of a circle, its radius would be slightly over 22 inches.

Considering the 40-inch wheel under the same circumstances, it performs the act of rising and falling 2 inches in the longer distance of about 21.5 inches, the radius of this rise being 38.75 inches. It is obvious that the latter is a much easier rise than the former, the lift being distributed over a length 16 per cent greater. Similarly, with the descent from the high point to the surface of the road again, this more gradual rise and fall convert the surmounting of the obstacle from a sharp upward bump and downward jounce into an easy and not unpleasant swinging up and down.

A drop into a hole, as illustrated by Fig. 488, shows the beneficial effect of the large wheel better, perhaps, than does the rolling over a rise. A rut in the road 8 inches across, into which the two wheels drop in passing, is shown. At *A*, the 28-inch wheel is seen to drop the considerable amount of $\frac{9}{16}$ inch, while at *B* the 40-inch wheel drops but $\frac{3}{8}$ inch into the same hole. Evidently the larger wheel has an advantage in so far as passing over obstacles or holes is concerned.

Again, on account of its larger radius, the arc of the larger wheel is flatter and has more length of tread in contact with the

Fig. 488. Diagram Showing Advantage of Large Wheels in Passing over Depression

surface of the ground, this being particularly noticeable on rough roads. Not alone does this mean added adhesion to the ground and thus lessening driving effort to propel the same car, but it also means a greater resistance to side slip or skidding, thus conserving the power and increasing the safety of the occupants. Other arguments could be offered in favor of large tires for easy riding, but those given should suffice.

PLEASURE-CAR WHEELS

Wood Wheels. Wood wheels are the most common form for pleasure cars in this country, being almost universal. Ordinarily, they are constructed of an even number of spokes, which are tapered at the hub end and rounded up to a small circular end with a shoulder at the rim, or felloe, end. Fig. 489 shows this construction, *A* being the felloe on which is the rim *B*, and *R* is the spoke which, at the hub end, tapers down to the wedge-shaped portion *P*. This matches up to the wedge-shaped ends of the other spokes, so that when the wheel is assembled they form a continuous rim around the central or hub hole.

The spokes are held at their inner ends by metal plates and by through bolts, which are set at the joints between the spokes so as to pass equally through each spoke, as shown at *D*. Not only do these bolts hold the spokes firmly to the wheel, but they have an expanding, or wedging, action tending to make the center of the wheel very rigid.

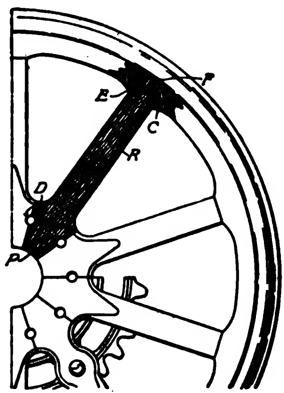


Fig. 489. Construction of Wood Wheels

The outer end of the spoke has a shoulder *E* and a round part *C*, which fits into a hole bored through the felloe. To prevent the felloe coming off after the spoke is in place, the spoke is expanded by means of a small wedge driven into it from the outside, as shown at *F*. In this way, the wheel is constructed from a series of components into a strong rigid unit.

Such wheels wear in two places, at the inner and at the outer ends of the spokes. The remedy in the latter case is to withdraw the small wedge and insert a larger one in its place. At the hub end, when wear occurs, this, too, must be taken up by means of wedges. Fig. 490 shows a method of doing this when the hub has no bolts at the joints. A false steel hub *A* is driven into the hub hole, after which wedges of steel are driven in between the wedge-shaped ends of the spokes. For slight cases of wear and squeaks, the wheel may

Fig. 490. Method of Tightening Spokes of Wood Wheels

be soaked in water, which will cause it to swell, taking up all of the space.

There are various modifications of this, nearly all of them changing the hub end of the spoke. In the Schwartz wheel, a patented form, each spoke is made with a tongue on one side of the wedge-shaped part and a groove on the other. In assembling the wheel, the tongue of each spoke fits into the groove of the spoke next to it, thus rendering the whole hub end of the wheel, when assembled, a stronger unit, being stronger in two directions, one of them of more than ordinary value. In driving the tongue into the groove, the wheel is rendered strong in a radial direction, but, when the wheel

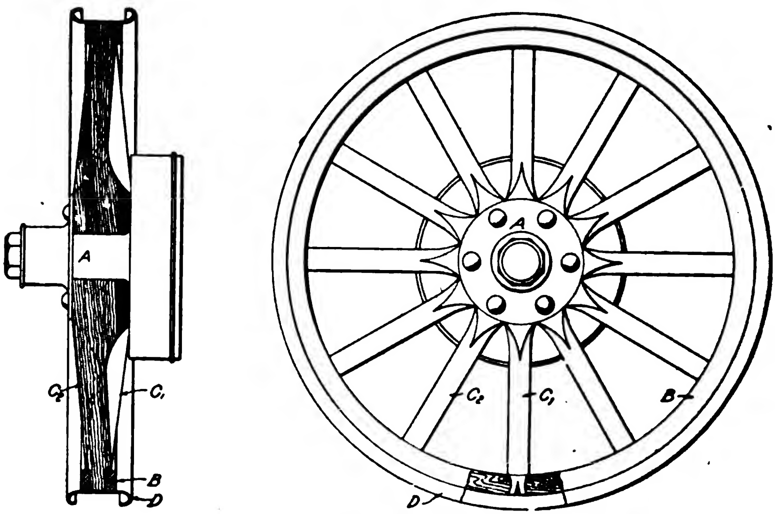


Fig. 491. Details of Wood Wheels with Staggard Spokes

is entirely assembled, the tongue-and-groove method leaves it very strong to resist side shocks, a point in which the wood wheel is weakest.

Staggered Spokes. As mentioned above, the wood wheel has little lateral strength, nor can it ever have, from the very nature of its construction, except in unusual cases, like the Schwartz patent wheel just described. A method of increasing the lateral strength somewhat is that of using staggered spokes, these being alternately curved to the outside and to the inside, as shown in Fig. 491. This gives one set of half the spokes forming a very flat cone with its apex, or point, at the inner side of the hub, while the others form another cone with its apex at the outside of the hub. Each one of these conical shapes is stronger to resist stresses from the side on which the point is located than would be the same number of spokes set flat. Hence, the staggered-spoke wheel has the advantage over the ordinary type in that it has greater strength from both sides. In the figure, *A* is the iron hub, *B* the felloe, C_1 the right-hand and C_2 the left-hand spoke, and *D* the steel rim for the tire. This is a 12-spoke wheel, 6 of the right-hand spokes C_1 and 6 of the left-hand spokes C_2. The section shows how these pass alternately to the one side or to the other, forming the strong cone shape.

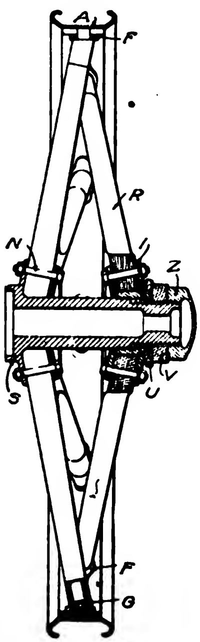


Fig. 492. Section of Steel and Wood Wheel

Fig. 493. Complete Steel and Wood Truck Wheel

Another method of handling this problem in a somewhat similar manner is the use of double sets of spokes, the spokes, however, being in two different planes separated a considerable distance at the hub. Of a necessity using the same felloe, the outer ends must be in the same plane. Fig. 492 shows a drawing representing a section through the center line of the wheel, while Fig. 493 shows a photographic reproduction of it.

In Figs. 492 and 493, *A* represents the steel rim on the felloe *F*, the latter being of metal in this case, as is also the wheel so it may be disassembled. The spokes *R* have a tubular end piece of metal *G*, which is set over the rounded end of each spoke and fits into a hole in the felloe. *I* and *S* are, respectively, the inner and outer parts of the hub, which are held together and to the spokes by means of the bolts *N*. *Z* is the hub cap, while *U* and *V* are filler pieces aiding in the dismantling process. The strength of the wheel is self-evident, but it is difficult to see the advantage of the disassembling feature, as a stress or strain which would break one spoke, would, in almost every case, break practically all of the spokes, thus necessitating a new wheel instead of new spokes.

Wire Wheels. Many of the little details of the automobile were inherited from its predecessor, the bicycle. Among these may be mentioned the wire wheel. Practically all bicycle wheels were and are of the wire-spoked type, and this same form of wheel was used on all earlier automobiles. It had no strength in a sidewise direction, nor did it, in fact, have much of anything to recommend it except its light weight. For this reason, it failed in automobile service, and received a setback from which it has even now not wholly recovered.

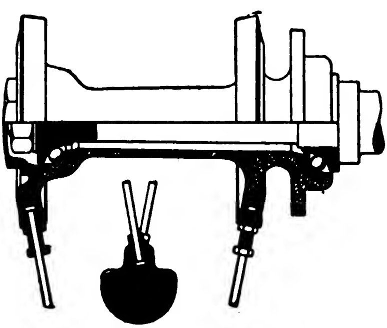


Fig. 494. Hub Details of Bicycle Wheel

Early Bicycle Models. Fig. 494 shows an early type of wire wheel for automobiles, its construction indicating clearly its bicycle ancestry. The spokes were set into a casting, which formed the hub, and into the steel rim by means of a threaded sleeve, the head on each end of the spoke resting on the inner end of the sleeve. The sleeves were screwed in and out to adjust the tension of the spokes. This tension was usually considerable, thus reducing in part the ability of the wheel as a whole to resist side stresses, for the piece already in tension could not be expected to sustain additional tension, or compression, or a combination of either with torsion, according to the way the force was applied. Then, too, the casting for the hub was wholly unsuited to resist stresses, and the distance apart of the spokes at the hub was not sufficient, making the cone so very flat that it had very little more strength than a perfectly flat wheel.

Following the failure of wire wheels, there was a rapid change to wood wheels, which were almost universal for several years. Soon after this change was made, there was an increase in the size and power of automobiles, which, in turn, was followed by a demand for lessened weights. In the meantime, makers of wire wheels, knowing their faults, began to re-design in order to eliminate them. Their success is best evidenced abroad, where about one-half of the French and more than two-thirds of the English cars, in addition to over seven-eighths of the racing cars in both countries, are now equipped with wire wheels.

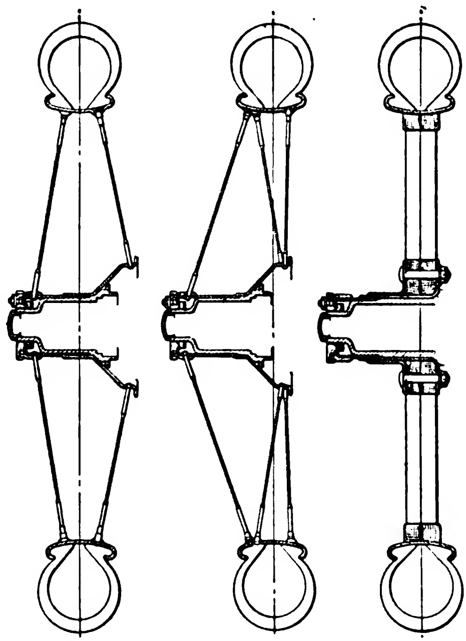


Fig. 495. Sections of Double and Triple Steel and Wood Spoke Wheels

New Successful Designs. This result has been brought about by a realization of the previous defects and their elimination. Thus, no more cast hubs are used, drawn or pressed steel of the highest quality and greatest strength being used instead. The spokes have been carried out farther apart at the hub, obtaining a higher cone and thus a stronger one. Spoke materials are better and stronger, besides being used in greater quantities, that is, larger spokes and larger numbers of spokes per wheel, in some cases a triple row of spokes being used in addition to the ordinary two rows. This additional row acts as a strengthener and stiffener much like the diagonal stays on a bridge. Fig. 495 shows a set of double-spoke wire, triple-spoke wire, and interchangeable wood wheels side by side for comparison, while in Fig. 496 is presented a recent triple-spoke front wheel in detail.

In the former figure, the relative depths of the various cones and their corresponding strengths are made evident, being side by side. In this comparison, it will be noted that the new triple-spoke wheel has a much longer outer cone than the double-spoke wheel, while, on the other hand, the inner cone has been flattened. The triple spoke has a greater depth, considering the set of them as an additional cone, than has the inner cone in the double-set wheels.

In examining closely the older double-spoke form and the newer triple type, it will be noted, also, how the wheel itself, or rather the tire and rim, have been brought closer in to the point of attachment, thus rendering the whole construction stronger and safer. In Fig. 495, it will be seen that the center line of both tire and rim passes midway between the inner and outer ends of the hub on double-spoke wheels, while on the triple form it is even with the inside end of the inner hub, being, in fact, farther in than is the case with the wood wheel. One thing will be noted in all these spokes, regardless of number, position, or inclination, and that is that their ends present a straight head. On the older bicycle spokes, the diagonal-spoke head was a great source of weakness, tending to create failure at the outset. The modern wire wheel is so constructed as to do away with this fault. By actual tests, the wire spoke—not the stronger triple spoke but the double spoke—has been found to have the following advantages: lighter weight for the same carrying capacity; greater carrying capacity for equal weight; superior strength from above or below in the plane of the wheel; lower first cost (it is doubtful if this will hold good for the newer triple-spoke forms); and, in addition, tests have proved superior strength in a direction at right angles to the plane of the wheel. So marked is the difference in weight of the two that five wire wheels are said to be lighter in weight than four wood wheels of equal carrying capacity.

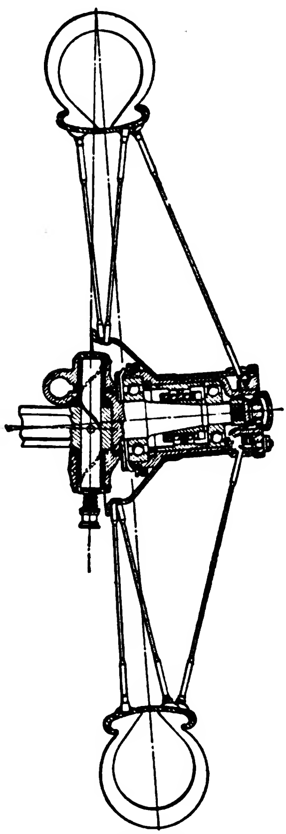


Fig. 496. Details of Triple-Spoke Front Wheel

All these arguments in favor of wire have been built up one by one, for much prejudice had to be removed. In spite of this, however, the wheel is slowly but surely building up a reputation and a long list of friends. Since, even now, England and the Continent continue to set the fashion in automobiles, it is not too much to expect to see wire-spoke wheels in common use in the United States in a few years. In fact, the dozen manufacturers offering this wheel in 1914, with ten more giving it as an option, have been increased to about forty who are fitting it regularly, with perhaps fifty or more offering it as an option in 1915. In fact, almost any car maker in the country will fit wire wheels for a slight additional charge.

For 1917 some 20 odd makes of cars are offered with wire wheels as regular equipment, and about 25 more offer this as an option without extra charge. As there are about 190 cars on the market, the former represents 10.5 per cent, and the latter 13.2 per cent of all makes; the two together total 23.7 per cent, or less than one-quarter. However, these figures do not quite indicate the relative popularity of wire wheels.

Wire Wheels Much Stronger. The increase in the use of wire wheels has been brought about by better designs; greater attention to the details of manufacture, assembly, and use; but primarily by the greater strength which has been built into the wire wheel. One way in which this has been done is by rearrangement of the spokes as, for instance, the triple-spoke form just described and shown in Fig. 469. Another and later form is the quadruple-spoke wheel as seen in Fig. 497. This is made and sold by the General Rim Company, Cleveland, Ohio, and is called the G-R-C wheel. As the sketch indicates, it has all the features of demount-

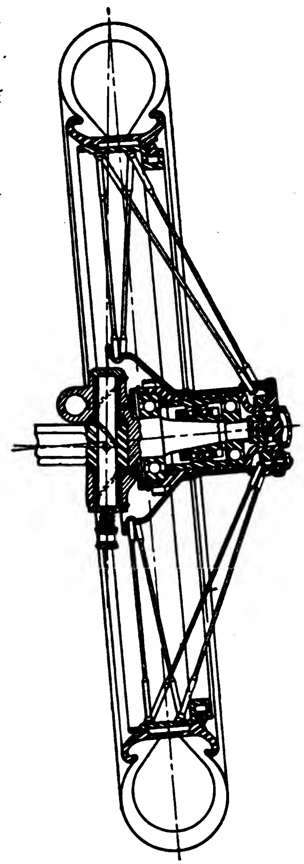


Fig. 497. G-R-C Quadruple-Spoke Wire Wheel

ability, etc., of other wire wheels, the notable differences being the spoke arrangement to give strength and the form of rim—a patented form to be described in detail later.

By comparison with Fig. 496, it will be noted that a double triangular section is formed in the G-R-C, the inner spokes forming the inside of the hub and the outside of the hub forming one triangle, while the outer spokes from each form the other. In Fig. 496, it will be noted that there is but the one triangle and a straight row of spokes.

Sheet-Steel Wheels. The sheet-steel wheel is really a form of wire-spoke wheel, with an infinite number of spokes joined together. It has many advantages, some of which might be mentioned as follows: strength, lightness, low first cost, low cost of maintenance, and cleanliness. To take them up in order, the strength of two steel plates set a few inches apart in a somewhat triangular form with the base toward the hub and well attached at the center and at the rim of the wheel, is self-evident. Aside from the natural strength of the steel plates—far in excess of the wire spokes—or round wood spokes, there is the strength of the triangular form. A strong connection at the top and at the bottom makes the whole construction very similar to a structural form. This shape closely resembles a box girder, having great resisting strength in all directions.

The light weight of the steel wheel comes from the thinness of the steel plates which are used, and similarly from the thin and light connecting members, either top or bottom. In Fig. 498 the junction at the top is seen to be nothing more than the steel rims for the tire, thus doing away with the usual felloe or substitute for it. In this figure, the wheel is seen to consist of the hub made with two flanges, to which the side sheets are bolted; the brake drum *I* bolted to the sheet on the inside, midway up its height; the steel rim mentioned before; and the bolts and rivets necessary to join the parts. At the hub, bolts are used to allow of dismounting the sheets in case of damage, for replacement or otherwise. At the rim, however, the plates are riveted to the rim, and riveted together.

Low first cost is brought about by the simplicity of the wheel. The wheel consists of the usual rim, not counted in the wheel cost, and two pressed-steel sheets flanged at the top, with a few holes punched in them. These sheets are very cheap to make, while the hub construction is much cheaper than the ordinary hub, for the reason that there are usually two parts where this construction requires but one, and this a very simple one needing little machining. Low maintenance cost is brought about by the rigidity of the whole construction; the few parts, which make few to replace or even to wear; the cheapness of these parts, when replacement is necessary; and the well-known strength and long life of sheet-steel plates.

On the score of cleanliness, it may be said that this is one of the drawbacks of the wire-spoke wheel, cleaning between and around

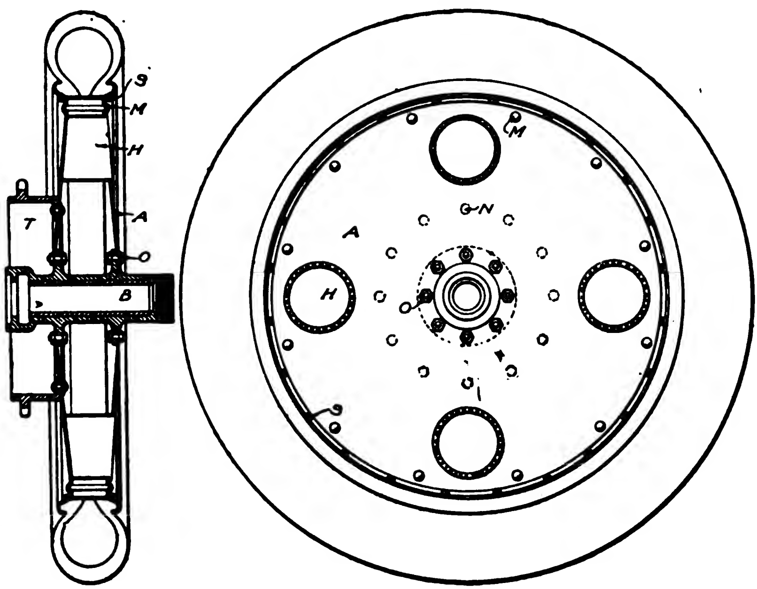


Fig. 498. Side and Sectional Views of Sheet-Steel Wheels

the spokes being very difficult, if not actually impossible. The large number of spokes makes the hub inside of the spokes impossible to clean, whereas, with the sheet-steel wheel, the cleaning consists in merely turning a hose on the sides of the wheel, the cleaning of the hub being entirely unnecessary.

It will be noted, too, in this illustration that the wheel has considerable spring, or should have, in a vertical direction. It is claimed for this type of wheel that this springiness is an added advantage as it allows the use of solid or cushion tires, and thus eliminates the troublesome pneumatic tire with its puncture and blowout possibilities. For commercial-car use, all of the advantages just mentioned are of double worth, for which reason the steel wheel is making great strides forward on commercial cars. Where the springiness of the wheels is not so desirable as strength, the sheet-steel plates may be replaced with either pressed- or cast-steel side members on which strengthening ribs are formed. The sides of the wheel have holes *HH* through them which are provided for ventilation, to decrease the weight of the side sheets, and to lessen the wind resistance to the wheel when moving rapidly. In some steel wheels these holes are omitted; in others a larger number than the four shown here are used. Fig. 499 gives a better idea of the general appearance of the wheel ready to use, being lettered the same as Fig. 498. The spokes shown in Fig. 499 are painted on the smooth exterior of the plates, but in other wheels these spokes are formed in the plates as previously mentioned.

Fig. 499. Sheet-Steel Wheel Complete

Steel Wheels Designed for Cushion Tires. Sheet-steel wheels, particularly those of very thin sheets, have a certain amount of springiness, this being utilized with solid and cushion tires on the assumption that the wheel will absorb the vibrations set up by the road inequalities. In Figs. 500 and 501, a wheel is shown which was designed for this express purpose. The wheel is called an elastic wheel and uses solid tires.

By means of the figures the construction is made clear, the wheel consisting of two halves, one a single sheet of metal attached to the hub and forming its own rim portion, and the other a section which consists of two sheets, one attached to the hub and forming its own rim portion, with another additional plate riveted to it near its outer end and attached to a middle flange on the hub. The two outer members of themselves would be very springy and consequently very weak, being of very thin metal. The diagonal extra sheet stiffens the whole construction, besides adding 50 per cent to its side strength. This is also of thin metal, so the whole wheel retains some springiness.

Parker Pressed-Steel Wheels. One fault with all the steel and sheet-steel wheels mentioned was that they did not resemble other wheels, consequently the people did not want them. Moreover, in many cases, their construction did not adapt them to the use of regular tires but, on the contrary, called for special and expensive forms. However, none of these drawbacks are present in a new form of pressed-steel wheel, Fig. 502. Upon close inspection it will be seen that this wheel has no felloe in the ordinary sense, the rim of the wheel forming the only felloe. In this respect, the wheel is an outgrowth of the former Healy demountable rim, the

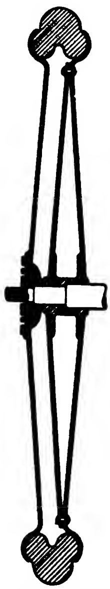


Fig. 500. Steel Wheel

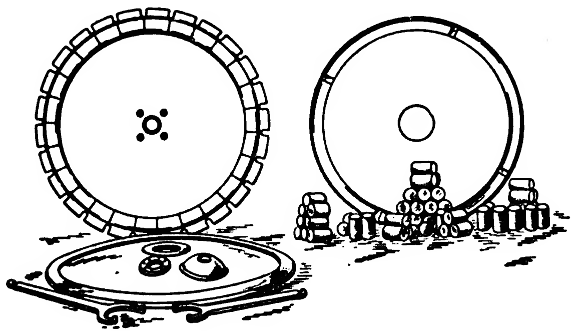


Fig. 501. Disassembled Steel Wheel

modern form being a combination of a demountable rim with steel spokes. This wheel is suitable for any car, the hollow steel spokes having great sustaining power. It is interchangeable with all ordinary wood artillery wheels of the same size, and fits between the usual hub flanges. The spoke portion is made as a pair of units, each forming half of all the spokes, the two being welded together. When finished in this manner, they have half the weight and more than twice the strength of the wood wheel, the greatest saving being at the rim, by the removal of from 60 to 100 pounds of metal and wood.

This wheel takes the ordinary demountable rim directly upon the ends of the spokes, the one shown being the No. 2, which is suitable for about twelve different rims as made by the largest manufacturers. The No. 1, whose only difference in appearance is a flat spot just under the bolt heads at the ends of the spokes, takes all one-piece clincher or straight side rims, whether clincher or Q.D. (quick detachable). The wheel shown is a 36- by 4½-inch size, made from .083-inch sheet steel, with ten spokes 1¾ inches round and a center portion, all of the same thickness of steel.

A number of other pressed-steel wheels, made, like the Parker, by pressing out two or more simple units, and welding these together, are making their appearance. These show great ingenuity and variety in the methods used to produce this same result and yet avoid the Parker patents. This form of wheel, having the appearance of wood, yet with greater strength and dependability and also of lighter weight, may perhaps be the final answer to the wheel problem; certainly this is possible if quantity production can bring them down below the price of wood wheels, which now seems apparent.

Fig. 502. General Appearance of Parker Hydraulic Steel Wheel

COMMERCIAL-CAR WHEELS

Requisites. On commercial cars the service is so different as to call for entirely different wheels. Of course, many commercial-car wheels are nothing but pleasure-car wheels with heavier parts throughout, but it is coming to be recognized that heavy trucks, tractors, and similar vehicles should have their wheels designed for the service required of them the same as lighter cars. No springiness or resiliency is required for heavy truck service, but simply these three things: strength to carry load and overloads; strength to resist side stresses; and such material, design, and construction as will make for low first cost and low cost of maintenance. A fourth desirable quality might be added to these, the quality of being adaptable or adapted to the tires to be used.

Wood Wheels. Taking Fig. 503 as an ordinary heavy vehicle wheel, let us see in what ways it fulfills or falls short of these requirements. The spokes are large in both directions and widened out at the felloe to give greater side strength. The felloe, which cannot be seen, may be judged as to size from the width and location of the dual tires, which would indicate great width and considerable thickness. This style of tire calls for a steel band shrunk over the felloe, while the heads of the cross-bolts show how the tires were put on and held on. All these make for great strength in both horizontal and vertical directions, and all parts except the spokes are simple to make, and even these are simple for the wheel manufacturer whose shop is rigged to make them. Moreover, to fill the last requirement, the wheel is adaptable to this tire or to any one of a number of motor-truck tires which might be used.

Fig. 503. Double-Tire Wood Truck Wheel

A slight variation from this is the double-spoke wheel, in which the spokes, in addition to being placed in double rows, are set so as to miss each other across the wheel, that is, each spoke of one row coming between two of the other. This placing allows the spokes to be made larger and stronger than in the ordinary case, while the double rows have the same strengthening effect as the tapering of spokes. The hub portion is assembled as two separate wheels, so that the work of assembling as well as of making the parts is slightly more than with the ordinary wheel. This is more than compensated for by the added strength. It is but fair to state that each of the last two wheels described is of English make.

In all wood wheels, the blocks composing the wheel and tire are of well-seasoned rock elm, sawed into wedge-shaped blocks, with the fiber lengthwise. The blocks are glued and nailed together until they form a circle. They are then turned round and to size in a large wood lathe, a shoulder ½ inch wide being formed at the same time on each side of the tire 2.5 inches from the tire surface. A heavy steel ring with a corresponding shoulder is then shrunk

Fig. 504. White Cast-Steel Wheel

over the wood shoulder on each side of the tire, drawing it together much like the ordinary steel tire on a wood wheel of a carriage. Bolts are run through these rings and through the wood blocks from side to side to prevent the blocks from splitting sidewise. To increase the life of this tire, steel wedges ¼ inch thick are driven crosswise into the face of it 2.5 inches deep around the whole tire about 3 inches apart. These wedges prevent the tire from slipping; in fact, they act like an anti-skid chain and do not harm the pavement, being set flush with the surface of the wood blocks.

It is said that one set of these tires was used for nine months, and at the end of that time they were still good for service. The tires reach clear to the hub, thus doing away with spokes and enabling the tires to be slipped over the hub and held in place by a removable flange bolted through the wood to the fixed flange on the opposite side of the hub.

Cast-Steel Wheels. The heavier the service the more unsuitable do wood wheels become, that is, wood-spoke wheels. For many five-ton trucks, practically all seven- and ten-ton trucks, and nearly all tractors, the cast-steel wheel is used, either spoked or solid, the spoked form being given the preference. Fig. 504 illustrates a spoked cast-steel wheel, fitted with a solid tire. The wheel is cast with ten heavy ribbed spokes, a ribbed felloe, and a grooved-felloe surface, into which the tire is set.

Miscellaneous Wheel Types. *Steel.* Steel wheels are gaining for heavy truck use, and a number of the better steel-casting firms are now getting into this work, with the result that better steel wheels are becoming available.

Other constructions, such as steel and wood combination wheels with removable and replaceable spokes, and the like, are rapidly going out of existence. Truck work is unusually severe, and it takes but a few weeks of actual use to show up any of the so-called freak wheels. The simplest seems to be the best, the only question at present being whether the material shall be wood or cast steel. Pressed steel may offer some opportunities in combination with welding, since good work has been done on pleasure-car wheels of this type.

Spring Wheels with Longitudinal and Tangential Springs. Spring wheels for both pleasure cars and trucks have not proved to be all that was claimed for them. For pleasure-car use they have gone out entirely; for truck use they are restricted to the smaller and lighter sizes, as the 1½- and 2-ton sizes driven at high speeds in city work. On these sizes, one or two well-designed forms are giving good service. The cherished dream of putting the pneumatic tire out of business through the medium of the spring wheel is still a dream.

When longitudinal springs are used to do away with the alternations of stresses peculiar to the radially disposed springs, the appearance of the wheel is much altered, as Fig. 505 shows. This wheel consists of an inner wheel, having its own spokes—ten in number—and its own felloe. To the felloe are attached by means of bolts V-shaped arms, which hold one end of a series of spiral springs, the other end of each of the springs being held in a similar V-shaped arm bolted to the opposite side of the outer felloe carrying the tire. There are eighteen of these springs in two sets of nine each. Those springs which have their near end fastened to the near side of the inner felloe have the far end fastened to the far side of the outer

Fig. 505. Seaton (American) Spring Wheel

felloe, while those attached to the far side of the inner felloe have the other point of attachment on the near side of the outer felloe.

When the wheel strikes an obstacle, a twisting action is set up, the outer felloe and tire moving while the inner felloe and axle remain stationary. This twisting of the springs tends to coil them tighter, which results, when the obstacle is passed, in the springs untwisting and turning the outer felloe and tire backward as far as it was previously moved forward. Since, however, the springs have a certain amount of stiffness in their coils, and the wheels do not rise and fall relative to one another, except in so far as the twisting action is concerned, it follows that considerable shock must be transmitted to the axle and thus to the body and its occupants. This wheel, therefore, while possessing strength to resist side stresses, does not give the smooth riding qualities so much desired.

A wheel very similar in appearance and action but with the wood spokes eliminated has been used very extensively in the last few years by the express companies and other big users of motor trucks. Starting with a few of them on front wheels, they have saved tires and tire money to such an extent that the companies have added more and more. Next they were tried on rear wheels. Seeing the good results obtained by the big companies with these wheels, many smaller firms and tradesmen with only one or two trucks have adopted them. They take a small size solid tire in place of a very large pneumatic and are said to cut the tire cost from one-half up to two-thirds and more. While used mainly for vehicles carrying a 1-ton load, they have been tried successfully on 2-ton vehicles.

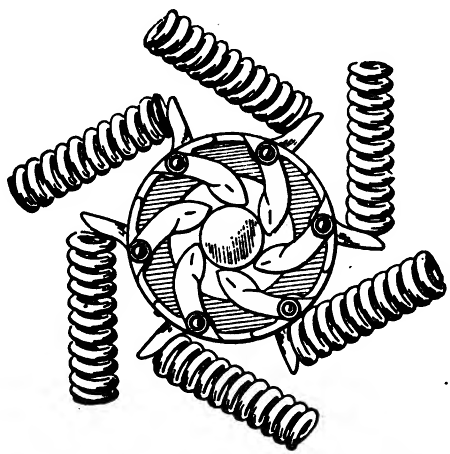


Fig. 506. Diagram of Action of Taylor Spring Wheel

It is in this class of service—the lighter vehicles for smaller firms—where every item of expense must be watched very carefully that the resilient wheel should show the best results. For heavy work, there seems little future for it.

A form of wheel which comes somewhere between the two just mentioned, having some side strength and easy-riding qualities, while at the same time participating in part of the principles of both those described, is that shown in Fig. 506, which is a diagram showing the construction. This consists of spiral springs used not radially nor longitudinally, but tangentially. Moreover, the springs are not attached directly to the hub, but to levers pivoted on an outer, or false, hub. When an obstruction is met with, so that the tension of the springs is altered, the springs act upon the levers and thus turn the false hub about the real inner hub by an amount corresponding to the character of the obstruction. This eccentric motion of the outer hub, induced by the spring action, takes up the shock of the road obstruction much as does the wheel shown in Fig. 505.

The construction is such as to allow of the springs being covered by means of a water-tight case, which will protect them from the elements and thus lengthen their life. This is a good feature which is lacking in all other wheels thus far shown.

Spring Wheels with Flat Spiral Springs. The flat spring bent into a semicircular or spiral form is little used for spring wheels. There is a double reason for this; they lack every desired quality, unless it be side strength. If stiff enough to handle considerable load, they are heavy, they are slow acting, and their action is long continued; if made light, they act too much and the vibrations are long drawn out. Moreover, if few springs are used, the breaking of a single one puts the wheel out of use; if many are used, the wheel becomes very heavy.

While a number of flat-steel spring wheels have been constructed both here and abroad, they have not been uniformly successful, as has been pointed out. A French form which was widely tried a few years ago had a pair of sets, each of six springs, with a long curving shape, one end attached to the hub and the other to the rim, while the leaves on the two sides were set in opposite directions. The idea was that loading would produce an eccentric movement of the rim relative to the hub, and that the opposing of the two sets of leaves would produce an absorption, one side absorbing the tendency to movement of the other. In practice, however, this idea did not work out, as it gave a noisy, hard-riding wheel, with a tendency for the springs to break. These disadvantages, added to its weight, put a stop to its use.

An American device, constructed along somewhat similar lines, but with all springs pointed in one direction, had only a limited use in the home town of the inventor and is not now used.

Modern Status of Spring Wheel. The more modern view is not that the solid tire will be eliminated, but that a form of steel-spring or other resilient wheel will be produced which will have all the advantages of wood and, in addition, will so save the solid rubber tires that mileages twice as great will be obtained. In this way, the tire cost will be cut in half, which will be sufficient within the ten-year life of the ordinary commercial car to warrant the purchase of the more expensive wheels.

In the use of spring wheels, as well as of wire wheels for pleasure cars, the tire and rim situations are closely inter-woven. No special form of wheel or rim can be successful which calls for a special tire in addition, because, in case of trouble on the road, in a small town, or anywhere outside of the big cities with large and varied sources of supply, the users would not be able to replace the tire. As will be pointed out later, the present rim-and-felloe situation, which might be described as chaotic, must necessarily continue until the tire situation is cleared up. That done—and it is now in a fair way of being done soon—the rim situation also will be quickly cleared up, and, following, that of the wheel felloes. The natural fitness of the various forms and the unfitness of others to meet popular demand is rapidly clearing the way for the engineers and manufacturers who are attempting this standardization work.

WHEEL TROUBLES AND REPAIRS

The removal and handling of wheels present probably the biggest problems in connection with them. True, broken wheels give the repair man a good deal to think about, but the quick accurate handling of jobs in which a broken wheel figures depends more upon possessing and knowing how to use certain equipment than anything else; the operations are so simple that they require no particular skill or knowledge.

Wheel Pullers. In handling wheels a wheel puller of some form is generally a necessity; wheels are removed so seldom that they are likely to stick, and they get so much water and road dirt that there is good reason for expecting them to stick or to be rusted on. This means the application of force to remove the wheel. For this purpose, a wheel puller is needed, and a number of these have been illustrated and described previously, as gear pullers, steering-wheel pullers, etc. Any one of these devices which is large enough to grasp the spokes of the wheel and pull the latter outward and, at the same time, press firmly against the protruding axle shaft will do the work well.

Sometimes, however, while owning a puller, a wheel breaks down on the road where this is not available, or the repair man is called without being told the trouble, so that he does not bring the puller with him. In such cases, the repair man must improvise some kind of a puller out of what he has on hand. Everyone carries a jack, so it is safe to assume that one of these will be available as well as some form of chain. If a chain of large size is not available, tire chains—particularly extra cross-links—may be fastened together to answer the purpose. If chain is lacking, strong wire, wire cable, or, in a pinch, stout rope can be substituted. Attach the rope, wire, or chain to a pair of opposite spokes of the wheel, Fig. 507, allowing usually about two feet of slack. Draw the chain out as tightly as possible, place the jack with its base against the end of the axle and work the head out by means of the lever until it comes against the chain. Then by continued but careful working of the jack, the wheel is pulled off the axle.

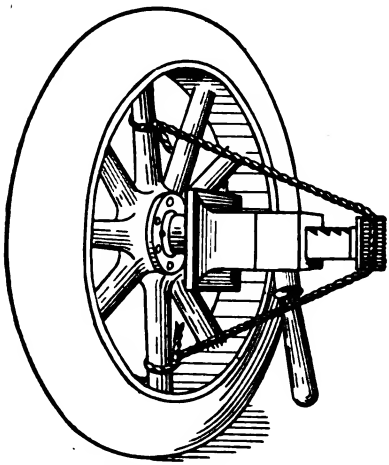


Fig. 507. Makeshift Wheel Puller for Road Repair Work

If rope, wire, or wire cable is used, it is advisable to place a heavy piece of cloth, burlap, or something similar over the head of the jack to prevent its edges cutting through this material. With rope only enough slack must be used to allow the jack in its lowest position to be forced under it; this must be done because there is so much stretch to the rope itself and so little movement in

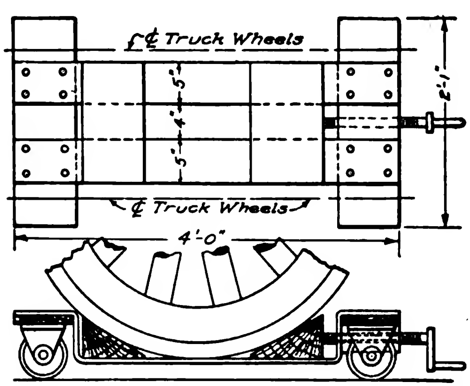


Fig. 508. Tire Platform or "Dolly" for Handling Truck Wheels

the ordinary jack, that the combination of rope and jack does not always work to advantage.

Similarly, the handling of heavy truck wheels gives much trouble even in the garage, for they are so big, heavy, and bulky that ordinarily two men are needed. One man can do the trick, however, with a platform or "dolly" like that shown in Fig. 508. This consists of a platform about 4 feet long by 25 inches wide, fitted with casters at the four corners. Inside of the central part are placed a pair of wedges, one of which can be moved in or out by means of a crank handle. To use this, the wheel is jacked up a little over 2 inches, and the truck pushed under. Then the movable wedge is forced in against the tire so that the two wedges hold the wheel firmly and carry all of its weight. Then the casters are turned at right angles so that the platform and the wheel may be moved off together. The truck wheel is removed in the usual manner, that is, with the aid of the wheel puller or such other means as the garage equipment affords. The dolly also forms a convenient means of handling the wheel when it is put back on its axle.

TIRES

Kinds of Tires. Broadly, there are three general classes of tires: the solid, the pneumatic, and the combination or cushion. The solid tire needs little comment or discussion here—being solely for commercial cars—except in so far as it is used with some form of spring wheel, hub, or rim, as just described. Similarly, the cushion tire is mostly used for electric cars, its use following that of the solid tire.

PNEUMATIC TIRES

The pneumatic tire was originally developed for bicycle use and in the beginning many single-tube tires were used. All of the tires used today have two parts—an inner and an outer tube.

Classification. Considering only the double-tube types, therefore, the pneumatic tire may be divided into three kinds: the Dunlop; the clincher; and various later forms brought out to go with the detachable demountable rims; and similar devices. These latter vary widely in themselves, but all are modifications of the clincher form, with minor differences of the difference in rims.

Dunlop. The Dunlop tire, so named after the Irish physician who invented and constructed the first pneumatic tire, is brought down to meet the rim in two straight portions, perfectly plain and of even thickness, that is to say, the tire has no bead, as it is now called. The tire fabric is brought down to a straight edge at the rim, as well as the rubber covering, as shown in Fig. 509. *A* is the steel rim of the wheel, *B* the inner tube, *C* the outer shoe, which at the rim or inner portion is brought down to the two straight parts *DD*.

This tire, like all of the early tires, had to be put on over the edge of the rim by sheer strength, coupled with the flexibility of the tire when not inflated. This was a hárd task, and, moreover, as soon as the tire was punctured or otherwise deflated, there was a strong possibility of its being thrown off, and possibly lost, at east after it had been stretched on and off the rim a few times.

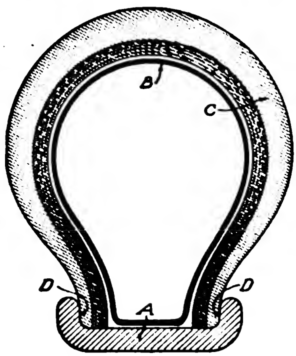


Fig. 509. Section of Dunlop Tire

Fig. 510. Section of Typical Clincher Tire

Clincher. To prevent this latter happening, the clincher rim and tire were brought out, each being dependent upon the other. In the clincher tire, the fabric is brought down to the rim, and then, instead of being left straight out as in the Dunlop, the material is formed into a hump, or bead, which is shaped just like the hollow formed in the rim. The latter differs from the usual Dunlop rim only in having this deep depression to fit the bead of the tire. Fig. 510 shows this, in which the parts are lettered as before. In both cases, the fabric of the tire is sketched in, and it may be noted that the layers are fewer in number in the older form.

The great majority of tires now in use are of this type, although, like the original Dunlop, it must be forced on and off the rim by the stretch of the deflated tire, and by sheer strength, coupled in this case with considerable natural ingenuity and some tools for lifting the hard non-stretchable beading over the edge of the rim at one point. This done, the rest is easy. For this purpose many tools have been bought; some good, some bad, and some indifferent. After a fashion, all do the work, but that tool is best which performs the operation most easily, most quickly, and with the least damage to the tire or rim. Fig. 511 shows a useful tool for this purpose.

The wire wheel and demountable rims, both allow quick road changes of damaged tires, leaving the work of tire repair to be done at home in the garage with proper heat, light, tools, and materials. This is rapidly bringing back into use the lower price clincher and straight-side tire forms, also many new tools have made their removal or attachment a much easier and more simple task.

Demountable Rim Types. Following the development of the clincher tire and rim until this form of tire was practically universal, came the first forms of the demountable rims, which consisted of a detachable edge or rim portion, like the edge of the clincher rim in section. These were locked in place in various ways in the different forms, but the first demountable rims—they were called detachable rims—were made by cutting the clincher rims into two parts, one of them detachable. This allowed of slipping the tire on over the rim in a sidewise direction, and did away with the stretching and pulling necessary with the plain clincher. Since this was a tire which was detachable more quickly than the ordinary tire, it was given the name "Quick Detachable", and now both parts are known to the trade as the Q.D. tire and rim.

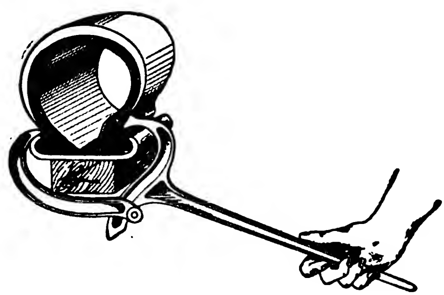


Fig. 511. Tire Removing Tool

Non-Skid Treads. All of the later developments in the clincher tire have been along the line of studded or formed treads to prevent skidding. In this many different things have been tried. Fig. 512 shows sections of many of the representative tires on the market. They are well known, and only the last three need any comment.

Fig. 512 *H* shows the Kempshall (English) tire tread, which is built up of a series of circular button-shaped depressions, or cups, which hold the pavement by means of the suction set up when they are firmly rolled down upon it. This tire has been very successful in England, but as yet has not been used much in this country.

The Dayton Airless tire, shown in Fig. 512 *I*, is a bridge-constructed cushion tire in which the usual air space is given over to a series of stiffening radial pieces of solid rubber, these with the tread forming the bridge or truss. Fig. 512 *J* shows the Woodworth adjustable tread for converting the usual smooth-tread tires of whatever shape or form into non-skids. It is a leather and canvas

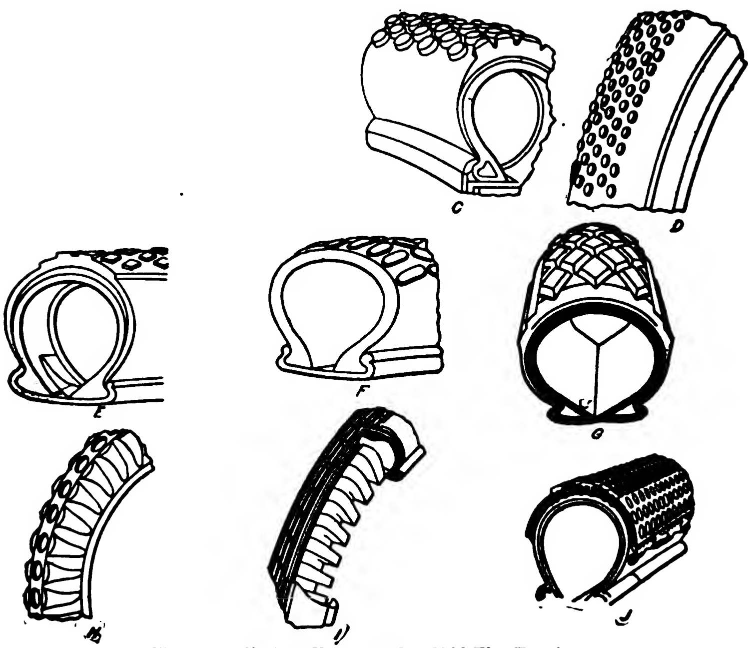


Fig. 512. Various Types of Non-Skid Tire Treads

built-up structure, shaped like the exterior of a tire, and freely studded with steel rivets. When in place, the tire has all of the appearance of a leather-tread tire with steel studs.

Proper Tire Inflation Pressures. With the recent great increase in the value of rubber and the price of tires, the advice of manufacturers on the subject of tire wear is of great and growing importance. Nearly every manufacturer of tires is now recommending a table of inflation pressures which agree among themselves more or less closely. In each and every case, however, the makers are advising higher pressures than those generally used, stating that the people do not pump their tires up hard enough to get the best results from the materials in the tires. There should really be no conflict of interests here as the owner should be as anxious to get his mileage out of the tires as the makers are to make good their guarantees.

Many makers have stated, as a result of their years of experience, that more tires wholly or partially fail or wear out from under-inflation than from any other one cause. It thus behooves the owner of a car to look well to the pressure in his tires, not occasionally but very frequently. As the majority of gages attached to pumps in public garages are seriously in error, each motorist is advised to purchase his own gage—one of the pocket type which is simple and inexpensive—and carry it with him at all times.

In some cases, it will be found that pumping the tires up to the makers' specified pressure will result in unusually hard riding, and the motorist must be his own judge as to whether he wants to ride more comfortably and get less wear out of his tires or to put up with the discomfort and get every cent of wear out of them. In this matter, very few will choose the latter course.

Use of Standard Pressure and Oversize Tires. There is really a different way out. If the tire pressure advised by the maker results in too hard riding for comfort while comfortable pressures result in too much wear, the motorist is advised to get large size tires. These on the same car will have a greater carrying capacity than the weight of the car by a large margin. Just in the proportion of the tire capacity to the weight of the car will be the pressure recommended to the pressure utilized.

A simple example will make this clear: Suppose, for instance, a car weighing 3850 pounds, equipped with 34- by 4-inch tires, for which the makers claim a carrying capacity of 1100 pounds per wheel and recommend a pressure of 95 pounds. If this pressure be too high for comfort, and lower pressures, say 80 or 85 pounds, result in too rapid wear, the motorist should use larger tires. For instance, a 34- by 4½-inch tire is scheduled to carry 1300 pounds per tire, and the pressure recommended is 100 pounds. The car weight per tire is 962 pounds, say 970. Changing to the larger tire gives a capacity of 1300 pounds per wheel, while the load is actually but 970. This change provides a surplus capacity which can be utilized to increase comfort.

Hence, if the tire be pumped up in the ratio of the carrying capacity of the tires to the actual weight carried, the spirit of the manufacturers' instructions will have been followed, comfort assured, and long life of the tire attained as well. Here the ratio of the capacity to the weight is as 1300 : 970. If now the pressure be figured from this, using the 100 pounds recommended, a suitable pressure will be obtained. Thus

$$1300 : 970 :: 100 : x$$
$$x = 74.6 \text{ pounds}$$

The pressure, therefore, in round numbers will be 75 pounds, and if this or any comfortable pressure above this be used, only the proper amount of tire wear will result, and a comfortable riding car will be assured.

However, this proposition, namely, changing from 34- by 4-inch to 34- by 4½-inch tires, is one which calls for entirely new rims, and possibly entirely new wheels, or at least new felloes, because the bottom diameter of the 34- by 4½-inch is different from that of the 34- by 4-inch. In such a case as this, the motorist would gain by changing to a still larger size, say 35- by 4½-inch, which change can be made without disturbing the old rims, as the 35- by 4½-inch is an oversize for 34- by 4-inch. This size also is recommended to carry 1300 pounds at 100 pounds pressure per square inch, but maximum pleasure and comfort will be obtained from it at between 72 and 80 pounds.

In general, the rule for oversize tires is this: Oversize tires are 1 inch larger in exterior diameter and ½ inch greater in cross-section than the regular sizes, and any tire so sized will fit interchangeably with the regular size on the same rim. In general, too, the even-inch sizes, as 30, 32, 34, etc., are considered as the regular sizes, while the odd-inch sizes, as 31, 33, 35, etc., are considered as oversizes. The above is for American or inch sizes only. The foreign, or millimeter, tire and rim situation is in an even worse condition, and changes of sizes are difficult in all cases and impossible in most.

Changing Tires. In the matter of changing tires, care must be exercised in selecting the new tire of such a size as will fit the old rim. A larger section of tire of the same nominal outside, or wheel, diameter would call for a smaller rim diameter, meaning a change in rims and possibly wheels. A larger nominal outside diameter will change the speed of the car and, if great, may be too much for the engine, calling for new gearing as well. The following tabular matter will be of interest, as it gives the changes in the metric size tires which can be made without altering either wheel or rim or changing the gearing.

Possible Tire Changes

760 mm. × 90 mm. wheels can be altered to	765 mm. × 105 mm.
810 mm. × 90 mm. wheels can be altered to	815 mm. × 105 mm.
	and 820 mm. × 120 mm.
840 mm. × 90 mm. wheels can be altered to	850 mm. × 120 mm.
870 mm. × 90 mm. wheels can be altered to	875 mm. × 105 mm.
	or 880 mm. × 120 mm.
910 mm. × 90 mm. wheels can be altered to	915 mm. × 105 mm.
	or 920 mm. × 120 mm.
815 mm. × 105 mm. wheels can be altered to	820 mm. × 120 mm.
875 mm. × 105 mm. wheels can be altered to	880 mm. × 120 mm.
	or 895 mm. × 135 mm.
915 mm. × 105 mm. wheels can be altered to	920 mm. × 120 mm.
	or 935 mm. × 135 mm.
880 mm. × 120 mm. wheels can be altered to	895 mm. × 135 mm.
920 mm. × 120 mm. wheels can be altered to	935 mm. × 135 mm.

These can be used without changing the gearing or the wheels, but to use different tires without changing rims is another matter. It will, therefore, be necessary to have another table of the various tires which are interchangeable on the same rim. Of the makes which are fairly international in character may be mentioned the German "Michelin" and the French "Continental". The following Michelin tires may be fitted to the same rim, the two tires on the same horizontal line being interchangeable in each case:

Interchangeable Michelin Tires

650 mm. × 65 mm. and	700 mm. × 75 mm.
700 mm. × 65 mm. and	750 mm. × 75 mm.
750 mm. × 65 mm. and	800 mm. × 75 mm.
800 mm. × 65 mm. and	850 mm. × 75 mm.
700 mm. × 85 mm. and	710 mm. × 90 mm.
750 mm. × 85 mm. and	760 mm. × 90 mm.
800 mm. × 85 mm. and	810 mm. × 90 mm.
860 mm. × 85 mm. and	870 mm. × 90 mm.

The following tires of the Continental make are interchangeable on the same rims:

Interchangeable Continental Tires

750 × 75 (motor cycle) and 750 × 80 (voiturette)
750 × 65 (motor cycle) and 750 × 65 (voiturette)
800 × 75 (motor cycle) and 800 × 75 (voiturette)
700 × 85 and 710 × 90 (light and heavy)
750 × 85 and 750 × 90 (light and heavy)
760 × 90 and 700 × 100 (light and heavy)
870 × 90 and 810 × 100 (light and heavy)
910 × 90 and 910 × 100
820 × 100 and 820 × 125
880 × 120 and 880 × 125
920 × 120 and 920 × 125
815 × 105 fit only 105 mm. rims

NOTE. Although the 105 mm. tire requires a special rim, a 90 or 100 mm. cover can also be fitted on the same rim in the case of necessity.

810 × 90 or 810 × 100 fit on the 105 mm. rim
875 × 105 fit on the 105 mm. rim
910 × 90 or 910 × 100 fit on the 100 mm. rim
895 × 135, 935 × 135, and 1000 × 150 require their own special rims

Speed Changes Due to Changed Tires. Before leaving the subject, it might be well to say a few words concerning the change of speed which a change in tire sizes will make in a vehicle, this in some cases being so serious as to impair the utility of an engine formerly found to be right in every particular. In the course of a very wide experience, the writer has found this to be the case with many old cars. Using the old small wheels and tires, the engine was able to negotiate all grades easily and make the required speed at all times. With a change to larger wheels and tires, the car ran faster at all times and gave much more trouble generally. It also proved a poor hill climber, so much so, in fact, that the owner had to go one step further and change the gearing so as to give the old speed ratios before the engine again acted satisfactorily.

Recent Tire Improvements. There have been but three recent notable improvements in tires which are briefly discussed.

Tire Valves. There have been several kinds of troubles with the old form of tire valve. It was spring actuated, and the springs were so small as to cause much trouble; further, it had to be screwed in place, requiring a special tool. There are several new valve forms with more than one seat, and others with an improved seat designed to screw in with the fingers and to offer little or no resistance to inflation.

Inner Tubes. Improvement has been made in inner tubes by the use of better and purer rubber in much thicker sections. Some of these have a partial fabric reinforcement; others are made and then turned inside out so that the tread portion is under compression, thus resisting punctures or internal pressure. Other designs present a tube larger than the inside of the tire before inflation; this produces a truss formation of the rubber, which the air pressure stiffens.

Cord Tires. The real improvement of value, however, is the cord tire. One form of this is shown in partial section in Fig. 513. This shows graphically that the difference between this tire and

Fig. 513. Section of Goodrich Silvertown Cord Tire, Showing Inner Construction

other forms is that the 4 to 6 or more layers of fabric have been replaced by two layers of diagonally woven cord. This cord is continuous, rubber impregnated, rubber covered, and, through its size, allows a great and very even tension. Lessening the amount and thickness of the fabric has given a greater percentage of rubber in the tire; consequently, the cord tire is more resilient. The advantages claimed for it are: less power used in tire friction, which means more power available for speed and hill climbing; greater carrying capacity in same size; saving of fuel; greater mileage per gallon of fuel; additional speed; quicker starting; easier steering, thus less driving fatigue; greater coasting ability; increased strength; and practical immunity from stone bruises owing to superior resiliency.

RIMS

Kinds of Rims. Nearly all rims are of steel or iron, but vary greatly as to types. The writer has therefore chosen only a few of the well-known ones, no preference being shown in this.

Rims will be taken up in the order of their development. Naturally, the first rims were of the plain type, while the latest are of the demountable, remountable, or removable types, all these being very much the same. Between the two came the clincher rim, which is properly a plain rim; and the quick-detachable rim.

Plain Rims. The form of rim first used was naturally the solid type, shown with the Dunlop tire in Fig. 509. This form is a simple endless band with two edges just high enough to prevent the tire from coming off sidewise when it has once been stretched in place. Nothing like it is used today, the nearest approach being the form of rim used with single-tube bicycle tires.

Clincher Rims. Clincher rims were brought out primarily to avoid the weaknesses of the Dunlop, viz, a weakness at the base, and, hence, it had an unusually heavy bead. Another fault which this tire remedied was the tendency under high pressure for the tire to draw away from the rim. This was avoided by the edge of the clincher being made fairly wide where it was designed to go into the pocket, or groove, formed by the contour of the rim.

It is the depth of this pocket, or groove, and the corresponding size of the edge of the bead on the tire, both excellent qualities, which make the tire hard to put on and take off. This may be seen from the previous illustrations of clincher tires, notably Fig. 510.

Quick-Detachable Tire Rims. It was this inherent difficulty of handling the clincher tire and rim which brought about the quick-detachable tire. This did not differ from the clincher tire in the tire portion, the difference being in the rim, which has one curved portion made in removable form, with a locking ring outside of it or made integral with it. In some quick detachables, the rim is expanded by a special tool and a spacing piece set into place, which holds the edge expanded. When this is done, the ring—as it is a simple ring with special ends—is held in place until released by the use of the special tool. On the end of the ring there are two little square lugs which project downward and have a hook shape. The one edge of the rim, made flat and straight on that side, has a slot with staggered, rectangular ends into which these lugs fit. It requires force to spring the rings together so the lugs will go into the slots, but once in place, the natural springiness of the rings holds them firmly in place, and holds the tire as well.

Figs. 514, 515, and 516 are given to show how this ring is put in place on a tire. Fig. 514 shows the beginning of the operation, and the instructions for the different steps will make them clear. Thus:

Always start with left end of the ring. Lock this in the rim as shown in Fig. 514, so that the end of the ring is flush with the slot provided for the second end. A dowel pin is provided to register the ring in the proper place. This must always be correctly centered or the ring cannot be applied. This done, the balance of the ring can be forced over the flange of the rim, as shown in Fig. 515, with the exception of the locking end. By means of the tool, the last locking end can be

Fig. 514. Putting on a Q.D. Tire. The Start

Fig. 515. Putting on a Q.D. Tire. Forcing Flange over Rim

raised and forced over the rim into the recess provided for holding the same in position preparatory to drawing the ends together, Fig. 516, showing the correct position of the tool.

Then by entering the two points of the tool in the holes provided in the ring, the ends may be drawn together, as shown in Fig. 516, and, with a slight additional leverage, the ends of the rings can be made flush.

Before proceeding further, it should be stated that the object of the quick-detachable rim is the quick removal of the tire, in order to allow a quick repair or substitution of the inner tube. On the other hand, the object of the demountable, remountable, removable, and other rims is the removal with the tire of the rim itself to allow the substitution of a new tire and rim, the tire being already inflated and ready for use as soon as applied. The object of the removable wheel is the removal of the entire wheel with rim and tire in order to substitute a spare wheel with already inflated tire.

It might be thought that these methods called for the carrying of extra weight, but the amount added is actually very small, as, by their use, tire tools and pump are dispensed with and their weight saved.

Fig. 517 shows the former Goodyear rim. This rim, as will be noted, is of the quick-detachable type, the idea being to remove the tire only. The rim itself has a button-hook shape with a slight ridge, or projection, answering to the handle. This is on the fixed side, the inner flange inside of the tire butting against it as a stop. The tire is pushed over against this, being held on the outside by a second flange of similar shape. The latter, in turn, is fixed in place by a locking ring, a simple split circular ring of deep oval section. This fits into the button-hook portion, its contour being such as to fit it exactly. In use, it is sprung into place, the outer edge of the hook on the rim and the natural spring of the ring preventing it from coming out. This makes a very simple and serviceable quick-detachable rim. To make doubly certain that the locking ring cannot jump out, a spreader plate is attached to the valve stem; screwing this down into place wedges the bead of the tire over against the outer flange,

Fig. 517. Former Goodyear Universal Rim

which, in turn, pushes the locking ring tight against the outer curved part of the hooked rim. When in this locked position, the upper part of the flange hangs over the locking ring, so that it cannot rise vertically, the only manner in which it could come off. This rim is shown with a detachable tire in position, but may be used with any standard clincher tire by the use of extra clincher flanges. Fig. 518 shows the rim with a set of these flanges in position, ready to take a standard clincher tire.

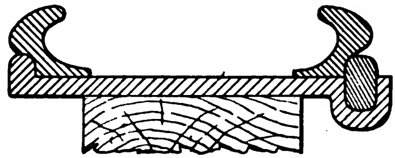


Fig. 518. Adapting Goodyear Rim to Clincher Tires

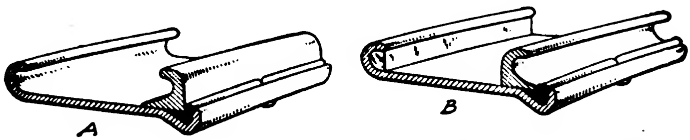


Fig. 519. Universal Q.D. Rim No. 2 Arranged for Clincher and Dunlop Tires

Quick-Detachable Number 2. Figs. 519 and 520 show the standard quick-detachable rim, now known as No. 2. This was adopted by the Association of Licensed Automobile Manufacturers

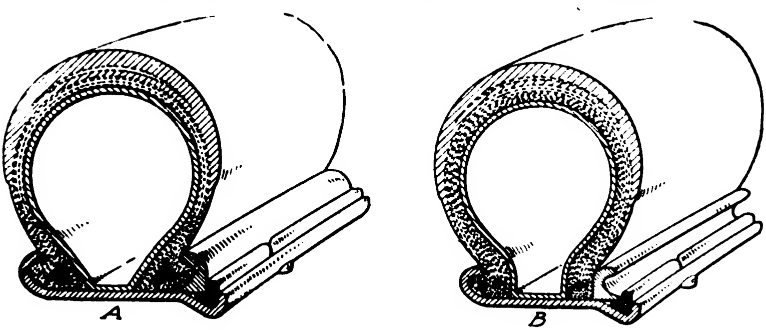


Fig. 520. Universal Q.D. Rim with Tires in Place

as a standard and given the above name. It has the feature of accommodating all regular clincher, or Dunlop tires. In Fig. 519, it is shown at *A* ready for a clincher tire and at *B* ready for a Dunlop tire, the adaptation for the straight sides being shown.

The two parts of Fig. 520 show sections of tires in place, making clear the exact use of this reversible flange. *A* shows a regular clincher tire in place, while *B* reveals the reversed flange in place with a Dunlop tire. Both Figs. 519 and 520 show the construction of the device, the outer dropped portion of the rim having a hole through it. The locking ring is split vertically and one end, just at the split, carries a projection or dowel pin extending downward. To put the rim on, this dowel pin must be fitted into the hole in the rim to give a starting place. When this has been done, one may force the balance of the ring into place around the wheel with any suitable, thin, wedge-shaped tool.

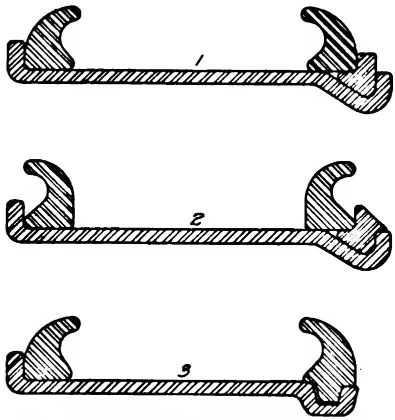


Fig. 521. Sections through Three Popular Q.D. Universal Rims

The shape of this locking ring with a right-angled groove in its inner edge permits the outer flange to overlap it, which insures the retention of the ring when once it has been put in place. Furthermore, it gives the outer side flange a wider seat on the rim, thus making it more stable and longer wearing.

As will be noted, the difference between these two rims—that is, the old Goodyear and the Universal No. 2—lies in the saving of one ring and the shape of the locking ring. Both of these are called universal rims because they may be used interchangeably for straight-

Fig. 522. Latch Used for Locking Single Combination Ring which Replaces Former Side Ring and Locking Ring

side and clincher types of tire. Other Q. D. Universals are shown in Fig. 521, although, in the opinion of tire men, the Universal form is slowly going out of use.

To explain these briefly, No. 1 is a modification of the Goodyear, with different shaped inner rings, while the locking ring and the lip formed in the felloe band to receive it are similar to those of Universal No. 2. In *2* the only difference from *1* lies in the locking ring, which has a modified Z-section, with a lip extending over the outer edge of the felloe band. The third section differs from the other two only in having the outer ring and locking ring combined into one, and the felloe band changed to suit this. This combination ring is held in place by means of a simple swinging latch, which is shown open and closed in Fig. 522. When opened, this permits raising the end of the ring, to which the shape of the felloe band offers no resistance. The whole inner ring is taken off, following around the circumference of the wheel, after which the tire is easily removed.

Quick-Detachable Clincher Forms. To return to the plain clincher tire and the Q. D. rim, which allows of its ready removal,

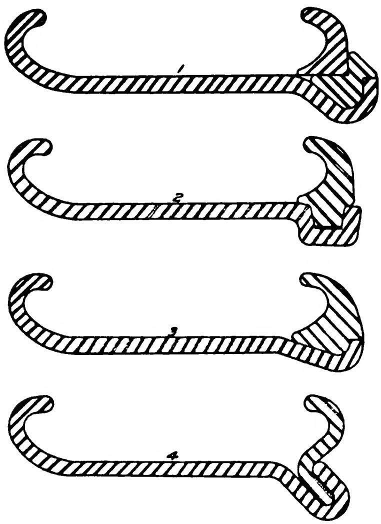


Fig. 523. Popular Forms of Q.D. Clincher Rims, Shown in Sections

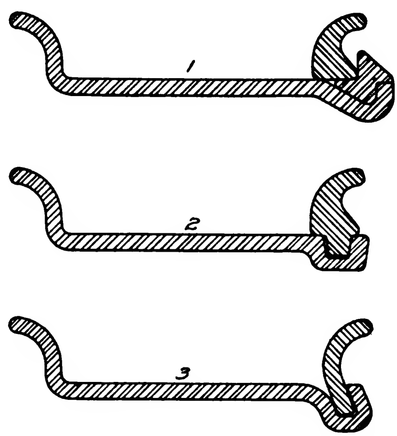


Fig. 524. Three of the Most Widely Used Straight Side Q.D. Rims

Fig. 523 shows four of the most prominent forms, these being indicated simply as flat sections of the rim, for the tire is the same in all cases. All these have the simple clincher edge on one side, with removable ring and locking device on the other. That at *1* has the same locking device shown at *2* in Fig. 521, the Z-shaped ring extending over the edge of the band. That at *2* is practically the same as *3* in Fig. 521. The one seen at *3* is similar to that at *2* except for the detailed shape of the ring as well as the lock (not shown). The advantage of the form shown at *4* is that the outer ring is self-locking, that is, the shape of ring and band are such that when the former is in place the tire itself locks it. Its only disadvantage is that it is harder to operate than the other forms, yet despite this fact it has been recommended for general adoption as the only Q.D. clincher rim worth continuing.

Q.D. Type for Straight Sides. To close the subject of straight side tires, the rims of the quick-detachable form now in use aside from those already shown are seen in Fig. 524. Here these are seen to be identical with *1*, *2*, and *4* of Fig. 523, except that the fixed side is arranged for a straight side instead of being made with a clinch. Here again, the last form of self-locking type has been recommended as a standard.

Demountable Rims. All, or practically all, demountable rims come under one of two headings—those in which the tire can be detached on the wheel without demounting (if it is so desired) and

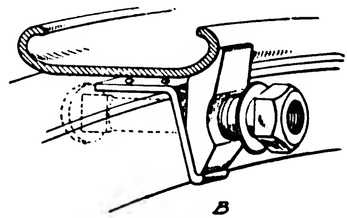


Fig. 525. Sections of Michelin and Empire Demountable Rims

those which are of the transversely split type and must be demounted before the tire can be removed. In addition, there is a second division of demountable rims into those which have a local-wedge form of attachment and those which have a continuous holding ring, this, in turn, being held by means of local wedges. Any of the plain demountables, which will be called demountables from now on, may be of either type of attachment, as is also the case with the first-named or demountable detachables.

Local Wedge Type. In the so-called local wedge type, which includes the well-known Continental forms (notably Standard Universal Demountable No. 3 and Stanweld No. 22 and No. 30), Michelin, Empire, Baker, Detroit, Prudden, Standard Universal Demountables No. 1 (formerly the Marsh), and No. 2, and others, loosening the six (or eight, as the case may be) bolts frees the rim directly without further work. In some of these, such as the Michelin; the various Continentals, including Stanweld No. 22 and No. 30;

Detroit; Baker; and others, the wedges carry a projecting lip, which makes it necessary to unscrew the nuts far enough to allow the removal of the wedge so as to pick this lip out from under the tire-carrying rim. In others, such as Empire, S.U. No. 1 and No. 2, the construction of the wedge and rim is such that loosening them frees the rim, the upper part of the wedge or clip swinging down to the bottom position as soon as loosened, because of its heavier weight and the fact that there is no projecting edge to prevent it. While this latter construction makes a faster operating rim, it is an open question as to whether it is as safe as the other form. These two constructions are shown very plainly in Fig. 525, in which *A* is the Michelin with lipped wedges, and *B* the Empire with plain wedges.

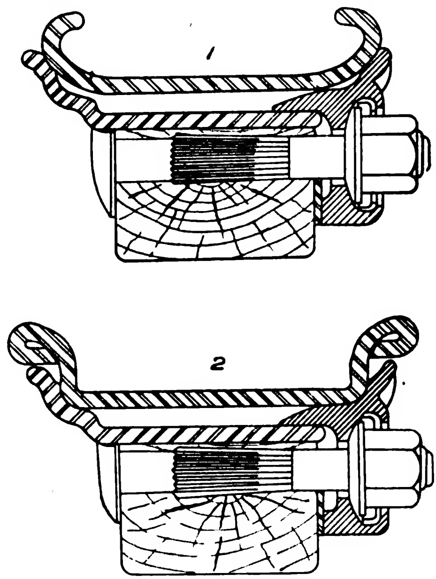


Fig. 526. Two Popular Demountable Rim Forms—for Clincher Tires above, for Straight Side below

In Fig. 526 is shown a pair of additional demountables, which are held by the local wedge method, the difference here being in the form of a wedge. Note that *1* has a solid clincher rim and *2* a straight side rim. The base, however, is the same for both and, as will be seen by examining this, has two curves in its upper surface, the straight side rim fitting into the lower

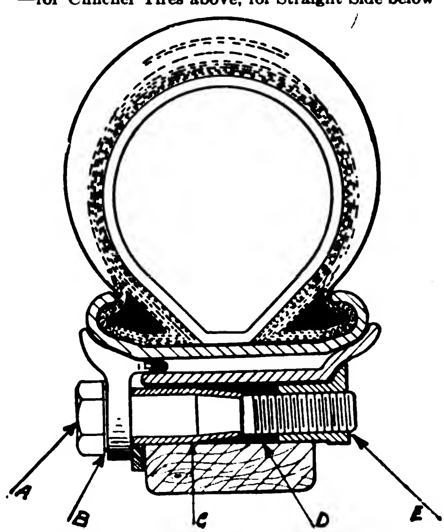


Fig. 527. Sectional Drawing Showing Construction of Baker Demountable Rim

or bottom one, while the clincher form of rim fits into the upper one. Note, also, that the wedges are the same for these two. This makes the demountable parts of the rim practically universal in that the owner can change from clincher to straight side or *vice versa* by simply purchasing the extra set of tire-carrying rims, no change in the wheels or means of attachment being necessary. For this reason, the felloe band shown under these two rims has been suggested as a standard for demountables.

Fig. 528. The First Operation in Removing Baker Demountable—Loosening the Bolts

Process of Changing Baker Local Wedge Type. In Fig. 527 is shown the Baker, which, as mentioned previously, is of the local wedge type of demountable, having a transversely split rim which must be removed from the wheel before the tire can be taken off. Perhaps this whole action will be shown more clearly by the progressive series of views, Figs. 528 to 538, which show the various steps in removing and replacing a tire and tube mounted on a Baker rim, the same as is shown in section in Fig. 526. First, all the wedge bolts except the two nearest the valve stem, one on either side, are loosened by means of the special brace

Fig. 529. Second Baker Demounting Operation—Jacking the Wheel and Starting to Pry off Rim

until the wedges swing out and down, as shown in Fig. 528. As mentioned previously, this means quite a little loosening, for the wedges have a long lip which projects under the tire-carrying rim. When this has been done, and as each one swings down out of the way, it is tightened just enough to prevent the wedges from swinging back.

This done, the wheel is jacked up off the ground, as shown in Fig. 529, and the point of the tire tool is inserted between the felloe band and the rim carrying the tire at the point opposite the valve, where, it will be remembered, the wedges were loosened, and the rim will be almost free. By prying the tire-carrying rim outward and working around it toward the valve and back again, it will finally be loosened to a point where, with the valve at the bottom, the rim and tire can be slipped off without lifting it. The extra tire and rim are now put in place.

Fig. 530. Third Baker Operation—Putting on New Tire and Lowering Wheel

This is shown in Fig. 530, where the reverse of the operations shown in Fig. 529 and just described is followed, that is, the valve stem hole is revolved to the top, the valve stem inserted, the rim pressed into place all around, then the wheel is revolved until

Fig. 531. Fourth Operation—Tightening Bolts on the New Tire and Rim

Fig. 532 Fifth Operation—Starting to Take the Rim out of the Tire—Beginning to Pry Short End

Fig. 533. Sixth Operation—Forcing Down the Short End of Rim

Fig. 534. Seventh Operation—Prying under the Loose End of Rim

Fig. 535. Eighth Operation—Raising the Free End of Rim, Using Both Hands

Fig. 536. Ninth Operation—Inserting Valve Stem and Beads in End of Rim

Fig. 537. Tenth Operation—Prying Tire Away from Rim to Let Latter Slip into Place

the valve stem comes to the bottom, so that the two wedges which have not been loosened are nearest the ground. Then the jack is let down and removed, the whole weight of the wheel coming on the bottom point where the wedges are already tight, never having been loosened.

This action is necessary as, with the weight on the other points where wedges are still loose, it would be necessary to work against the car weight. At this point, as Fig. 531 shows, the nuts are loosened, using the special brace until the wedges can be inserted under the rim. This done, the nuts are tightened to hold them there. This tightening is continued until the little studs, or lips, in the rim rest on top of the outside edge of the felloe band, using the tire tool to force them in, if necessary. The new tire carried is supposed to be ready for use, that is, inflated to the proper pressure, so that these four actions complete the work of making a roadside change.

When it is desired to repair the tire which has been removed, it is carried home on its rim just as taken off the car wheel, and the rim is removed from the casing as follows: Rim and tire are laid flat on the garage floor, as shown in Fig. 532, so that the outer end of the diagonal cut in the inside of the rim which is farthest from the valve stem is uppermost. An inside plate will be found on the rim which covers the two rivet heads on either side of the cut, with a central hole for the valve stem. This plate is called the anchor plate and must be removed. To do this, begin at the short end of the rim, which does not have the valve stem—as, in this position, it will be held in the long end—and insert the sharp end of the tire tool or a screwdriver under the bead or between the bead and the rim.

These two actions, as shown in Fig. 533, bring the two short sides of the rim closer together and thus reduce the diameter. When the extreme end has been freed in this way, the operation is repeated some 5 or 6 inches farther around, that is, that much farther away from the slit. This done, a considerable portion of one end will be free. Then turn the rim and tire over so that this free part comes at the top instead of at the bottom and, standing on the part which is still tight, insert the tool between the rim and the entire tire.

This frees the entire end, but, to make sure, the tool must be moved a little farther along so as to free more of it. When enough has been freed to allow grasping it with both hands, as shown in Fig. 535, the tool is dispensed with and, taking a firm grip on the rim, at the same time standing on the tire at the point where tire and rim still contact, pull upward strongly. When followed all the way around this pulls the rim entirely out of the tire.

Having the casing and tube free, they may now be inspected and repaired. When this is done, or if it is not done, and a new tire or tube or both are used, the worker is ready now to replace the rim. This is practically the reverse of the method just followed out. As shown in Fig. 536, the rim is laid on the floor; then the end which has the valve-stem hole drilled in it is raised, and the valve stem inserted. Next the beads are pulled into the rim, it being necessary to press them together somewhat tightly in order to do this, but, with a little practice, it soon becomes an easy matter. All this is done with the other part of the rim underneath the tire.

The inserted end of the rim is followed around with the thin end of the tire tool, as shown in Fig. 537, the position of the tire above the rim allowing the workman to stand on it and thus use his weight to press the two sides of the tire together and, at the same time, to force them into the rim. This operation is followed right around the inside circumference of the tire, the free, or short, end of the rim being the last part to enter. On account of the shape of the joint or cut in it, this should slip readily into its proper place, but if it does not, the thin end of the tool can be used to pry it into place, or a hammer can be used on the longer side to drive it in.

Fig. 538. Eleventh Operation—Inserting Anchor Plate

The rim being fitted snugly into place all around, the anchor plate is inserted, Fig. 538, to prevent the short end slipping out again, and the tire is ready for inflation. If it is to be carried as a spare tire, the dust cap should be screwed into place over the valve stem, so as to preserve the threads which might be damaged in handling.

Rim with Straight Split. This covers the action of practically all the demountables in which the transversely split rim is used, necessitating the removal of the rim and tire from the wheel before the tire can be taken off the rim. However, not all rims are split on a diagonal as is this one, and Fig. 539 is presented to show this single feature on another rim, which otherwise is somewhat similar. Here the rim is split at right angles, having a plain thin rectangular plate *A* attached to the free end, or that which is removed first, while the other end has a swinging flat tapered plate with a cam-shaped end *B*, the action of which is to expand the rim to its fullest diameter and lock it there. In the top figure, it is locked—that is, the rim is expanded as it would be when in use and just after it had been removed for replacement. When the rim is to be removed from the tire, the latch *B* is swung out of the way, as shown in the lower figure, when the catch *C* which holds the two ends together can be opened by lifting the tire with this portion at the bottom and then dropping it a couple of times. This done—usually this action will be accompanied by the free end spring inside the fixed end—continuation of the removal is an easy matter. The rim shown is the Stanweld No. 20.

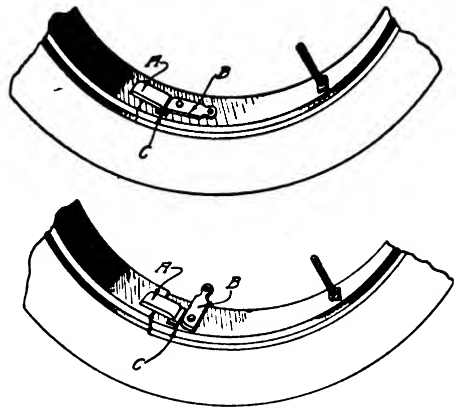


Fig. 539. One-Piece Rim, Showing Right-Angled Split and Locking Device
Courtesy of Standard Welding Company, Cleveland, Ohio

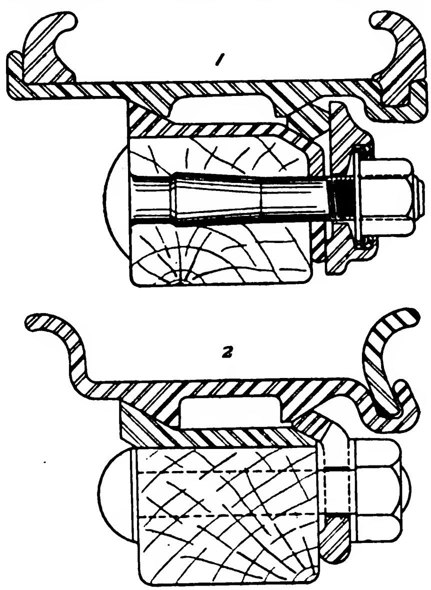


Fig. 540. Sections through Two Popular Forms of Demountable-Detachable Rims

Comparison of Continuous Holding Ring Type with Local Wedge Type. To return to demountable-detachable rims, these may and do include a number of those quick-detachable forms previously shown and described. In Fig. 540, a pair of typical forms is shown, that at *1* being fitted for a clincher tire, while that at *2* is for a straight side. Looking at the detachable part of the rim, *1* will be recognized as that previously shown at *3*, Fig. 521, where it was described as a universal rim, the inversion of the two rings converting it from a clincher to a straight side, or *vice versa*. Similarly, *2* will be recognized as the form of detachable shown at *3* in Fig. 524.

Here, however, both are fitted to be used as demountables, this being accomplished by the formation on the under side of the band of a pair of wedge-shaped projections. The felloe band is so made and applied that it forms one surface to contact with one of these wedges, while the other is formed variously. At *1*, a separate ring is used with the flat outside clips to hold this against both felloe band and rim, while at *2* the wedges or clips have an extension which presses against the outer wedge on the rim. This latter distinction divides these two into the two classes mentioned previously — one into the continuous holding ring class, the other into the local wedge type.

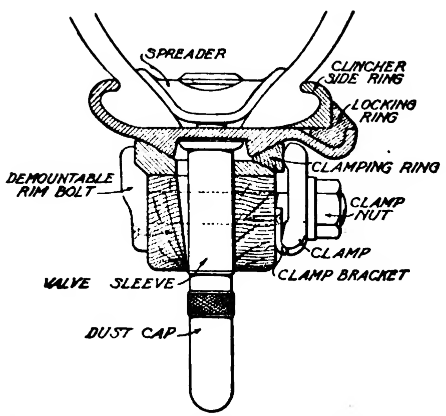


Fig. 541. Section of Tire and Rim of Firestone Demountable Tire

These forms are shown to illustrate this point and also because, despite this difference, they have practically similar felloe bands. This felloe band—that is, of the form shown in *2*—has been recommended as a standard for all demountable-detachable rims. Another and different example of the clamping-ring demountable-detachable type is shown in Fig. 541, this being the Firestone rim. Here, it will be noted, is the felloe band just mentioned, while the detachable-rim portion is that previously shown at *1* in Fig. 523 as having the Z-shaped locking ring and being adapted to clincher tires only. The rim band is made with the two wedge-shaped projections on its underside.

Perlman Rim Patents. Late in the summer of 1915, considerable consternation was caused among tire and rim manufacturers when it became known that the Perlman rim patent had been adjudged basic by the courts, and that, on the strength of this decision, an injunction had been issued against the Standard Welding Company, of Cleveland, Ohio, some few of whose rims have been previously described. Perlman's original patent was applied for on June 29, 1906, and, in addition to this record, the fact was established that the owner had a Welch car which had traveled over 150,000 miles and on which were a set of the original rims. The case dragged through the courts and was discontinued some seven or eight years ago. Perlman persisted, however, although he had to revise and alter his application many times; the basic patents were finally allowed, and issued to him in February, 1913. This means, of course, that the patent will not expire until the year 1930.

Perlman's locking elements and the principle involved are shown in Fig. 542, which is a section through the rim and felloe. In Perlman's suit, it was claimed that the wedge end of the bolt which was covered in his patent, included all wedge-operating rims, whether actuated from the center, as in Fig. 542, or from the side. This contention was supported by the court, and negotiations are now in process between Perlman and many manufacturers of the so-called local wedge type of rim. As this would appear to cover all the rims shown and described in Figs. 525 to 541, inclusive, the influence of this decision upon the industry can be imagined. Moreover, the length of time which this basic patent has to run precludes the possibility of delaying action by prolongation of suits, as has been done in similar cases. A notable example of this is the case of the Selden automobile patents, which were fought on one ground or another over a long period of years.

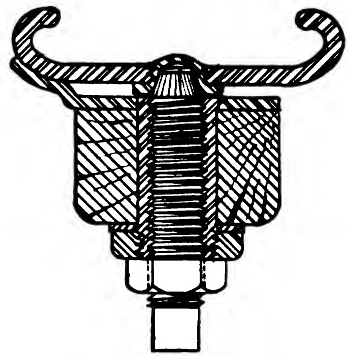


Fig. 542. Section of Perlman Rim, Showing Locking Device

Standard Sizes of Tires and Rims. As might have been noted in going over the above discussion of tires, plain rims, detachable rims, and, finally, demountable rims, all these different constructions require widely differing wheel sizes. It has been proposed to standardize wheels, that is, the outside diameter of the felloe and with it the thickness of felloe bands as well as their shapes or contours, one for each tire cross-section. The proposed reduction of tire sizes to nine standards is as follows: 30- by 3-inch, 30- by 3½-inch, 32- by 3½-inch, 32- by 4-inch, 34- by 4½-inch, 36- by 4½-inch, 38- by 5½-inch and probably 36- by 5-inch, supplying these sizes and these only to manufacturers of cars; additional oversizes are allowed for car users, one for each size above, that is, 31- by 3½-inch for 30- by 3-inch, 31-

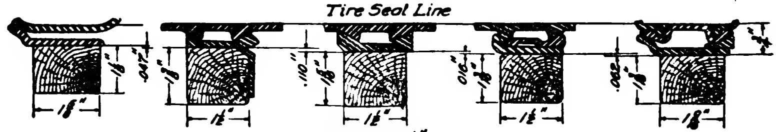


Fig. 543. Typical Felloe, Band, and Rim Sections for Popular Demountable Rims

by 4-inch for 30- by 3½-inch, 33- by 4-inch for 32- by 3½-inch, 33- by 4½-inch for 32- by 4-inch, 35- by 4½-inch for 34- by 4-inch, 35- by 5-inch for 34- by 4½-inch, 37- by 5-inch for 36- by 4½-inch, 39- by 6-inch for 38- by 5½-inch and probably 37- by 5½-inch for the 36- by 5-inch. Rim standardization will follow the adoption of these sizes. In this event, the standardization of demountable rims will come in time.

At the present, there is a wide range of difference, as will be noted in the drawing, Fig. 543, which shows felloes for the most widely used demountable rims, depicting the band and rim in each case. The drawing should be read crosswise, each horizontal line showing the differences to be found in the makes mentioned in that particular tire cross-section size. Thus, the *D* sections show the differences for 3½-inch tires, *E* those for 4-inch tires, *F* those for 4½- and 5-inch tires, and *G* those for 5½- and 6-inch tires, rims for which are not produced by all makers.

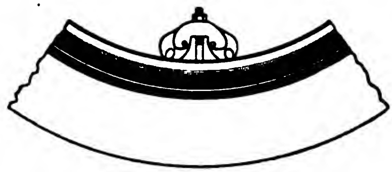


Fig. 544. Operating Device on the Ashley-Moyer Double Q.D. Rim for Wire Wheels

Other Removable Forms. Outside of the regular range of wood wheels and the standard tires for them, any different wheel calls for a different treatment. As has already been mentioned under the subject of Wire Wheels, few of these have anything but a solid one-piece clincher rim; first, because the wheel itself is removable, thus making it as easy to change wheels as to change rims in the ordinary case; and second, to save weight and complication.

Demountable for Wire Wheels. However, demountable forms have been produced for wire wheels, one being shown in Figs. 544 and 545. This is the G-R-C double Q.D. rim as the makers prefer to call it, in action a demountable-detachable form, the clincher rim being of the straight split type, in fact, a Stanweld No. 20. This is made with a double wedging surface on the

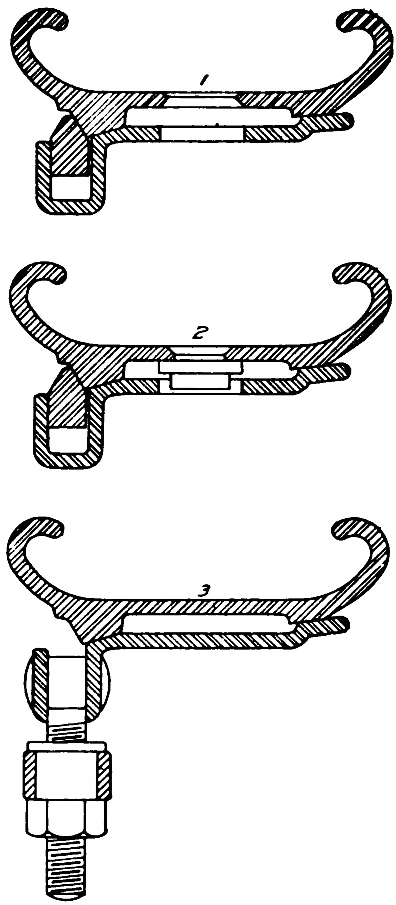


Fig. 545. Section through Rim and Band of G-R-C Rim, Showing Wedging Band and Its Operation

outside and a single one on the inside. The latter contacts with another on the false rim to which the wire spokes are attached, as does also the inner wedging surface on the outer wedge. The outer wedging surface is made so as to come just above a fairly deep slot in the false rim. In this is placed a ring with a double wedge-shaped upper edge and a square lower edge. This ring is split at one point and locked in the highest position at the point diametrically opposite.

At the split point, a pair of bent-arm levers, Fig. 544, are connected to the two ends. Attached to a middle point of each of these is one end of an inverted U-shaped member, the center and upper part of which form a bearing for a locking stud, which is attached to one end of the ring. Above this is placed a nut. As will be noted, this forms a toggle motion, the action of which is to expand the whole ring when the nut is screwed down and to contract it when the nut is screwed up.

Fig. 546. Construction of Parker Hydraulic Steel Wheel Spokes, and Operation of Locking Device for Rims

This is the precise action used, the single ring forming the whole locking means, and being actuated by the toggle mechanism through the medium of screwing the nut up or down. While at its best on wire wheels because of its simplicity, this rim is, of course, applicable to wood wheels. At present, its makers are specializing on the wire-wheel forms.

Parker Rim-Locking Device. Another rim-locking device which does not come under any of the standard divisions, being devised for use on the Parker hydraulic wheel, previously shown in Fig. 502, is the Parker modification of the former Healy rim. As shown in Fig. 546, which shows the end of a steel spoke in section, this is made with a cup at the upper and inner end, while at the outer is a loose clip, through which passes a bolt with a head on the outside. Tightening the bolt by means of the external head draws the clip up the incline at the bottom of the cup, against the wedge on the underside of the rim, the amount of pressure exerted depending solely upon that applied to the bolt head. As the two wedge shapes oppose each other, this holds the rim as firmly as is possible. It will be noted that this construction does away altogether with the use of felloe bands or false rims used on other forms of rims or wheels, thus saving much weight. Moreover, a great part of the weight is saved at the outside, where the flywheel effect of rapid rotation is thus lessened. Moreover, the absence of additional metal here would give the tire more chance to radiate its heat, and thus would preserve it better. This construction, considering its many advantages, should have a wide use.

Similarly, with all demountable rims, the tendency is toward wider use, with which comes lower cost, as well as a better understanding of their use, abuse, attachment, and detachment. With the standardization of tires to a few standard sizes, say 9 instead of 54, it will be only a few years before all kinds of rims, including demountables, will be standardized, at which time the latter will come into universal use.

TIRE CONSTRUCTION

Composition and Manufacture. Tires consist of two parts, the tube and the shoe, or casing. The former is a plain ring of circular cross-section, made of pure rubber, containing an air valve, and is intended only to hold the air. The shoe, or casing, on the other hand, provides the wearing surface, protects the air container within from all road and other injuries, and constitutes or incorporates the method of fastening itself to the wheel. In its construction are included fabric—preferably cotton—some pure rubber, and much rubber composition, the whole being baked into a complete unit by heat in the presence of sulphur, which acts somewhat as a flux for rubber.

Considering a typical tire, there enters into its make-up, starting from the inside, six or seven strips of frictional fabric, that is, thin sheets of pure gum rubber rolled into intimate contact with each side of the cotton, making it really a rubber-coated material. Next, there is the so-called padding, which is more or less pure rubber, has a maximum thickness at the center of the tread, and tapers off to nothing at the sides, but usually carrying down to the beading.

Above this tnere is placed a breaker strip, consisting of two or three layers of frictioned fabric impregnated in a rubber composition. This, too, is thickest at the center and tapers off to the sides, but ends at the edge of the tread. Finally, there is the surface covering, called by rubber men the tread; this contains very little pure rubber, being thickest at the center and extending with gradually decreased thickness almost down to the bead.

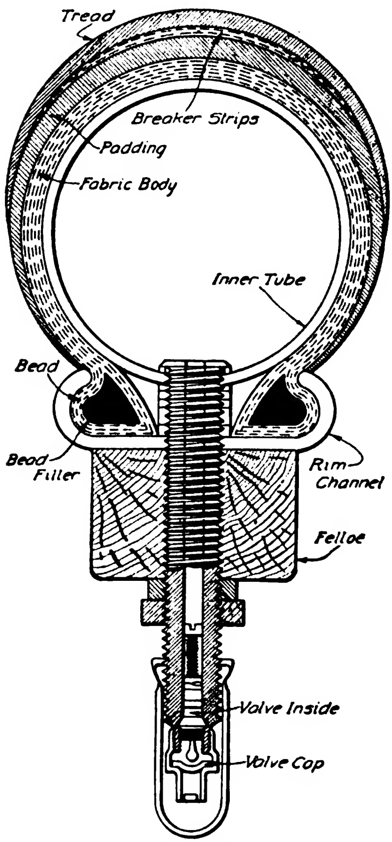


Fig. 547. Section through Assembled Tire and Tube, Showing Construction and Parts of the Tire and Tire Valve

The last two of this series of layers constitute the real wearing surface of the tire, and when the surface is so worn that the breaker strip may be seen, it is time to have the tire retreaded. When the wear has gone through this, if the padding be fairly complete, retreading will still save the tire, but if wear has gone clear down through that so as to expose the fabric, the show must be run to a finish and then discarded.

All this construction can be noted in Fig. 547, which shows a section through a tire, with the inner tube in place, the section being taken so as to pass through the center of the tire valve. This should be borne in mind when examining this figure, for the location of the inner tube inside the tire, as previously described, is likely to be misleading.

Bead. In the reference to tire construction, no mention has been made of the bead. This is a highly important part of the tire, for it is the part which holds it in place on the wheel. It is made of a fairly hard rubber composition, the fabric being carried down on the sides so as to cover it. In a cross-section, it has a shape very close to an equilateral triangle resting on its base; around the wheel it is curved to fit the rim. The method of attaching the tire has a considerable influence on bead construction, since, in the clincher type of tire, in which the shoe must be stretched on over the rim, the bead must be extensible in order to insure easy mounting. In the quick-detachable and straight-side forms of tire there is no need for this stretching, so the bead can be made of stiff and rigid material as well as cut down somewhat in size.

The straight-side or Dunlop type of tire is seldom made with much of any bead, the layers of fabric being carried straight down. A more modern form of tire has a pair of woven-wire cables incorporated in the bead to make it stiffer and stronger, and this is said to have been very successful. As has been pointed out previously, this could be done only with the quick-detachable form, not with the clincher type.

In both the clincher and the quick-detachable forms, the bead holds the tire to the wheel by means of parts of the rim, which bear on it from above, as well as sidewise, the internal pressure when the tire is inflated pressing it against these parts very firmly.

Fig. 548. Views of Tire Valve, Showing Closed and Open Positions

In both the clincher and the quick-detachable forms, the bead holds the tire to the wheel by means of parts of the rim, which bear on it from above, as well as sidewise, the internal pressure when the tire is inflated pressing it against these parts very firmly.

Tire Valves. In Fig. 547 there is shown a section through the tire valve but on a small scale. As this is a very important part and little understood, a larger view is shown in Fig. 548. This is in two parts, *A* at the left showing the valve closed, and *B* at the right indicating the position of the various parts when the valve is open. Note that the lower part of the valve is hollow, so that air inside of the tire has access to the valve seat. Note that the valve is held down on this by the threaded portion above it. This valve seat forms a slight taper which rests against an equally slight taper inside of the valve stem.

One condition of the tire valve holding air pressure is that the two valve seats be clean and smooth and free from scratches or cuts and foreign matter. Now it will be observed that the valve-seat portion of the valve has a hole through the center, in which the stem is a loose fit. This large hole passes all the way up through the threaded portion. The stem has a projection below the valve seat, which normally is held up against the bottom of the seat by the spring, this being strong enough to hold it up so tightly that no air can pass between the two. There are other conditions for valve tightness. The spring must be strong enough to hold these parts together; and the surfaces must be clean and true so that when held together, no air can get through.

Action of Valve. The action of the valve is this: When air is pumped in, it passes down around the central stem until it meets the projection, which it forces down against the pressure of the spring and, when there is air inside, against the pressure of the internal air. As soon as this is pressed down, the air passes in, and if the external pressure is stopped, as at the end of a stroke of the pump, the spring and the internal pressure push the projection back into place, and no air can escape. On the next pressure stroke of the pump, this is repeated, the whole process continuing until the tire is filled.

Leaky Valves. It will be noted that with a good clean spring, projection, and valve seat, the pressure of the air itself holds the valve tight. Thus, when a valve leaks, it is a sure sign that some part or parts of it are not in good condition. If the valve is not screwed down far enough, air can leak out around the valve seat, so that leakage may be remedied by screwing the whole valve farther down into the stem. If the valve stem is too tight a fit in the central hole, it may stick in a position which allows air to pass. This can be remedied by a drop of oil placed on the stem and allowed to run down it. But not more than one drop should be used as oil is the greatest enemy of rubber, and the tube with which the valve communicates is nearly pure rubber.

If the spring is too weak to hold the projection against the bottom of the valve seat, the valve will leak. This can be remedied by taking out and cleaning the spring, also stretching it as much as possible. In general, however, the best plan of action with a troublesome tire valve is to screw it out and put in a new one. These can be bought for fifty cents a dozen, and every motorist should carry a dozen in a sealed envelope, also a combination valve tool. When trouble arises with the valve, or a tire leaks down flat with no apparent cause, screw out the valve with the tool, screw in a new one, make sure it is down tight, and pump up again. The few cents it will cost to throw away a valve, even if it should happen to be good, will be more then compensated for by the time saved. Another point is that the whole valve assembly is so very small that it is difficult to handle.

Washing tires often is a good practice, since water does them no harm, while all road and car oils and greases will be cleaned off, nearly all of these being injurious. Frequent washing will also serve to call the attention of the owner to minor defects while they are still small enough to be easily repaired, and thus they are prevented from spreading. When not in use, tires should be wrapped, so as to be covered from the light, and put away in a dry room in which the temperature is fairly constant the year round. They will not stand much sunlight, nor many changes in temperature. Cold hardens the tires and causes the rubber to crack. Heat has a somewhat similar effect and also draws out its life and spring.

In general, of all things to be cared for and repaired promptly, no one thing is of more importance than the tires. If this rule is kept in mind, better satisfaction in the use of the car will result. So, too, with other repair work; if tools and appliances are made available and repairs made as soon as needed, the car will be better understood and give more satisfaction than if the opposite course be pursued. A few months of use of a car will do more to emphasize this than any amount of talk. Keep your car in good condition and you will reap the benefits of the little work you do upon it.

TIRE REPAIRS

Repair Equipment

Vulcanization of Tires for Repair Man. In practically all of the following material the point of view is that of the professional repair man, or of the garage man about to take up tire repairs, as distinguished from that of the average owner or amateur repairer. The lesser tire injuries and their repairs are handled from an amateur standpoint in another part of this work.

Vulcanization, to the unitiated, sounds very mysterious, but it really is nothing more or less than cooking, or curing, raw gum

Fig. 549. Small Vulcanizing Outfit for Single Casing of Six Inner Tubes
Courtesy of C. A. Shaler Company, Waupun, Wisconsin

rubber. In the processes of manufacture a tire is cooked, or cured, all the component parts supposedly being united into one complete whole. A tire is repaired preferably with raw gum or fabric prepared with raw gum, and, in order to unite this to the tire, vulcanization or curing is necessary. The curing, in addition to uniting the parts properly, gives the proper strength, or wear-resisting qualities, which raw rubber lacks.

Types of Vulcanizing Outfits. *Shaler Vulcanizer.* This curing, or cooking, is done by the application of heat, in a variety of ways. Generally, very small individual vulcanizers have a gasoline or alcohol cavity, holding just enough of the liquid so that when lighted and burned the correct temperature will be reached and held for the correct length of time. The larger units are operated by steam or electricity; the latter is preferred for its convenience, but the former is used by the majority of repair men. The source of heat is immaterial so long as the correct temperature is reached and maintained for the right lengh of time. Too hot a vulcanizer will burn the rubber, while too low a temperature will not give a complete cure.

For the average small repair man, the outfit shown in Fig. 549 will do very nicely, at least to start with. This will handle a single casing or six tubes, or in a press of work, both simultaneously. This outfit is operated by gasoline, contained in the tank shown above at the right, but the same outfit can be had with pipe arrangements for connecting to a steam main, or for electric heating. In the case of either gasoline or steam, there is an automatic temperature controlling device which is a feature of the Shaler apparatus. As shown, casings are repaired by what is known as the "wrapped tread method", the repair being heated from both inside and outside at once, the outside being wrapped. Tubes are handled on the flat plate, shown in the middle of the framework, the size of which is 4½ by 30 inches, this being sufficient, so the makers say, to handle six tubes at once.

Haywood Vulcanizer. For larger work, a machine something like the Haywood Master, shown in Fig. 550, is excellent. This is a self-contained unit, carrying its own gasoline tank, steam generator, and other parts. It handles four casings at once, while the tube plate *G*, 5 by 18 inches, is large enough for from three to four tubes, according to the allowance per tube made in the Shaler outfit. The separate vulcanizers are not designed for the same part of a casing, a side wall and bead vulcanizer being shown at *D*, a sectional vulcanizer for large sizes at *E*, a sectional vulcanizer for small and medium sizes at *F*, and a side wall and bead vulcanizer for both clincher and straight-side tires at *H*. The gasoline tank is marked *C*, with vertical pipe in which is the gasoline cut-off valve *K*. This leads down to the gasoline burner M, where the gasoline in burning vaporizes the water into steam. The water gage L, which indicates the amount of water available, is placed on the side of the steam generator A. Above this steam generator is the steam dome at B,

Fig. 550. Master Vulcanizer with Self-Contained Steam Generator
Courtesy of Haywood Tire and Equipment Company, Indianapolis, Indiana

from which the steam pipes lead to the various molds. The returns, or rather drips, will be noted, also the steam gage (not marked) and the cut-off valve in the supply pipe to the sectional molds. In addition to the molds shown and a full supply of parts and tools, sectional vulcanizers for 2½- and 3-inch tires, relining mold for 2½-, 3-, and 3½-inch tires, and relining mold for 4-, 4½-, 5-. and 5½-inch casings come with the device.

This outfit with the extra molds, described but not shown, gives a very complete equipment for the small shop doing average

Fig. 551. Battery of Vulcanizing Mold for Various Sizes of Tires

repairing. In fact, when a shop outgrows this type of equipment, it must specialize in tire work and purchase special equipment.

Separate Casing Molds for Patch Work. In the way of separate molds for casings, an excellent example of the localized heat type is shown in Fig. 551. By this is meant the form designed to vulcanize a small short section of a tire. The illustration shows five sections capable of handling, respectively, 2¼-, to 3-inch (motorcycle), 2½- to 3-inch (small car), 3½- to 4-inch, 4½- to 5-inch, and 5½- to 6-inch tires, thus covering the entire range. These molds have a special arrangement in that the heating portion is divided into three sections, into each of which steam can be admitted separately. This allows the use of one, two, or all the sections, according to the nature of the repair.

In Fig. 552 is shown how it is possible, with this apparatus, to vulcanize the tread portion only by admitting steam solely to the larger bottom steam chamber around the tread, similarly, with the right-hand bead or side wall or the left-hand bead or side wall. When a complete section is to be vulcanized, all sections are opened. The importance of this will be realized in a simple consideration of the fact that the tire itself has already been vulcanized and further heat is not only not good for it, but is distinctly bad, as it deteriorates the rubber. Where the heat

Fig. 552. Section of Vulcanizer, Showing Steam Cavities

is needed, however, is not the raw rubber which has just been added at the repair point, this being practically useless until it has been cured.

Vulcanizing Kettles. *Horizontal Type.* When it comes to vulcanizing an entire tire, as, for instance, when a new tread has been put on, or other very large repair, what is known in the trade as a "kettle" is needed. This is simply a heavy steel tank, large enough to take one or more entire tires, steam being admitted to its interior to vulcanize them. The kettle shown in Fig. 553 has a capacity of two casings 36 inches in diameter or smaller. It is of the type in which no bolts or nuts are used for fastening the cover, this being held fast by the projecting lugs which lock under other projections on the top of the kettle when the cover is turned. A special rubber packing ring also is used, Fig. 554, effectually sealing the kettle against steam leakage. This kettle resembles a doughnut in shape, the tires lying within the circular cavity.

Fig. 553. Vulcanizing Kettle, Horizontal Type

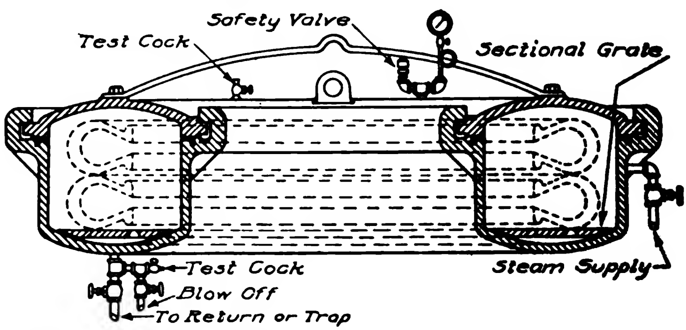


Fig. 554. Section of Horizontal Vulcanizing Kettle

Large Vertical Type. When the work goes beyond the capacity of size and type of tank or kettle shown in Fig. 553, which will handle two casings at a time, and at least two, perhaps four, kettles full an hour, that is, from 40 to 75 casings a day, it becomes necessary to use a larger type of kettle, made in vertical types only. These consist simply of large round steel shells with hinged heads, into

Fig. 555. Shaler Electrically Heated Inside Casing Form

which the tires can be rolled and piled, after which steam is admitted to the whole interior. They vary in size from 36 inches inside diameter by 24 inches in length to 48 inches diameter by 40 inches in length.

Inside Casing Forms. Another requisite of the tire specialist is an inside casing form, such as is shown in Fig. 555, or something similar. Many tire repairs are inside work, and even on those which are external, it is important to have an inside form against which the tire can be pressed and firmly held while vulcanizing. This particular form is heated by electricity, the wires being shown at the left; it is 14 inches long and has an external shape to fit the inside of all casings.

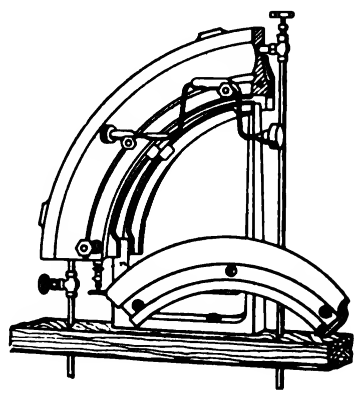


Fig. 556. Side-Wall Vulcanizer

Side-Wall Vulcanizer. A shop doing a great deal of work can use to good advantage the side-wall vulcanizer shown in Fig. 556.

It has a single central member through which the steam passes, and also has bolted-on side plates, the insides of which are formed to suit either clincher or straight-side tires. In the figure, the side plates are not both in place, one being shown on the work table below. The brace shown is used to remove the clamping nuts quickly and easily. This form is very useful on all side-wall or bead operations. It applies greater pressure along these parts of the tire than an air bag; it exactly

Fig. 557. Retreading Vulcanizer with Tire in Position
Courtesy of Haywood Tire and Equipment Company, Indianapolis, Indiana

fits the tire, and the size and shape make it possible to vulcanize a 36-inch tire in four settings.

Retreading Vulcanizers. Retreading vulcanizers differ from the sectional molds of Figs. 549, 550, and 551 in that the heat is applied at one particular point or, rather, strip along the middle of the top surface of the casing and extending down only as far as the side walls. Such a device, shown in elevation in Fig. 557, and in enlarged sectional detail in Fig. 558, is used solely for retreading or vulcanizing a new tread strip around the tire. The complete unit extends around about one-third of the whole tire surface so that when putting on a complete new tread the mold must be used three times. The section, Fig. 558, is numbered as follows: casing, 2; inner mold, 1; new tread to be vulcanized, 3; vulcanizer proper, 4; clamp, 5; and steam space within which the heating is done, 6.

Layouts of Equipment. There are two ways of installing an outfit somewhat like that just described, namely, by the non-return system and by the gravity-return system.

Non-Return Layout. A typical installation according to the non-return system is shown in Fig. 559. A steam trap must be placed in the system to remove the water and discharge it either into the sewer or into a tank so that it can be used again. In the figure there is shown a tube plate, a three-cavity sectional vulcanizer, two inside molds, and a medium size kettle of the vertical type placed in order from right to left. A pressure-reducing valve is shown which permits the use of a higher pressure in the boiler, thus maintaining an even steady pressure on the vulcanizers regardless of fluctuations at the boiler.

Fig. 558. Section of Retarding Vulcanizer
Courtesy of Haywood Tire and Equipment Company, Indianapolis, Indiana

Gravity-Return Layout. When the coil steam-generator or flash type of boiler is used, the gravity-return system is utilized, this being a method of piping by means of which the condensed steam is returned to the coil heater to be used over again. This makes it necessary to set the apparatus so that the water of condensation will run back to the coil heater, which means that the pieces must be in a series, each successive one being set a little lower down to the boiler. Figs. 560 and 561 show a side view and plan view, respectively, of a small

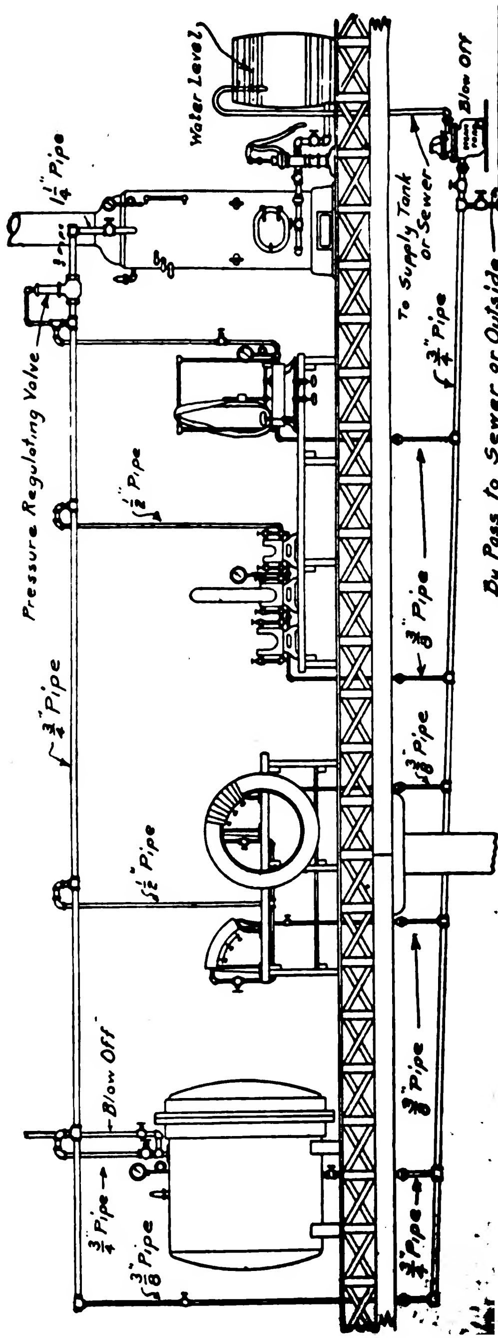


Fig. 559. Diagrammatic Layout for Non-Return Vulcanizing Plant

plant arranged on this plan. The outfit consists of the coil heater, which may be fitted to burn gas or gasoline, two inside molds, a large tube plate, and a three-cavity sectional vulcanizer. The outfit

Fig. 560. Elevation of Gravity-Return Vulcanizing Plant

differs from Fig. 559 only in the absence of the kettle; on the other hand, the tube plate in Fig. 560 is larger.

Small Tool Equipment. In addition to these larger units, the well equipped tire repair shop should have a considerable quantity of small tools, among the necessities being those shown in Fig. 562. At *A* is shown a flat hand roller and at *B* a concave roller. *C* shows an awl, or probe, which is used for opening air bubbles and sand blisters. *D* is a smooth stitcher; *F* a rubber knife, of which two sizes are advisable, a large and a small; and *G* a 10-inch pair of shears for

Fig. 561. Plan View of Gravity-Return Vulcanizing Plant

trimming inner tube holes, cutting sheet rubber, etc. *H* is a steel wire brush for roughing casings by hand; a preferable form is a rotary steel wire type driven by power at high speed. *I* is a similar wire brush for roughing tubes; and *J* another brush with longer wires, also for roughing casings; *K* is a tread gage for marking casings to be retreaded; and *L* a fabric knife necessary in stepping down plies of fabric. *M* is a pair of plug pliers for placing patches inside of small tube repairs; *N* is a cement brush for heavy casing cement, another very much smaller and lighter one—preferably of the camel's hair type—being used for tube cement. *O* is a hand

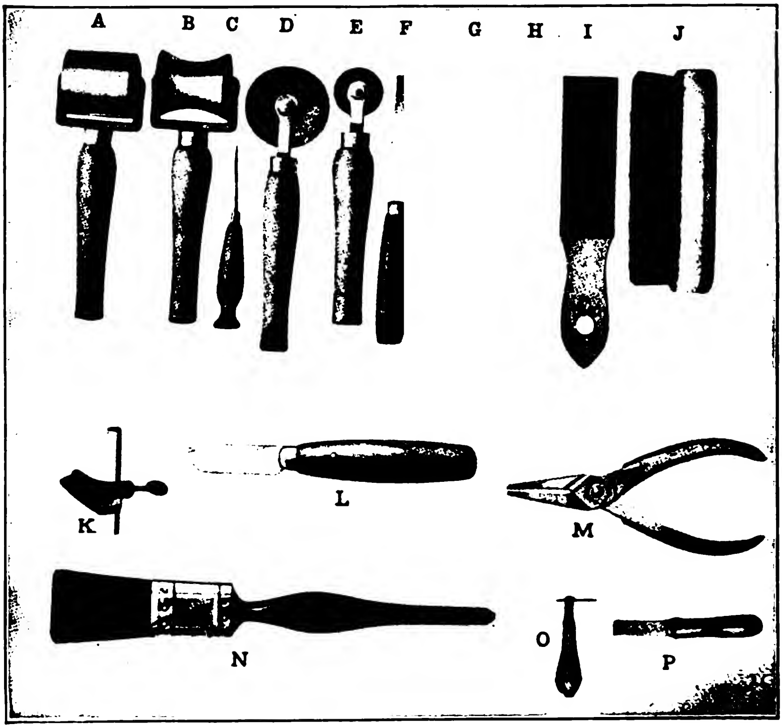


Fig. 562. Collection of Tools Necessary for Vulcanizing Work

scraper and *P* a tread chisel; *Q* performs a somewhat similar function, being a casing scraper for cleaning the inside of a casing preparatory to mending a blowout.

In addition to the small tools shown in Fig. 562, it is necessary to have several tube-splicing mandrels; a large number of various sizes and shapes of clamps for all purposes; rules, try-squares and other measuring tools; tweezers for handling small patches, tools for recutting threads on tire valves; tire spreaders, for holding casings open when working inside; a casing mandrel or tire last of cast iron for holding a casing when making repairs; a tread roller for rolling down layers of raw stock evenly and quickly; a considerable amount of binding tape; thermometers; and such motor-driven brushes, scrapers, etc., as the quantity and quality of the work warrant.

Materials. Each repair shop must carry such a supply of tire-repairing material as the nature and quantity of its business demands. Among other things may be mentioned: Tread stock, rebuilding fabric, single-friction fabric, cushion stock, breaker strips, single-cure tube stock, combination stock, cement, quick-cure cement, soapstone, valve bases, valve insides, valve caps, complete valves, vulcanizing acid, various tube sections, tire tape, cementless patches, as well as many other tire accessories to sell. Many good tire-repair shops find a legitimate use for special tire-repairing preparations on the order of Tire-Doh.

Inner Tube Repairs

In general, all tire repairs come under one or more of the following headings; puncture; blowouts; partial rim cut or rim cut all around; and retreading or recovering, and relining.

Simple Patches. Under the heading of punctures are handled all small holes, cuts, pinched tubes, or minor injuries. Generally, these can be repaired by putting on a patch by means of cement, or with cement and acid curing. When well done, this method is effective. This kind of a job seldom comes to the repair man, and, when it does, it is principally because the owner is too lazy to do the work. About the only two cautions necessary are relative to cleanliness and thoroughness. The tube and patch should be thoroughly cleaned. Again the patch should be large, well cemented, and the cement allowed to dry until just sticky enough to adhere properly. Many a simple patch of this kind has been known to last as long as the balance of the tube.

Large Patches. *Cleaning the Hole.* Whenever the hole or cut is large, it is recommended that the repair be given more serious attention and vulcanized. The ragged edges of the rubber should be trimmed smooth with the tube shears or knife, the minimum amount of rubber being cut away. The hole, however, should be made large enough to allow the insertion of an inside patch. Then the tube around the hole should be cleaned thoroughly. This is best done with a cloth wet with gasoline, cleaning not only the outside but the inside around the hole and at the edges. In order to make a good job of this, it should be gone over several times; the larger the hole the more care should be used in cleaning around it.

Preparing the Patch. Having the hole well cleaned and ready, these cleaned parts should be painted with two coats of vulcanizing cement, which is allowed to dry. This must be thoroughly, not partly, dry. Then the proper patch is selected, the smaller size being sufficient for small patches, while in the case of large repairs, the patch should be from ½ to 1 inch larger all around than the hole. If this is not a prepared patch, one side should be cemented just as the tube was previously. If a prepared patch is used, the semi-cured side should be placed in, that is, with the sticky or uncured side toward the tube from the inside.

When the cement on the patch is just sticky enough, it should be inserted and the tube pressed down against it all around, slowly and carefully so as to get good adhesion. Next the cavity about the inside patch is filled with gum or pure rubber, preferably in sheet form as it comes for this purpose. This is filled in until the surface is flush. It is preferable to use a little vulcanizing cement to hold this rubber in place, particularly if a piece of sheet gum is cut to fill the hole.

Vulcanizing the Patch. The repair is now about half completed and is next vulcanized. The length of time, if steam is used, varies with the amount of steam pressure; if the portable gasoline or alcohol type of vulcanizer is applied the time varies with the temperature. As this time variation is so wide, it is impossible to give an invariable rule. Thick tubes require a little longer than thin ones, large patches longer than small ones, wide patches more than narrow, etc. The vulcanizing must be carefully and thoroughly done, and, as the success of the whole job depends upon this one process, the arrangement of the tube on the plate, of the soapstone on the new rubber and on the vulcanizer to prevent adhesion, of the wood or rubber pad above the patch, of the clamp and its pressure, should all have careful attention. With 60 pounds steam pressure available, from 10 to 12 minutes is about right, with 75 pounds from 8 to 10 minutes. In any case, the rubber should be cured just firm enough not to show a slight indentation from the point of a lead pencil. This is a good test to use at first, although after a short experience, the workman will be able to judge of the condition from the feeling, color, and general appearance of the patch.

When the size of the plate is small, the tubes should be held up above it out of the way, partly to allow the full use of the plate surface, but also to keep the tubes from being damaged.

Inserting New Section. *Preparing the Tubes.* In case the damage to the tube is too great to permit the use of a patch, for instance, in case a blowout makes a wide hole perhaps 7 inches or more long, in an otherwise good tube, it is advisable to cut out the damaged section and insert a new section in its place. Sometimes old tubes of the same size can be used for this, but, if not, sections can be purchased from the larger tire and rubber companies.

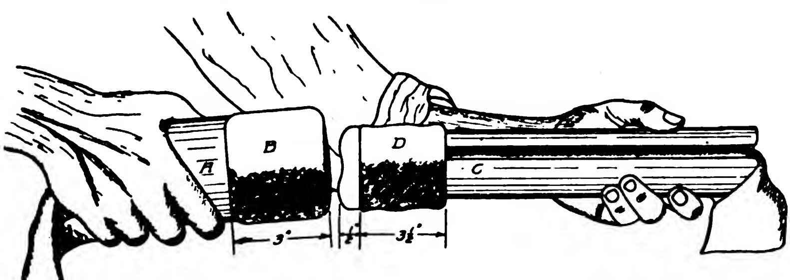


Fig. 563. Sketch Showing Method of Inserting New Section in Inside Tube

In the repair, proceed as follows: After cutting out the damaged section, bevel down the ends very carefully, using a mandrel to work on and a very sharp knife. As the appearance and, to a large extent, the value of the repair will depend upon these beveled ends, this should be done in a painstaking manner. Next select the tube section and cut it to size, that is, from 5 to 6 inches longer than the section which was cut out and which this patch is replacing. This allows 2½ to 3 inches for the splice at each end. Bevel the ends of the tube as well, and, after beveling all four ends, roughen them with a wire brush or sandpaper.

Making the Splice. Having the tube and repair section beveled and buffed, the ends to be joined should be coated with one heavy or two light coats of acid-cure splicing cement. With the tube and patch properly placed on the mandrels—tube on the male and patch on the female—turn back the end to be repaired and the end to be applied as shown in Fig. 563. At *A* is shown the female mandrel on which is the patch *B*, turned back from the end of the mandrel about the right distance, say 3 to 3½ inches. On the male mandrel *C* the tube *D* has been turned back about 7 to 7½ inches, then turned back again on itself about 3 to 3½ inches.

Just as soon as the cement has dried thoroughly on the tube, apply a coat of acid to the patch and immediately place the two mandrel ends together and snap, blow, or push the end of the patch over on to the end of the tube. This frees the female mandrel, which can be laid aside. Immediately wind the patched portion (still on the male mandrel) with strips of muslin or inner tubing. In 15 to 20 minutes the cement will have formed a permanent union, the wrappings can be removed, and the tube withdrawn through the slot in the mandrel.

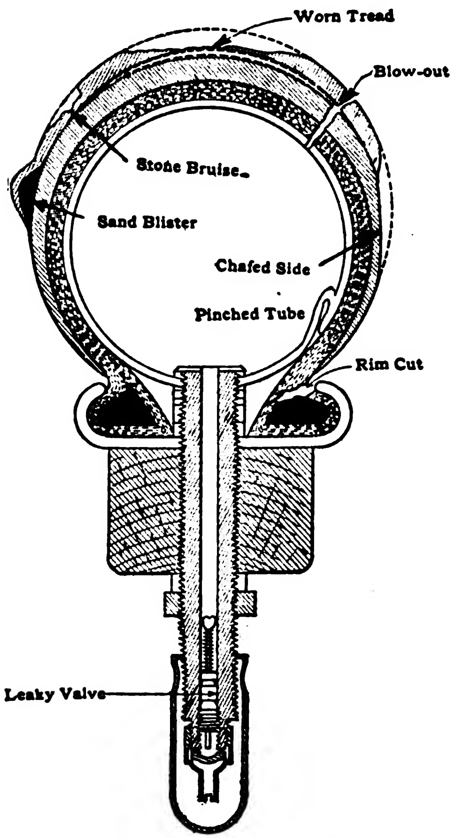


Fig. 564. Section of Tire, Showing Forms of Troubles

This done successfully, the whole operation is repeated for the other splice. If the splice does not cure together well, it indicates either that the acid supply is poor or else the splicing was not done quickly enough after applying the acid.

Outer Shoe, or Casing, Repairs

Classifying Troubles. Some of the common tire troubles—those of the inner-tube variety just discussed, and casing troubles as well—can be clearly shown by suitable illustrations. For example, a section through the tire showing how the troubles occur is sometimes very useful, as shown in Fig. 564. Here the pinched tube and blowout are indicated, the results of these on the inner tube and also their method of repair having just been described. These troubles together with punctures, leaky valves, and porous rubber in the tubes about cover the extent of inner tube troubles. Because of their more complex construction, casings have more numerous and more varied troubles, which, consequently, are more difficult to repair. The more common casing troubles are blisters, blowouts, rim cuts, and worn tread, the latter indicating the necessity for retreading. These will be described in order.

Sand Blisters. The sand blister shown on the side of the tire, Fig. 564, is brought about by a small hole, such as an unfilled puncture hole, in combination with a portion of the tread coming loose on the casing near this hole. Particles of sand, road dust, dirt, etc., enter, or are forced into, this hole and move along the opening provided by the loose tread. Soon this becomes continuous and the amount of dirt within the break forces the surface rubber out in the form of a round knob known as a sand blister. This is cured by cutting open the blister with a sharp knife on the side toward the rim and picking out all dirt within. When the recess is thoroughly cleaned, the hole and the radial hole in the tire tread nearby should be filled with some form of self-curing rubber filler, a number of kinds of which are sold. The double benefit of this is to close the hole so that the trouble is not repeated and to keep out moisture which would ultimately loosen the entire tread.

Fig. 565. Method of Preparing Layers of Fabric or Patching Blowouts—Inside Method

Blowouts. The blowout, which is perhaps the most important casing repair, may be made in two ways: the inside method, in which the whole repair is effected on the inside; the combination inside and outside method.

Inside Repair Methods. Refer back to Fig. 564 for the general tire construction and to Fig. 565 for this particular case, the inside of the tire is held open by means of tire hooks and the inside fabric layers or plies removed for a liberal distance on each side of the opening. As shown in Fig. 565, a lesser amount of the second layer should be taken than of the first, and still less of the third and each subsequent one. On 3½- and 4-inch tires it is not advisable to remove more than two plies; on 4½-inch tires three, as shown; and on the larger sizes four plies. The edge of each layer of fabric should be beveled down thin, as well as the material directly around the blowout.

Outside Method

Apply a coat of vulcanizing cement and when it has dried, say for an hour, apply another. When this has dried enough to be sticky or tacky, fill as much of the hole as possible with gum. When this is filled in level, apply the fabric patch. This is made up to match the fabric cutout, that is, if three layers are removed, it should consist of three plies stepped-up to match, and an extra last ply of bareback fabric unfrictioned on one side. This last layer should extend 3½ to 4 inches beyond the ends of the patch.

When this is properly applied and carefully smoothed down, the tire is placed in a sectional mold, clamped in place, perhaps wrapped with muslin strips to hold it tightly against the mold, and heat applied from the inside. This makes an excellent repair and a fairly quick and easy one, but it is not applicable for large blowouts; at least, it is not as effective as the inside and outside method.

Inside and Outside Method. In the inside and outside method, the material is removed from the outside, stepped down, and beveled in the same manner as for the method just described. Fig. 566 shows a tire with a medium size blowout, which has been stepped down for a sectional repair, four plies having been removed. The rule for the number of plies to remove is about the same as before, except that in the larger sizes this should depend more on the nature of the injury. It should be noted, however, that in this case the plies have all been removed right down to and including the bead. This is done to give the new fabric a better hold and to make a neater job and one that will fit the rim better. Give the whole surface two good coats of vulcanizing cement, allowing it to dry thoroughly.

Apply the same number of plies of building fabric as were removed, with the addition of chafing strips of light-weight fabric at the bead. Over this building fabric apply a thin sheet of cushion gum, slightly wider than the fabric breaker strip; then a thickness of fabric breaker strip over this; and then over this fabric another sheet of gum, slightly narrower than the previous sheet. All this, however, should be built up separately and applied as a unit and not one at a time, as described. These several plies should be well rolled together on the table. All edges should be carefully beveled off, especially the edges of the new gum where it meets the old, as it is likely to flow a little and leave a thin overlap which will soon pick loose.

No fabric is removed from the inside, but the hole is cleaned, its edges beveled, then filled with tread gum, and the inside reinforced with a small patch of building fabric; over this lay two plies of building fabric of considerable size. Now the whole casing is placed in a sectional mold, a surface plate applied to the outside, and heat applied both inside and outside. This will heat the tire clear through and make a good thorough job of curing.

Rim-Cut Repair. *Partial Cut.* To repair a partial rim cut, one or two plies of the old fabric are removed, unless it is severe, when three plies may be taken off. This is removed right down clean as explained under Blowout Repairs, and the cement and new materials applied in the same way, with the omission of the fabric breaker strip. However, care should be used to carry all building fabric layers not only down around the bead to the toe but up on the inside far enough to secure a good hold and ample reinforcement. If this should make the rim portion somewhat more bulky, remember it was a case of doing this or getting a new tire.

Complete Rim Cut. Where the rim cutting is continuous, the old side-wall rubber is removed up to the edges of the tread, and the old chafing strips and one ply of old fabric to about an inch above the beads removed also. Cut through the side-wall rubber all around, but be very careful not to cut into the fabric body, or carcass. The whole of the side wall and chafing strips can be removed in one operation. Apply two coats of cement and, after this is thoroughly dry, put on a patch consisting of one ply of building fabric, one ply of chafing strip, and a surface, or outside, ply of new tread gum. This is made on the table and the parts thoroughly rolled together. When completed, vulcanize in a sectional mold with sectional air bag and bead molds or endless air bag; apply to a split curing-rim wrap, and vulcanize in heater or kettle. The tire is repaired, but not vulcanized, and, with the ends of the three applied plies of material loosened to show, may be seen in Fig. 567.

Fig. 567. Method of Handling Rim Cuts

Retreading. Retreading is a job which must be done very carefully, not only because of the job itself, but also because this is probably the most expensive single job which can be done to a tire, and the worker should make sure before starting that the wire warrants this expense. It should have good side walls and bead, and the fabric should be solid and not broken apart.

Repairing the Carcass. In the usual case, it is advisable to remove not only the surface rubber and fabric breaker strip, but also the cushion rubber beneath the breaker strip, that is, the tire should be cleaned off right down to the carcass, and the latter cleaned thoroughly. As the rubber sticks, a rotary wire brush will be found useful and quick. However, this should be used carefully so as not to gouge the carcass. After buffing, the loose particles of rubber should be removed with a whisk broom or dry piece of muslin. In this cleaning work the carcass should be kept clean and dry. Apply two coats of vulcanizing cement and allow both to dry; the first should be a light coat to soak into the surface fabric; the second should be a heavy coat.

Building Up the Tread. In building up the tread, it should not be made as heavy as the former tread, as the old worn and weakened carcass cannot carry as heavy a tread as when new. Furthermore, it takes longer to vulcanize a heavy tread and presents more opportunity for failure. In the building-up process, the proportioning of weights is important, and should be taken from the tabulation below, which represents years of experience in tire repairing:

Size of Case (in.)	Ply toward Fabric (in.)	Second Ply (in.)	Third Ply (in.)	Fourth Ply (in.)	Fifth Ply (in.)	Last Ply Over All	Complete Tread Consists of
3	2¾	3½				*See Note	3 plies
3½	2¾	3½	4¼			*See Note	4 plies
4	3¼	4	4¾			*See Note	4 plies
4½	4	4¾	5½			*See Note	4 plies
5	4¼	5	5¾	6½		*See Note	5 plies
5½	4¾	5½	6¼	7	7¾	*See Note	6 plies
6	5¼	6	6¾	7½	8¼	*See Note	6 plies

* Note—Determined by condition of case after buffing and cementing.

Size of Case (in.)	Width of Breaker Strip (in.)
3	1⅝
3½	2⅛
4	2½
4½	3
5	3⅝
5½	4
6	4½

This tread strip is built up on the table with exceeding care, all edges being rolled down carefully. When the strip has been prepared and the carcass is ready for it, one end should be centered on the carcass, and then the balance of the strip applied around the circumference, being careful to center it all around, as the workman in Fig. 568 is doing. After it has been applied all around, it should be rolled down carefully, all air pockets opened with a sharp pointed awl, and the gum at the edges of the plies rolled down with the corrugated stitcher. When ready, vulcanize in a kettle, using an endless air bag with tire applied to a split curing-rim, and wrapped—preferably double wrapped—all around.

Use of Reliner. Many a casing which appears good on the outside but which really is unsafe because of fabric breaks on the inside
orarily prolonged,
r. By this is not
and fabric reliner
a regular built-up
ized in place so as
to be an integral part of the tire. For ordinary breaks, use a single ply of building fabric on a casing which has been entirely cleaned out and which has had two coats of vulcanizing cement thoroughly dried
eak, use two plies
fit; the under ply
ides and coated on
one, and the upper ply should be frictioned on one side only, the side toward the tube being bareback. Use an endless air bag for internal pressure, apply to a split rim, wrap, and vulcanize in a kettle from 35 to 45 minutes at a steam pressure of 40 pounds.

Fig. 568. New method of Putting on New Tread

Summary. By the application of parts of the foregoing instructions and the use of much common sense, coupled with a knowledge of the construction, use, and abuses of tires, the repair man will be able to handle any form of tire repair brought to him. In starting out, perhaps he could not do a better thing than to take an old tire apart to see just how it is constructed. This will give a much more clear idea than any number of diagrams, sketches, or photographs.

The tire repair man should remember, too, that this is no longer a game, but that, by means of scientific apparatus and the application of correct principles, it has been brought up to a high state of perfection; an expert can predict with reasonable accuracy what will happen in such and such a case, if this and that are not done. In short, the tire-repairing business within the last few years has been brought up to a stage where it, or any part of it, is a dependable operation. The tire repair man should handle all his work from this advanced point of view; it will pay the largest dividends in the long run.

SUMMARY OF INSTRUCTIONS

Q. What are the units comprising the final-drive group?

A. Universal joints; driving shaft; final gear reduction; axle-shaft differential; axle enclosure; torque rod, or tube, or substitute tor this: radius rod, or tube, or substitute for this; brakes; wheels; and tires.

Q. Why are these called the final-drive group?

A. Because they constitute the final drive of the car, beyond the power-producing unit, the engine; the connecting and disconnecting unit, the clutch; and the speed-changing unit, the transmission.

Q. What is the function of the universal joint?

A. In the final-drive group, it is used to transmit power at an angle, as, from a horizontal-transmission shaft to an inclined-driving shaft.

Q. How does it do this?

A. The construction is such that the driving shaft is attached to one set of pins, while the driven shaft is attached to another, the axes of these intersecting in a common point. As the driven shaft can turn about its pins in one plane and, with the complete joint, about the driving shaft pins in another, as well as combinations of the two, complete freedom, or universal movement, is assured.

Q. What are the power losses in a universal?

A. In a well-designed and fitted universal joint, working practically at zero angle, there is no loss, but as the angle increases, the loss increases until at about 20 degrees, it may reach 2 or 3 per cent.

Q. Why is such a joint needed?

A. The final drive must be at the center of the rear axle, which is comparatively low, say 17 inches with 34-inch wheels or 18 inches with 36-inch wheels, while the power must originate at the engine which cannot be set as low as this, that is, the power must be generated at a higher level than that at which it is used. An inclined shaft and universal joints must be used somewhere in the system.

Q. What other considerations necessitate universal joints?

A. The engine level varies little, while the rear end of the chassis varies up and down through a considerable range. In addition, the rear end carries perhaps 85 per cent of the load and sustains greater road shocks because of this fact. The design is such as to keep the front, or engine, end as quiet and as nearly stationary as is possible. These considerations necessitate a flexible connection between the two ends, so that one can move frequently and through considerable distances, while the other moves seldom and through very small distances. In addition, the rear end must sustain considerable side sway, so that freedom in a sidewise direction is necessary. The only way in which these necessities can be obtained is through the use of universal joints.

Q. What is a slip joint?

A. One which will allow sliding, or slipping, of one part or shaft within the other. Thus, under certain restraining conditions the rise and fall of the rear end may mean approaching or receding of that end to and from the front portion. With a slip joint, this is made easy.

Q. What is the usual form of a slip joint?

A. Generally, this takes the form of a squared shaft within a squared-out housing, although sometimes the square is rounded off to give a slight universal action.

Q. What is the modern form of universal joint?

A. A thin flexible disc of steel, leather, fiber, or laminated fabric, with the driving shafts bolted to two opposite points and the drive shaft bolted to two others between them has been found to be much simpler, lighter, cheaper, and better than the average universal, although it allows only limited angular motion. The engine is being gradually lowered, while the rear wheels are constantly being increased in size; so the difference of level is not as great as it was, and there is less need for the full universal.

Q. What is the biggest advantage of these to the repair man?

A. They allow the removal of a driving shaft, or a unit on either side of such a joint much more quickly and easily, with less work, than any other form, similarly, in replacement after the repair is completed. In addition, they have no loose parts to be lost or mislaid with consequent trouble and delay of the work.

DRIVING SHAFTS

Q. What is the usual type of driving shaft?

A. The usual driving shaft is of small diameter and solid. Cold rolled steel is used on the lower priced cars, but forged steel machined at the ends (at least) is used on the better cars. On many of the most expensive machines, the shaft is fairly intricate in shape and is machined all over after forging, sometimes ground after hardening.

Q. What would be the advantage of a spring shaft?

A. Being flexible, it would cushion the shocks so that none of these reached the engine. Such shocks as are induced by jerking the throttle wide open, or stepping on the accelerator pedal suddenly or, on the other hand, a sudden application of the brakes.

Q. What is its real disadvantage?

A. Being small, the owner of the car and the driver would always mistrust it, and would not feel free to drive as they would with a larger and more dependable shaft.

Torque and Radius Rods

Q. What is torque?

A. Torque is turning effort, or force, applied to rotation, in the case of an automobile, to rotation of the driving shaft, and from it to the rear axle and wheels by means of the final reduction gears.

Q. What is a torque rod?

A. A rod, bar, or tube, provided to take, not the torque, but the equal opposite reaction from the torque application to the final drive.

Q. What is the manifestation of this torque reaction?

A. A tendency of the driving shaft and driving bevel gear to rotate up and around the bevel-driven gear in a counter-clockwise direction.

Q. How does the torque rod absorb this?

A. By extending this forward and attaching it to a frame cross-member at the front end and to the rear axle housing at the rear end, this counter-clockwise motion of the driving shaft is prevented.

Q. What is driving effort?

A. The force applied to the rear wheels tending to move the car forward. It is transmitted to the car, or frame of the car, as a push.

Q. How is this push transmitted to the frame?

A. In one of three ways; through special radius rods which transmit it directly to the frame; through a central tube which handles both torque and driving effort, transmitting this first to a frame cross-member, then to the main side members and through the springs, which are modified in attachment so as to take care of these extra stresses.

Q. Which is the best form?

A. The use of radius rods, one on each side, transmitting the stresses directly to the frame, is undoubtedly the best form, but also the most expensive, the heaviest, and includes the greatest number of parts.

Q. Which is the most simple form?

A. The use of the springs, the so-called Hotchkiss drive, but this also reduces the easy-riding qualities of the car because the springs, which should be flexible for easy riding, must be made somewhat rigid in order to transmit torque and driving reactions.

Q. Which is the cheapest?

A. Undoubtedly the use of the springs is the cheapest form, as it eliminates all additional parts, and simply necessitates a pivoted form of springing end in place of the usual shackle there.

FINAL DRIVES

Q. What are the usual methods of final drive?

A. Final drive is usually by one of these methods: roller chain, silent chain, spur gear, bevel gear, spiral bevel gear, worm and gear, rollers.

Q. Are all of these in use today?

A. All but the roller, although the two forms of chain drive have almost gone out of use for pleasure cars and are becoming less popular even for truck use.

Q. Which is most popular?

A. For pleasure-car use, the spiral bevel form, and for motor trucks, the worm.

Q. Why is the spiral bevel popular on pleasure cars?

A. Because of its many advantages. It is just as simple as the straight bevel, needs no additional parts, is more quiet, perhaps more efficient, is less likely to cut or wear, can be removed as readily, and has other minor advantages.

Q. Why is the worm popular for trucks?

A. It has all the needed qualities; it is efficient, silent, easy to handle, and allows bigger gear reductions than any other form. Furthermore, various gear reductions are interchangeable by changing other parts, and the worm has other advantages.

Q. Why is the worm not used more on pleasure cars?

A. Because it is not so well adapted to high speeds of 50 to 60 miles an hour and higher, which may be demanded, and because the large reduction between engine and rear axle, which is its biggest advantage, is not needed on pleasure cars.

Q. What are the three mostly used forms of rear axle?

A. The full floating, semi-floating, and three-quarter floating.

Q. Which is the best form?

A. From an engineering standpoint, the full floating is undoubtedly the best, but it is also the most complicated, with the largest number of parts, and the most expensive to construct.

Q. Which is the most simple form?

A. The semi-floating form is the most simple, but it lacks advantages which the majority of car owners want. It is the cheapest to make, but is made so through the lack of these advantages.

Q. Which is the compromise form?

A. The three-quarter floating form seems to offer a maximum number of advantages with the minimum of disadvantages. It has practically all the advantages of the full floating with less cost. It has all the advantages which the semi-floating lacks and costs but little more.

Q. Which is the most popular form?

A. The floating still has the greatest number of makers, but the three-quarter form is rapidly gaining in popularity and, in another year, will displace the full floating as the most popular, both as to the number of makers and as to the actual number of cars.

Q. Describe the internal-gear axle?

A. In this form a spur gear is used to drive an internal gear of larger diameter. This construction enables the separation of load carrying and power transmitting, so that one part of the axle can handle each.

Q. For what is this used mostly?

A. The internal-gear axle is used mainly on motor trucks, although a few heavy pleasure cars have been built with it.

Q. What is a differential?

A. A mechanical device for allowing the rear wheels to travel different distances when turning a curve or corner.

Q. How is this done?

A. By combinations, or nests, of gears and a divided rear axle, one-half being fixed to each half of the differential, with only the nests of gears connecting the two. As these are free to revolve as a unit, or stand still and have their gears revolve, the drive can either be transmitted all to one wheel, half to each wheel, or divided unequally.

Q. What is the usual differential form?

A. The usual differential gear is constructed with bevel or spur gears, the bevel form being more popular, the spur cheaper.

Q. What is undesirable in present differentials?

A. Present differentials have the disadvantage that they work for resistance not distance. This permits the wheel, which we do not want to slip, to slip on icy places so that the car cannot pull itself free, the differential making a bad matter worse.

Q. If the differential worked correctly, how could this be?

A. In such a case, since the differential worked only for difference in distance, and there was no difference in distance on an icy place, the power would be transmitted equally to the rear wheels. One would slip, but the other on firm ground would use its share of the power to pull the car off the icy place.

Q. How is it expected that this result will be attained?

A. By the use of helical gears, which, like the worm of a steering gear, are not reversible but will transmit power only in one direction.

Q. In addition to correct differentiation, what is it expected these differentials will do?

A. Eliminate skidding, always dangerous and always a possibility with present forms. The connection between skidding and present differentials has never been explained, but can be readily proved by the simple process of building a car without a differential.

Q. What forms of bearings are used in rear axles?

A. All the different kinds of bearings are used in rear axles: plain ball, plain straight solid roller, straight flexible roller, tapered roller, a few plain bronze bearings, ball-thrust forms, and others.

Q. Which form is most popular?

A. There is little choice between the two forms of roller and the ball bearing. In fact, the majority of axles use several different forms of bearings; so it is difficult to compare the work of the various bearing types.

Q. How can a broken spring clip be repaired?

A. A good substitute for a spring clip can be made from two flat plates and four bolts to reach from one plate to the other. The purpose of the spring clip is to hold the spring to the axle; this combination will do the same thing.

Q. How would you line up a rear axle?

A. With a try-square and plumb bob, working downward from the main frame, determine the distance from the rear end of the frame to the back side of the rear axle, on each side of the car. If the two do not agree exactly, the axle is out of square by the difference, or by half this difference on each side. Loosen the spring bolts, set the axle correctly, tighten the bolts, and check up the measurements again.

BRAKES

Q. What are the two general types of brakes?

A. The contracting-band, which is an external brake, and the internal-expanding shoe.

Q. How are these used?

A. There is no set rule; some designers use only the internal-expanding form, claiming this is more powerful and dependable; others use only the band, claiming this is cheaper to make and repair and just as good; still others take no side but use both forms.

Q. Has there ever been any agreement in relation to brakes?

A. Up to about a year ago, it was general practice to use the internal-expanding shoe brake for the emergency, or hand, brake. This was the case whether the band form was used for the foot, or running brake, or another expanding shoe.

Q. Does this rule hold now?

A. No. Many hand-operated brakes are of the contracting-band form, while many foot-operated forms, which would be considered the service, or running, brakes, are internal expanding. The tendency toward unit power plants is bringing back a shaft brake of the band type, operated by the hand lever.

Q. Where are the brakes generally located?

A. Except for the tendency just mentioned, the brakes have been located as much as possible in the rear wheels, on the assumption that this gave the most direct and thus the best application of the braking force.

Q. How are brakes arranged on the rear wheels?

A. When both brakes are placed on the rear wheels, practice is sharply divided into two camps. The one places the running brakes as a band form on the outside of the drum, claiming this makes a smaller lighter drum, a more compact group on the wheel, and less expensive because the drum is cheaper. The other places the two brakes side by side, making both of the internal-expanding shoe form inside a wide drum, claiming this is more effective, more powerful, and that the brakes are better protected against dirt, dust, and water because entirely enclosed, and thus are more effective and need less attention.

Q. What is the electric brake?

A. A new device which substitutes the rotation of an electric motor for hand or foot application of the brakes. This is put into action by a finger lever on the steering post, which makes contact, through suitable resistance, between the battery and the motor. When the motor rotates a cable is wound up and this pulls the brakes.

Q. Is this a powerful form?

A. Not only very powerful but also very quick to act, so that care must be used in applying it.

Q. What is the hydraulic brake?

A. A new form for heavy trucks and tractors, in which the use of an oil, which transmits power equally and without loss, is substituted for the usual rods and levers in the application of the brake. The construction is such that the driver can apply the brakes by a stroke of the hand lever, and if this does not give sufficient power to stop the truck, he can let the lever go forward and then pull it backward again; this action soes not release the brakes but does apply more force, that is, it can be worked continuously until sufficient power is applied to stop the vehicle, a peculiarity of this particular form.

Q. What is the vacuum brake?

A. A new form which utilizes the suction of the engine to create a vacuum in a special braking cylinder, the movement of a piston in which applies the brake. The amount of action depends on the amount of suction, that is, regulated by the amount the valve is opened, and this is dependent upon the pressure applied to the finger lever or toe button, whichever is used.

WHEELS

Q. What are the usual forms of pleasure-car wheels?

A. The plain wood form and the wire wheel comprise 99 per cent of all pleasure-car wheels; the wood forms about three-quarters and the wire about one-quarter of the total.

Q. What are the tendencies in wheel sizes?

A. On small cars the tendency is toward larger and larger sizes, but on the larger heavier cars the tendency is away from the very large sizes of a few years ago. The latter tendency has been brought about by the standardization of tire sizes, and the elimination of 38s, 40s, and larger sizes formerly made.

Q. What are the different forms of wire wheels?

A. The double-spoke form, which is lacking in lateral strength; the triple-spoke; and the quadruple-spoke. The two latter make up in strength what the former double-spoke form lacked. Except for number of spokes, these do not look any different to the casual observer.

Q. What is the sheet-steel wheel?

A. A form in which the whole wheel construction consists of a pair of sheet-steel members. These are given a slight taper, sometimes have holes through them for ventilation and to make them lighter, and frequently are painted to resemble wood-spoke wheels. The steel sheets are made thin enough to be flexible.

Q. What is the pressed-steel wheel?

A. A newer form in which a simulation of one-half the entire wheel spokes, hub and all, is pressed out of thin sheet steel, and a pair of these welded together so that the finished product has all the appearance of a wood wheel with the usual number of spokes, but without the rim which this construction eliminates.

Q. What are the usual truck wheel forms?

A. Most truck wheels are of heavy wood or cast steel. The latter do not weigh a great deal more than the former; because of the greater strength of the material, less of it can be used.

Q. Which is the most popular?

A. The wood form is still the most popular, despite its disadvantages for heavy truck use, but the steel form is gaining rapidly.

Q. What are the advantages of steel?

A. Greater strength, particularly to resist side stresses; better ventilation and removal of heat from the tires; more firm foundation for the tire so that it holds its shape better; and longer life at less cost.

Tires

Q. What are the general divisions of all tires?

A. Pneumatic, cushion, and solid.

Q. What is the principle of each?

A. The pneumatic tire has an interior air bag which is pumped full of air, the tire gaining its resiliency from this. The cushion tire is so constructed as to have a central air passage or other yielding space so that it gives a cushion effect under loads. The solid tire is a solid mass of rubber, its only give being the natural yield of the rubber.

Q. Is there a distinct field for each?

A. Yes. Pneumatics are used only on pleasure cars and the lighter trucks or delivery wagons; cushion tires are used mostly on slow-speed electric pleasure cars and a few light trucks; solid tires are used only on the heavy trucks.

Q. What is the big disadvantage of the pneumatic form?

A. Its liability to puncture or blow out, or loose its air otherwise, after which the tire is useless until the fault is mended; in fact, the tires are actually in the way, and running a deflated tire only cuts it to pieces.

Q. What are the divisions of pneumatic tires according to shape and method of holding?

A. While there are other forms, practically all tires today are in one of two classes, the clincher or the straight side.

Q. Describe the clincher type?

A. This is made with a bead or hard portion at the base, which forms a projection around which the clincher rim fits. The rim has the shape of a flattened U with the ends curled in, and the beads on the tire fit into these curled ends or clinches.

Q. What is the advantage of this?

A. The clincher form is held firmly on the rim, while the stiffness of the bead contributes more rigidity of form and permanence of shape to the whole tire.

Q. Describe the straight-side form.

A. This type of tire has no bead, the fabric forming the side walls being carried straight down to form the base without additional thickness of material.

Q. What are the advantages of this?

A. Its simplicity and lighter weight, with greater air space are the advantages of the straight-side form. In addition, in the newly standardized rim forms, the form of rim adapted to the straight-side tire is more simple, lighter in weight, and lower in cost than any other. It has been found by experience that the holding power of the beads was unnecessary as the inflated tire could not come off the wheel whether it had a bead or not, since its diameter at the base could not be increased in any possible way sufficiently to pass over the larger size rim.

Q. What is an oversize tire?

A. In the standardization of tires and rims, for each even tire size, which is called a standard, there is an oversize made which will fit on the same rim without any other changes.

Q. What is the difference between standard and oversize tires?

A. All standard tires are made in even inches of outside diameter, and all oversize tires are made in odd inches of outside diameter, so that the rule for oversizes is this: An oversize is one inch larger in diameter and ½ inch larger in cross-section, that is, the Ford size is 30 by 3½, the oversize for this, according to the rule, is 31 by 4; an average large car size is 36 by 4½, the oversize for this is 37 by 5.

Rims

Q. What are the general different rim forms?

A. Rims are generally divided into these forms: plain, which is no longer used; clincher, which is gradually going out; quick-detachable in its various forms; and demountable rims, now almost universal.

Q. What are the differences in these?

A. The clincher rim is a solid form, and the tire has to be stretched to get it on or off the rim. For this reason, it has to be made with a more or less yielding base, but even at that, tire removal is very difficult. The quick-detachable form is made with a locking ring on one side to replace the solid side of the clincher, so that tires can be applied easily. The demountable rim is a form which is used in combination with the others, this being a modification of the felloe of the wheel by which the entire tire and rim are removed in case of trouble, and then are replaced by another tire and rim which have been carried for this form.

Q. What are the advantages of this?

A. All roadside work is eliminated. When a puncture or blowout occurs, the driver simply jacks up his wheel, takes off tire and rim, and puts on the square tire and rim—the tire being inflated—lets down his car by means of the jack and drives off. The worn, or damaged tire, is carried at the rear in place of the spare, and is mended in the convenience and comfort of the garage or left at a tire repair station for that purpose. It saves work, time, and trouble at a time when these are of the greatest value to the owner. Given demountable rims, supplied on the car by the manufacturer, the car can be operated with all these conveniences without extra tire expense.

Q. How are demountable rims held in place on the wheels?

A. Nearly all demountables are held by means of wedges, with separate bolts to press these into place, or else a construction in which the bolt and wedge are combined.

TIRE REPAIRS

Q. What is vulcanization?

A. Vulcanization is the curing, or cooking, of raw rubber. By this curing it is more suitable for hard usage and its soft pliable character is changed without injuring its resiliency. If these were unchanged the tire would cut and would not wear.

Q. How is this accomplished?

A. By the application of heat in moderate quantities and in dry form. The heat is not applied directly but through metal. In the usual tire-curing mold the central space for the tire is surrounded by metal, with a hollow annular space outside of this into which the steam, which is generally used, is introduced. The heat from this steam penetrates the metal inside and vulcanizes the tire.

Q. Are all vulcanizers operated by steam?

A. Practically all the larger ones are, but many of the smaller forms of the portable type burn gasoline in the heating space, others use electric resistance coils.

Q. What is the advantage to the private owner of a vulcanizer?

A. When a tire is cut badly, he can apply raw rubber as a patch or repair, and then vulcanize this for the double purpose of curing and of uniting it with the older part of the tire. In this way, tire life is much prolonged at little expense.

Q. Is vulcanization profitable as a business for a repair shop?

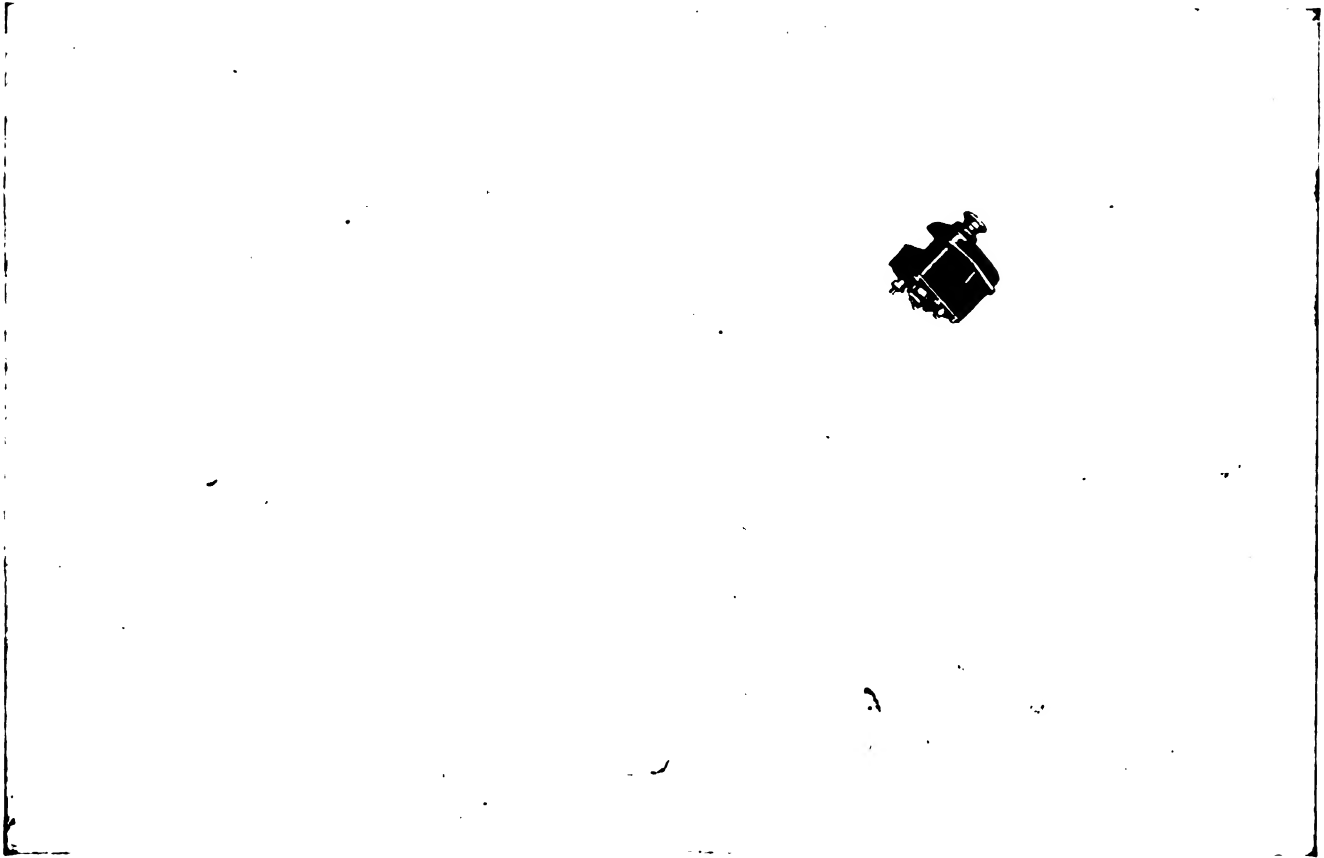
A. It is said to be highly profitable, after suitable equipment has been purchased and a trade built up. It is said to be a more steady and stable business than any other, for, as soon as an owner has been convinced of the value of vulcanization of tubes and casings, he will bring in all his tire repairs.

Q. What is a sand blister?

A. A small opening in a casing, into which sand has entered and continues to enter until the outer surface is swelled up just like a blister. If neglected, this will ruin the casing.

Q. How should a sand blister be cared for?

A. By the immediate removal of the sand and the cleaning of the cavity, after which it should be filled with a tire-repairing cement or tire-filling compound. The sand can be removed by cutting a small hole in the underside of the blister with a sharp penknife.



NORTH EAST MODEL "G" STARTER-GENERATOR MOUNTED ON DODGE CARS
Courtesy of North East Electric Company, Rochester, New York

ELECTRICAL EQUIPMENT FOR GASOLINE CARS

PART I

INTRODUCTION

Importance of Electricity on Automobiles. Starting with nothing more than a few dry cells and a wiring system that would have shamed an itinerant bellhanger, the electrical equipment of the automobile has constantly increased in importance, until within the last few years it has become the most essential auxiliary there is on the machine. Electricity now starts the motor, ignites the charge in the cylinders, lights the car and the road ahead, sounds the horn, and in some instances shifts the gears and applies the brakes. In addition to performing the numerous functions already mentioned, it has even gone as far as to displace the flywheel, clutch, and gearset altogether, in which case the car is provided with as many gradations of speed as a steam car. It seems quite likely that along this line is to be one of the most important developments of the next few years.

Inherent Weakness of Electrical Devices. Even in the present highly perfected state, the electrical equipment still constitutes the weakest element among the motor auxiliaries. In fact, it is subject to more frequent defection than any other single element of the entire construction of the automobile. This must not be taken as implying that it is defective in any sense, as it is quite the contrary, ignition, lighting, and self-starting systems having been developed to a degree of reliability that was undreamed of in the earlier days. But owing to its nature, the electrical equipment is more susceptible to derangement. Consequently, a rather substantial proportion of the minor troubles of automobile operation that still survive to harass the motorist arise from some failure of the electrical system. Of course, many of these are due to the inexperience or ignorance of the motorist himself, and for this reason it behooves the student to give more than the usual amount of attention and study to this branch of the subject.

ELEMENTARY ELECTRICAL PRINCIPLES

Knowledge of Principles Necessary. To acquire a good practical working knowledge of electricity as applied to the automobile today, it is essential not merely to find out *how* things are done, either by watching the other fellow do them, or by studying "pictures in a book", but also to learn *why* certain things are done and *why* they are carried out in just such a way. In other words, the man whose knowledge is based upon theory and principles applies knowingly the cause to produce the effect and is certain that the desired effect will be produced. On the other hand, the man who works only with his hands aimlessly goes from one thing to another trusting chiefly to luck to accomplish two things. One of these is to strike upon the remedy for the trouble the cause of which is sought, and the other is to deceive the spectator—usually the owner of the car—into believing that the fumbler really knows what he is about.

There are accordingly two distinct classes of knowledge as regards the electrical equipment of an automobile—one which is picked up by rote, an isolated point at a time, and applied in the same manner, and the other which is based upon a clear insight into the underlying reasons for the various actions and reactions that make up the different electrical phenomena involved. If we want to know what is wrong with an electric motor, it is essential that we should know what makes an electric motor operate when everything is right. In the same way, it would be groping in the dark to attempt to investigate the reasons for the failure of a dynamo to generate current, or a storage battery to give up its charge, if we had no knowledge of why a dynamo, when run by an outside source of energy, normally produces a current, or why an accumulator literally "gives back" what has been put into it when its circuit is closed after charging.

It will accordingly be the function of this introductory chapter to give a brief résumé of the principles underlying the operation of what has come to be the most important auxiliary of the gasoline motor as applied to the automobile—its electrical equipment.

A thorough understanding of these principles will go a long way toward enabling one to remedy the various minor ills that afflict the apparatus, and to recognize at once those of a nature serious enough to be beyond the first aid which even the best equipped garage is capable of giving. It is worse than a waste of time to hunt for a short circuit or a ground as the cause of failure of the dynamo to generate, when an inspection of its parts reveals the fact that its armature winding has been burned out. Again, one can hardly expect the motor to continue starting the gasoline engine when the owner's neglect of the storage battery has permitted the plates to sulphate so badly that they are practically worthless. Contempt of "book knowledge" is not wholly a thing of the past, and many men consider themselves "practical" in insisting upon learning how to do things with their hands alone. The best-paid man, however, and he who can instruct others how things should be done, is the man who uses his head to acquire a knowledge of the theory upon which practice is based, and then employs his hands to much better effect by letting his brain guide them.

THE ELECTRIC CIRCUIT

Current. Just what electricity is we do not know—maybe we never shall know—but it is a matter of common knowledge that it is one of nature's prime forces and as such is universal. The air, the earth, the water, the clouds, our bodies and those of animals, and other inanimate objects such as trees, houses, and the like are all electrified to a greater or less degree all the time. The amount of electricity that any given object possesses at a given moment depends upon its capacity (the electrical meaning of which is given later) and the conditions of surrounding objects. For example, a room will hold a certain amount of air; if it is uninfluenced by other conditions, we know that the room is full of air at an approximate atmospheric pressure of 15 pounds to the square inch (the usual pressure at sea level). The room may be considered in a normal "state of charge".

There is nothing that differentiates the air in this room from that of the room adjoining. It is perfectly quiet and nothing is disturbing it; there is no tendency for it to move. If, however, all the openings of the room are tightly closed with the exception of a duct for the admission of more air under the impulse of a powerful compressor, in a very short time there will be a marked difference between the air in this room and the air in the other rooms. Instead of the normal atmospheric pressure of 15 pounds per square inch, there will be a pressure against all parts of the room—floor, walls, and ceiling—of 50, 60, or 100 pounds, according to the length of time the compressor has been working and the degree of tightness with which the various openings have been closed. Thus there will be a great deal more air in the one room than in its neighbors. If it were electricity instead of air, the room would be said to be highly charged.

The air in this room, on account of the pressure which it is under, is constantly seeking an outlet, and it will gradually leak out through various small openings, probably without its escape being noticed. The same conditions obtain when a body becomes electrified beyond its capacity to hold a charge—the charge of electricity will leak away without giving any indication of its passing. Turning again to the room containing the compressed air, if a door or window of that room is opened suddenly, the pressure is immediately released through that opening and anyone standing in front of it would say that a strong current of air blew out. In the case of electricity, if any easy path of escape is provided, the entire charge will rush away from the body, and there is then said to be a current of electricity "flowing" from this point of escape to whatever other object equalizes the pressure by becoming charged. An electric current is accordingly electricity in motion; it is simply said to flow. But to cause it to do so there must be pressure. The electrical term for this pressure is *potential* or *voltage.*

Electrical Pressure. Every day in the year the earth transmits a greater or less proportion of its electrical charge to the atmosphere, or receives a charge from the latter, but unless the conditions are favorable there is no visible indication of this *difference of potential* as it is termed. It must be borne in mind that this difference of potential, or difference in electrical pressure, between two points is what causes a current to flow. Given a hot day in summer, however, when the air is heavily charged with moisture and low cumuli, or rain-charged clouds form in great masses, then the electrical charges from the earth and the air accumulate in these great banks of dense water vapor instead of passing up to the higher regions of the atmosphere. When the charge exceeds the capacity of the clouds, and the electrical pressure, or difference of potential, between two neighboring clouds or between a cloud and the earth becomes very great, we have the familiar phenomenon of lightning, the electricity escaping in a several-mile-long flash instead of by means of the little spark with its snap as it passes from one object to another under similar conditions.

Resistance. It is thus apparent that electricity is an element that can be expressed as a quantity, and likewise one that can be subjected to pressure. The unit of quantity is the *coulomb;* the unit of electrical pressure is the *volt;* the unit of current is the *ampere*, equal to one coulomb per second. Resuming the simile previously given, 500 cubic feet of air per minute forced into a room under 100 pounds pressure may be likened to a current of 500 amperes at 100 volts. And, just as the opening allowed determines the rate at which air will escape, so the electrical outlet influences in the same manner the current that will flow. From this it is evident that there is another factor to be considered. This is resistance.

If a half-inch hole is bored in the door of the room, the air will escape at a pressure of 100 pounds to the square inch, but only a few cubic feet per minute can pass through the orifice. If a very fine wire is used to tap the given charge of 500 amperes at 100 volts, the current will have a potential of 100 volts, but very few amperes will pass through the fine wire. If the pressure back of the air is increased, however, more air will be forced through the small opening in the same time; and if there is a greater potential back of the electrical current, more current will be passed through the fine wire. Thus the factors of electrical quantity, pressure, and flow are all related and are all dependent on the factor of resistance. The unit of resistance is the *ohm.*

Ohm's Law. From this interrelation has been deduced what is known as Ohm's law, usually expressed as $I=\frac{E}{R}$, or current equals voltage divided by resistance, E denoting the electromotive force, which is only another term for voltage or potential—the electrical moving force back of the current I.

As a practical application of the preceding formula, take the case of a small conductor connecting the battery and starting motor of the electrical starting system on an automobile. The diameter of the wire is such that the length required to connect the two points has a resistance of 10 ohms. One ampere is that amount of current which will pass through a conductor having a resistance of one ohm under a pressure of one volt. The starting system in question operates at 6 volts. Hence, $I = \frac{6}{10} = .6$, that is, the battery would be able to force only .6 ampere through that small wire, and the starting motor would not operate.

It is apparent from the foregoing that the formula for Ohm's law may be transposed to find any one of the three factors that may be unknown. For example, given the conditions just mentioned, we may determine how much resistance the wire in question has. The resistance equals the voltage divided by the current: that is, $R = \frac{E}{I}$, or resistance equals $\frac{6}{.6} = 10$ ohms. Or again, if it is desired to learn what voltage is necessary to send a current of .6 ampere through a resistance of 10 ohms, the solution calls for an equally simple transposition of the formula. Given any two factors, then the third may be readily determined.

Ohm's law is absolutely fundamental in all things pertaining to electrical operation, and the man who wants to make his knowledge of the greatest practical use will do well to familiarize himself with it. Naturally it does not enter into repair work to more than a small fraction of the extent that it enters into the design of motors, generators, and other electrical devices, but a knowledge of it is of distinct value.

Power Unit. To go back to the simile of air under pressure, it is apparent that the energy released by the lowering of this pressure may be made to perform useful work, such as driving a compressed-air drill, running a small air motor, or the like. So with the electric circuit, the drop from a higher to a lower potential, which causes a current to flow, is a source of power. Electrical power is the product of the amperage or current multiplied by the voltage at which it is applied. The power unit is the *watt* and it is equivalent to one ampere of current flowing under a pressure, or potential, of one volt. There are 746 watts in a horsepower.

Electrical computations, however, are based on the metric system to a large extent, so that instead of being figured in horsepower, electrical energy is figured by the kilowatt, or a unit containing one thousand watts, and the charge therefor is based upon the length of time for which this amount of energy is employed. From this comes the now familiar expression "kilowatt-hour".

The power equivalent is expressed as $P=I\times E$, current multiplied by electromotive force (potential), and, as in the case of Ohm's law, with any two of the factors given, the third may be readily determined. For example: How much power is developed by a 6-volt starting motor if 125 amperes of current are necessary to turn the automobile engine over fast enough to start it? The amount of current given is an arbitrary average taken simply for the purpose of illustration, for in overcoming the inertia of an automobile engine a great deal of current is required at first, the drain on the battery often exceeding 250 amperes for a few seconds, then dropping as the engine turns over to about 50 or 60 amperes. Taking 125 as the average, we have $125\times 6=750$ watts$=.75$ kilowatt, or slightly over one horsepower.

Granting that one horsepower is necessary to turn over a $3\frac{1}{2}$ by 4-inch six-cylinder motor at 75 r.p.m.—a speed that has been predetermined as necessary to cause it to take up its own cycle under the most adverse starting conditions—and given a 6-cell storage battery capable of developing a potential of 12 volts, then we have: $I=\frac{P}{E}$, or current$=\frac{746}{12}=62.1+$ amperes, which represent the average demand upon the storage battery to start that engine under normal conditions. This illustration and the previous one show the working of Ohm's law; doubling the voltage halves the amount of current necessary. As the life of a storage battery is largely determined by the rapidity as well as by the number of its discharges, and as the storage battery is the weakest element in any electric lighting-and-starting system, it may well be asked why the 12-volt standard is not universally adopted, or why, as is done in some cases, a 24-volt battery is not employed and the current consumption again reduced by half. Just why this is not done is explained in detail in the section on the voltages employed in electric starters generally.

Conductors. To lead steam or air under pressure from a boiler or compressed-air reservoir to the point at which it is to be utilized as energy, it is desirable to use a conductor that will not waste too much of this energy in useless friction. That is, the conductor must be of ample size in proportion to the volume to be conveyed, smooth in bore, and free from sharp turns or bends. The transmission of electrical energy involves some of the same factors. While neither the smoothness of the bore nor the presence of bends and turns has any effect, they have their counterpart in the conductivity of the material of which the wire is made, the size of the wire in proportion to the amount of current to be carried being also a matter of prime importance.

Resistance of Materials. Materials differ greatly in their ability to conduct an electric current, or, to put it the other way around, they differ in the amount of resistance that they offer to the passage of the current. Silver in its pure state heads the list in the table of relative conductivities, and it is accordingly said to possess a relative resistance of one, or unity; the resistance of every other material may be expressed by a number which represents the resistance of that particular substance as compared with pure silver. Naturally silver does not represent a great possibility for commercial use, and so copper, which is second on the list, is almost universally employed. Pure copper is very soft and is lacking in tensile strength; it is therefore alloyed, and it is also hardened in the drawing process; both of these processes increase its resistance slightly over the factor usually accorded it in the standard table of specific conductivities of materials. In this table, German silver (which is an alloy containing no silver whatever and having but a few of its properties), cast iron, steel, carbon, and similar substances will be found well down toward the end. They are known as "high-resistance" conductors and are usually used where a certain amount of resistance to the current is desirable.

It must be borne in mind that ability to conduct a given amount of current without undue loss through resistance depends upon the size and the length of the conductor quite as much as upon the material. In other words, if a steel rail is only one-thirtieth as good a conductor as a copper cable, it will require a cross-section of steel thirty times as great as that of a copper cable in order to conduct the current with the same ease—that is, to make a conductor of equal resistance. An illustration of this may be seen in the overhead copper wire of the usual trolley system. This wire of about one-half inch diameter forms one of the conductors, while the two steel rails form the "return". A similar example may be found in what is known as the single-wire system of installation for an electric starter in automobiles. A single copper cable conducts the current from the battery to the starting motor, while the steel frame of the automobile is the return side of the circuit, or vice versa.

Voltage Drop. It is evident that the resistance of a circuit varies inversely as the size of the conductor—the larger the cross-section of a conductor, the less its resistance—and increases directly as its length, besides depending upon the specific resistance of the material. The specific resistance of the metals constituting electrical circuits on the automobile are (silver being 1.0); copper 1.13, varying more or less with its hardness; aluminum 2.0; soft iron 7.40; and hard steel 21.0. Thus, 9.35 feet of No. 30 copper wire are required for a resistance of one ohm, while only 5.9 inches of hard steel wire of the same gage are required to present the same amount of resistance to the current. If the length of the conductor is doubled, its resistance is doubled, which accounts for the placing of the storage battery as close as possible to the starting motor. Furthermore, the heavy starting currents which are required by the motor demand the use of heavy copper cable for this circuit. If two wires are of the same length but one has a cross-section three times that of the other, the resistance of the former is but one-third that of the latter. If a circuit is made up of several different materials of different sizes joined in series with one another, the total resistance will be the sum of the resistance of the various parts.

In addition to being affected by the cross-section and the length, the resistance is also influenced by the temperature. All metals increase in resistance with an increase in temperature, that of copper increasing approximately .22 per cent per degree Fahrenheit. The change of resistance of one ohm per degree change in temperature for a substance is termed its *temperature coefficient*. Metals have a positive temperature coefficient; some materials, like carbon, have a negative temperature coefficient, that is, they decrease in resistance with an increase in temperature.

It is consequently necessary to employ wires of proper size to carry the amount of current required by the apparatus in circuit —such as lamps—without undue heating, which would cut down the amount of current flowing. For the same reason it is also desirable to make the circuits as short as practicable, since in addition to cutting down the current, the resistance also cuts down the effective voltage. That is, there is a fall of potential, or drop in voltage, between the source of current supply and the apparatus utilizing it, due to the resistance of the conductors between them. This voltage drop is further increased by joints in the wiring and by switches. It is apparent that the lower the voltage of the source of supply, the more important it becomes to minimize the loss, or voltage drop, in the various circuits. For this reason lighting or other circuits on the automobile should never be lengthened where avoidable. When necessary to extend a circuit for any reason, wire of the same diameter and character of insulation as that forming the original circuit must be employed, and the joints should be as few as possible, all mechanically tight, and well soldered. The voltages employed in the electrical systems of automobiles are so low—varying from 6 to 24 volts, with a strong tendency to standardize the 6-volt system—that any increased resistance is likely to cause unsatisfactory operation.

Non-Conductors. In going down through a table of specific conductivities of various materials, the vanishing point is reached with those that cease to be conductors at all. Such materials are known as nonconductors or insulators, and some substances vary in the degree of insulation they afford quite as much as other materials do in their ability to conduct a current. Glass, rubber, shellac, oil, paraffin wax, wood, and fabrics are all good insulators when perfectly dry. Distilled water has such a high resistance as to be almost an insulator, but in its natural state water contains alkaline salts or other impurities that make it a conductor. Consequently, when any otherwise good insulating substance is wet, the current is likely to leak across the wet surface of the insulator. This is particularly the case with a current of high potential, or high tension, and explains why it is of the greatest importance to keep all parts of the secondary side of the ignition system perfectly dry. The potential which causes the current to arc across the gap of the spark plug is so high that it will leak across even slightly damp surfaces, such as the porcelains of the plugs. This leakage is often visible, especially in the dark, and it may also be detected by placing the bare hand on the porcelain.

Just as the amount of current to be carried determines the size of the conductor to be employed, so the potential or pressure under which this current is transmitted determines the amount of insulation that will be necessary. The latter is also affected, however, by mechanical reasons, for example, by the liability of the conductor to chafing or abrasion. The best grades of copper cable employed for both ignition and starting-lighting systems on automobiles today are stranded, that is, composed of a number of fine wires, to make them flexible. The stranded cable is then tinned to prevent corrosion due to the sulphur in the insulation, after which it is covered with a soft-rubber compound of a thickness dependent upon the purpose for which the wire is intended. For high-tension ignition wire this rubber covering is about three-sixteenth inch thick. This covering is vulcanized and is then further protected by braided linen, or silk-cotton thread which is made waterproof by being impregnated with shellac or some other insulating compound.

Circuits. When air under high pressure escapes from its container, it simply mingles with the atmosphere, and as soon as the difference in pressure is equalized there is no distinction between it and air in general. But to equalize a difference in potential of an electric current there must be a conducting path between the points of high and low potential. This is termed a circuit. Current to operate trolley cars is fed to the motors of the car from the overhead wire and returns through the tracks to the generators at the power house. This is known as a *ground-return* circuit. In the single-wire electric starting system of an automobile, current from the storage battery reaches the starting motor through the starting switch and a single heavy cable, and returns through the frame and other metal parts of the car itself, or *vice versa*. This is another instance of a ground-return circuit.

Both the primary and secondary sides of the ignition system of an automobile are also grounded circuits. In contrast with this, the circuit may be composed of copper cables directly connecting both poles of the battery and switch with the starting motor. The highly insulated cable employed for both ignition and starting systems is expensive and the use of a single wire greatly simplifies the connections, considerations which account for the general use of this type of circuit. A circuit is said to be open when there is a break in it which prevents the current from flowing, as

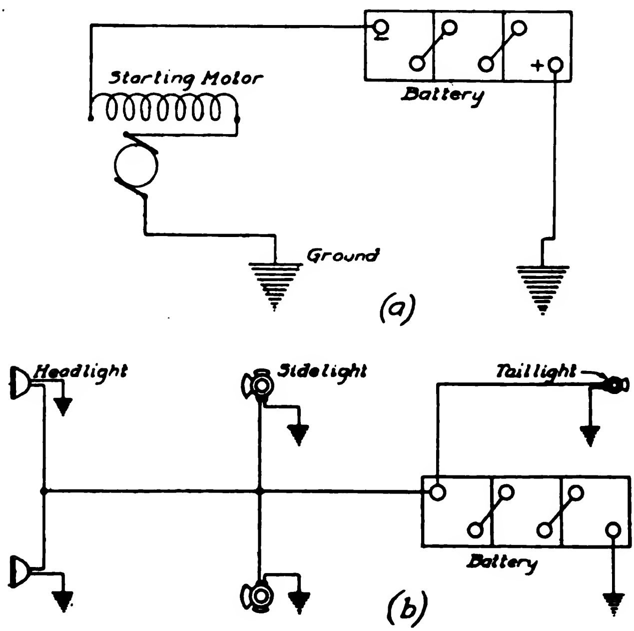


Fig. 1. Typical Starting-Lighting Wiring Diagrams. (a) Series Circuit of Starting Motor; (b) Multiple Circuit of Lamps

when the switch is opened, or when a connection or the wire itself is broken.

Series Circuit. The connections between a storage battery, switch, and starting motor, comprise the simplest form of circuit, in which the motor is said to be in series with the battery, and the cells of the battery are in series with one another. This is termed a series circuit and a break in it at any point opens the entire circuit. The starting motor, Fig. 1 (a), requires the entire output of the storage battery for its operation.

To make clear the distinction between this and other forms of circuit, it must be borne in mind that, in equalizing a potential difference, electric current flows from the positive or plus side of the source of supply, whether a battery or generator, to the negative or minus side (plus and minus being arbitrary signs employed to distinguish the positive and negative sides of a circuit or of an instrument). The current is said to flow out on the positive side of the circuit and to return on the negative side. In the case of a series circuit as described, the current flows through each piece of apparatus in turn; each receives all the current in the circuit at a potential proportioned to the resistance of the apparatus in question. For example, in the simple starter circuit referred to above the starting motor receives the entire output of the 3-cell storage battery at its full voltage of 6 volts, less the drop in voltage due to the resistance of the circuit. If there were two starting motors instead of one in the circuit, both in series, both would receive all the current but at only half the voltage.

Multiple or Shunt Circuit. As opposed to this, in a multiple circuit, Fig. 1 (b), in which every piece of apparatus is connected to both sides of the circuit "in parallel", each piece of apparatus in the circuit receives current at the same voltage but draws from the circuit the current determined by its resistance. The failure or withdrawal of any one or more instruments in a multiple or parallel circuit has no effect on those remaining. The lighting circuits of an automobile equipped with a 6-volt starting system are an example of this. Each lamp is designed to burn to its maximum illumination at 6 volts, but the 25-candle-power headlights take more current than the 5-candle-power side lights or the 2-candle-power taillight, owing to the difference in the size and resistance of their filaments. Removing any one of the bulbs has no effect on any of the others, because all are in parallel.

Series-Multiple Circuit. A combination of the two forms of circuits is sometimes necessary to accommodate different devices designed for varying voltages. For example, it is usually found expedient to burn 6-volt lamps on the 12-volt starting systems. In such a case, the starting motor is in series with the battery and receives the full voltage as well as the full current. The lamps are divided into two groups, each group comprising a parallel or multiple circuit of its own, and these two groups are connected in series so that the lamps in each circuit receive 6 volts, but the circuit as a whole takes the battery current at 12 volts. Such a combination

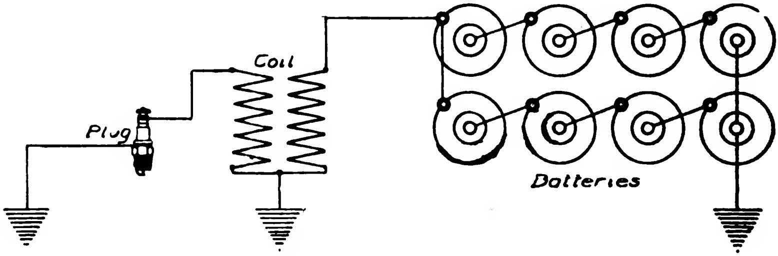


Fig. 2. Dry Cells in Series-Multiple for Ignition Circuit

is known as a series-parallel or series-multiple circuit and is more or less commonly used for connecting dry cells for ignition use, Fig. 2.

Circuits may also be in parallel, that is, practically a circuit on a circuit. The method of connecting up the voltmeter that is mounted on the dash of the car is an instance of this, a wire being led from each side of the main circuit to the instrument. The instrument is then said to be *in shunt*, Fig. 3, and the amount of current that is diverted to it is entirely dependent on the resistance. As a voltmeter is wound to a high resistance, Fig. 4, it is designed to take very little current for its operation. The

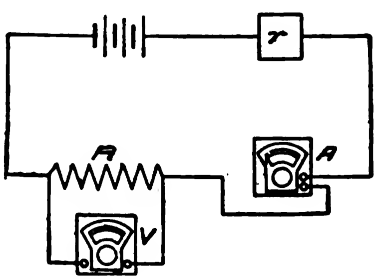


Fig. 3. Diagram Showing How Voltmeter Is Shunted in the Circuit

ammeter, Fig. 5, on the other hand, is intended to indicate the entire current output of the generator on charge or discharge, and is accordingly connected in series so that all the current passes through it. (Owing to the heavy rush of current taken by a starting motor in overcoming the inertia of the gasoline engine, the ammeter is not included in this circuit.)

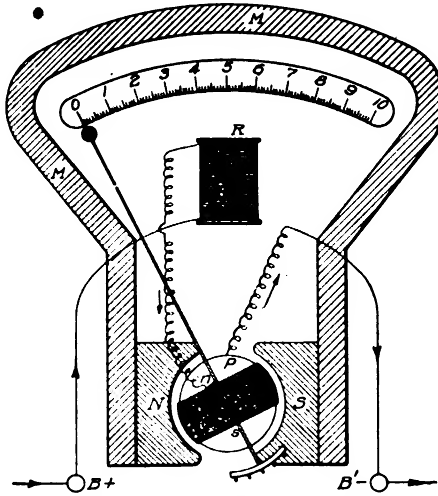


Fig. 4. Diagram of Voltmeter Principle

Short-Circuits and Grounds. The previous paragraphs have made clear the necessity for having a complete path or circuit for the current in order that its power may be utilized. There must be a connecting cable on one side and there must be a return on the other (grounded circuit). If instead of passing through the apparatus, such as the starting motor, the current finds an easier path through an abrasion in the insulation of the cable and some metal part against which that touches, it is said to be *short-circuited*. A case such as that cited, where a stripped cable touches a metal part, so that the current completes the circuit without passing through the motor, is usually termed a *ground*. This should not be confused with the ground return previously mentioned as a characteristic of the wiring of many of the starting and lighting systems in use on automobiles today. It is indeed a ground return but not an intentional one. It is also true that a ground of this type is a short circuit, but it does not necessarily follow from this that

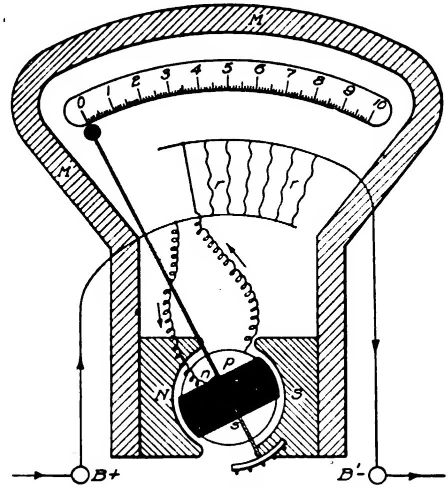


Fig. 5. Diagram of Ammeter Principle

all short circuits are grounds, as short circuits may occur from many other causes—for instance, where two wires touch at uninsulated points or where stray metal makes contact with connections, etc.

Size of Conductors. The influence of the factor of resistance makes plain the reason for using wires of different sizes for the various circuits of the ignition starting and lighting systems of the automobile. If an ample flow of compressed air is desired for power purposes, a liberal outlet must be provided, while if only a small spray is required, as for cleaning purposes, a small-bore tube will suffice. If we try to employ the small-tube line for power purposes, we shall not gain the desired result because its resistance is so great that it will not permit a sufficient flow of air. For the same reason a conductor of much larger diameter and, therefore, of correspondingly low resistance must be employed to handle the heavy current necessary to operate the electric starting motor, than is needed for the comparatively small current which is demanded by the ignition system.

Whether it is mechanical or electrical in its nature, the power necessary to overcome resistance is liberated in the form of heat. Mechanical resistance is friction and its presence between moving bodies always generates heat. Electrical resistance may, for the purpose of illustration, be termed internal or molecular friction, and it also results in heat. The extent of the rise in temperature of a conductor or wire, depends entirely upon the proportion that its size and, consequently, its current-carrying ability bear to the amount of current that is sent through it. Roughly speaking, if a wire is three-fourths the size it should be to carry the starting current, it will become uncomfortably warm to the hand after the motor has been operated several times in succession. If it is only one-half the size it should be, continuous operation of the starting motor for a few minutes will doubtless burn off most of the insulation. Further reducing its size would cause the wire to become so hot as to set fire to the insulation the moment the current was turned on, and any great decrease in diameter would result in the immediate fusing of the wire itself. The wire would literally "burn up" and in a flash.

It would not be practical to attempt to conduct live steam

TABLE I

American Wire Gage (B. & S.)

at high pressure through a cardboard tube. Nor is it any more so to attempt to send a heavy current through "any old piece of wire". Electric lighting and starting systems as they exist on cars today are of all degrees of merit. The cars themselves have reached a stage of reliability where their useful life is now on the average from five to ten years or more. Consequently, there are a great many cars in service equipped with electric systems that were brought out several years ago. These are the cars on which the repair man will get a great deal of his early experience, and he need not take it for granted that just because the electric systems have worked for a certain length of time they were properly designed at the outset. Overheated conductors not only indicate excessive resistance caused by small wires or poor joints, but they also indicate a waste of power that is being drawn from the battery and dissipated in the air. The utilization of this energy or rather the prevention of its transformation into heat would mean all the difference between poor and good operation between an efficient and a wasteful system.

Heating Effect of Current. The amount of heat that a given current will produce in passing through a conductor of a certain size is expressed by Joule's law: The number of heat units developed in a conductor is proportionate to its resistance, to the square of the current, and to the time that the current lasts.

The heat generated, therefore, increases in direct proportion to the resistance. For example, if the cable between the starting motor and the battery be replaced by one-half its size, the resistance will be doubled and the heat generated will increase in the same proportion, the current remaining the same in both instances. Increasing the current, however, adds to the amount of heat generated, as the square of the increase. Thus, if with the original starting cable above mentioned, the amount of current necessary to start the motor has to be doubled, owing to gummed lubricating oil or stiff bearings, the volume of heat generated will increase fourfold. The amount of heat generated also increases in direct proportion to the time that the current lasts. It will be easy to realize from this why abnormal conditions may quickly bring the heating effect of the current to a point where the insulation of the wires, or even the wires themselves, may be endangered. For instance, in the case of a motor that is very hard to start, the discharge from the battery is greatly increased in turning it over, and the starting motor must be operated for a very much longer period to get the engine under way, causing a direct increase in the heating effect, due to the longer time that the current is passing through the cable, and a fourfold increase for the additional current necessary.

Heat Generated in Starting Motor. Take the case of a motor that requires 150 amperes for the first few seconds and 50 amperes once the engine is turning over freely. If stiff bearings or gummed oil cause the initial current to rise to 200 amperes and the running current to 80 amperes for a period three times as long as would ordinarily be required to start, there will be a very considerable increase in the number of heat units generated. This is one of the reasons why it is good practice to use the starting motor intermittently when the engine does not at once fire and take up its own cycle, instead of running the starting motor continuously until the engine begins to fire and generate its own power. A much more important reason, however, is the fact that the intermittent use of the starting motor is not nearly so hard on the battery, as the storage battery recuperates very quickly when given short periods of rest between the demands for its power. Running the starting motor for ten periods of 30 seconds each, with a like interval between the attempts to start, will not discharge the battery anything like as much as will operating the starting motor continuously for five minutes. A longer rest between trials will be of greater benefit to the battery.

Heating Effect on Lamps and Fuses. It must not be concluded from the above that the heating effect of the current is always detrimental, as it is taken advantage of in many ways. Two of the commonest of these are the incandescent lamp and the fuse. In the case of the former, the increase in heat with an increase in resistance is mainly depended upon, the filament being made of such a size that a given amount of current at a certain voltage will just bring it to incandescence. For this reason an increase in the current, or voltage, will burn the filament and destroy the lamp. The fact that the heating effect increases as the square of the current is taken advantage of in the design of fuses which are made of soft alloys that will melt at comparatively low temperatures. Resistance is also a factor in the fuse, as in cutting down the cross-section of the fusible wire the resistance is increased, while the current-carrying capacity of the wire is decreased. The cross-section, or diameter, of the fuse is gaged to carry the amount of current that is a safe load for the circuit and the apparatus in it plus a reasonable factor of safety to prevent the fuse from burning out, with a small percentage of increase that would do no damage. For example, a 10-ampere fuse, such as is used in connection with many automobile-lighting generators, would seldom burn out with an increase in the current to 12 amperes or even to 15 amperes for short periods, as the time element is also important. Some other applications of the heating effect are electric welding, blasting fuses, soldering coppers, cooking utensils, and the like.

Chemical Effect of Current. The passage of an electric current likewise has a chemical effect depending upon the nature of the conductor. This may take various forms, such as the conversion of one chemical compound into another, as in the case of the storage battery; the decomposition of water into hydrogen and oxygen; the deposition of metals, as in electroplating; or the decomposition of metals, as in electrolysis.

TABLE II

Carrying Capacity of Wires

B. & S. Gage	Circular Mils	Rubber Insulation	Other Insulation
		Amperes	Amperes
18	1,624	3	5
16	2,583	6	8
14	4,107	12	16
12	6,530	17	23
10	10,380	24	32
8	16,510	33	46
6	26,250	46	65
5	33,100	54	77
4	41,740	65	92
3	52,630	76	110
2	66,370	90	131
1	83,690	107	156
0	105,500	127	185
00	133,100	150	220
000	167,800	177	262
0000	211,600	210	312

MAGNETISM

Natural and Artificial Magnets. It has been known for many centuries that some specimens of the ore known as magnetite (Fe_3O_4) have the property of attracting small bits of iron and steel, Fig. 6. This ore probably received its name from the fact that it is abundant in the province of Magnesia in Thessaly, although the Latin writer Pliny says that the word magnet is derived from the name of the Greek shepherd Magnes, who, on the top of Mount Ida, observed the attraction of a large stone for his iron crook. Pieces of ore which exhibit this attractive property for iron or steel are known as natural magnets.

Fig. 6. Natural Magnet or Lodestone

It was also known to the ancients that artificial magnets could be made by stroking pieces of steel with natural magnets, but it was not until the twelfth century that the discovery was made that a suspended magnet would assume a north-and-south position. Because of this property, natural magnets came to be known as lodestones (leading stones); and magnets, either artificial or natural, began to be used for determining directions. The first mention of the use of a compass in Europe was in 1190. It is thought to have been introduced from China.

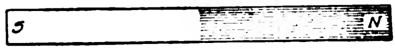


Fig. 7. Bar Magnet

Artificial magnets are now made either by repeatedly stroking a bar of steel, first from the middle to one extremity with one of the ends, or poles, of a magnet, and then from the middle to the other extremity with the other pole; or else by passing electric currents about the bar in a manner to be described later. The form shown in Fig. 7 is called a bar magnet, that shown in Fig. 8 is a horseshoe magnet.

Fig. 8. Horseshoe Magnet

Poles of a Magnet. If a magnet is dipped into iron filings, the filings are observed to cling in tufts near the ends, but scarcely at all near the middle, Fig. 9. These places near the ends of the magnet, in which its strength seems to be concentrated, are called the poles of the magnet. It has been decided to call the end of a freely suspended magnet which points to the north, the north-seeking, or north pole, and it is commonly designated by the letter N. The other end is called the south-seeking, or south pole, and is designated by the letter S. The direction in which the compass needle points is called the *magnetic meridian.*

Fig. 9. Location of Poles of a Magnet

Laws of Magnetic Attraction and Repulsion. In the experiment with the iron filings no particular difference was observed between the action of the two poles. That there is a difference, however, may be shown by experimenting with two magnets, either of which may be suspended, Fig. 10. If two N poles are brought near each other, each is found to repel the other. The S poles likewise are found to act in the same way. But the N pole of one magnet is found to be attracted by the S pole of the other. The results of these experiments may be summarized in the general law: *Magnet poles of like kind repel each other, while poles of unlike kind attract.*

This force of attraction or repulsion between poles is found, like gravitation, to vary inversely as the square of the distance between the poles; that is, separating two poles to twice their original distance reduces the force acting between them to one-fourth its original value, and separating them three times their original distance reduces the force to one-ninth its original value, etc.

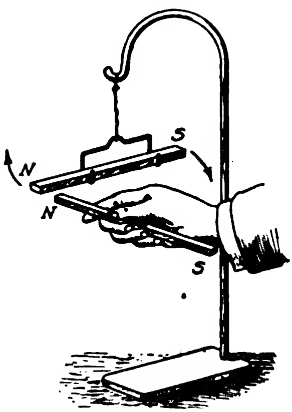


Fig. 10. Experiment Proving the Law of Magnetic Attraction and Repulsion

Magnetic Substances. Iron and steel are the only common substances which exhibit magnetic properties to a marked degree. Nickel and cobalt, however, are also attracted appreciably by strong magnets. Bismuth, antimony, and a number of other substances are actually repelled instead of attracted, but the repulsion is very small. Until quite recently, iron and steel were the only substances whose magnetic properties were sufficiently strong to make them of any value as magnets. Recently, however, it has been discovered that it is possible to make rather strongly magnetic alloys out of non-magnetic materials. For example, a mixture of 65 per cent copper, 27 per cent manganese, and 8 per cent aluminum is rather strongly magnetic. These are known as the *Heussler alloys.*

Electromagnets. The identity of magnetism with electricity is readily established by some very simple experiments that have been repeated so often as to become classics. By taking a bar of iron and winding some insulated wire around it in the form of a coil and then connecting the terminals of this coil with a battery or other source of current, the bar becomes magnetic. One end of it is the positive, plus, or north pole of the magnet, and the other the negative, minus, or south pole. Break the connections or otherwise "open the circuit" and the magnetism instantly disappears. Reverse the connections to the battery by attaching the wire previously at the positive pole to the negative, and vice versa, complete the circuit again, and the bar is once more magnetic, but now the pole that was previously north or positive is south. The bar is once more a magnet, but its polarity has been reversed by reversing the direction of flow of the magnetizing current. This bar of iron with a coil of wire wound around it is known as an electromagnet because it becomes magnetic only when a current is passing through the coil. If a rod of hard steel is substituted for the bar of soft iron and the current passed through it, the bar will be found to be strongly magnetic after the current has been shut off. That is, the bar of steel has, through the action of the current, become a permanent magnet like that shown in Fig. 7. This method is often used for making permanent magnets from hardened steel.

To determine the polarity of a magnet it is only necessary to hold a small pocket compass near it; let the compass needle come to rest normally and then bring the compass near to one end of the magnet. If the needle continues to point in the same direction and gives evidences of being strongly attracted to the magnet, the end to which it is being held is the south pole. Bring the compass near to the other end of the magnet, and the needle will turn away sharply, showing that like poles repel each other.

Magnetic Field. If a bar magnet is placed on a sheet of glass and a handful of fine iron filings thrown around it, they will automatically assume the position shown by Fig. 11. As originally dropped on the glass some of the filings may not be within reach of the influence of the magnet, but if the glass be gently tapped and tilted slightly, first one way and then another, they will arrange themselves in the symmetrical pattern shown. This gives a graphic illustration of the *field of influence* of the magnet, usually termed the magnetic field. This field is most powerful at the poles, as will be noted by the attraction of the filings at the N and S points, representing the north and south poles of the magnet. At intermediate points along the length of the magnet the filings will be seen to have placed themselves as if to indicate a circular movement of the lines of force. This is the magnetic circuit and these concentric circles represent the magnetic flux, or flow. If the magnet is then removed from the glass and the north pole extension of it placed

Fig. 11. Field of Force about a Bar Magnet

Fig. 12. Field of Force about a Single Pole

centrally under the glass, a striking illustration is given of the magnetic field around the pole, Fig. 12. A bar magnet has been shown here for purposes of simplicity, but a common horseshoe magnet such as can be had for a few cents will serve equally well for the experiments.

By carrying the experiments a little further, the identity of magnetism and electricity is strikingly shown. Take a piece of

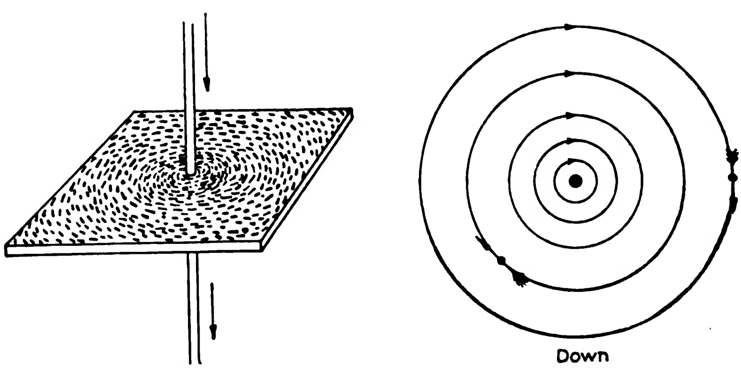


Fig. 13. Field about a Conductor Carrying a Current

cardboard or heavy paper, punch a hole through its center and pass through this hole a wire connected to two or three dry cells. Scatter on the paper the filings used in the previous experiments, then complete the circuit by touching the end of the wire to the other terminal of the battery. The filings will immediately arrange themselves as shown in Fig. 13, illustrating the magnetic field which is always present around any current-carrying conductor.

Lines of Magnetic Force. Punch another hole through the cardboard and rearrange the circuit of the dry cells so that the wire passes from the positive battery terminal up through one hole of the cardboard and down through the other hole to the zinc or negative. Scatter the filings as before and touch the loose end of the wire to the negative terminal. The arrangement of the filings will then be that shown in Fig. 14, the positive field being at the left and the negative at the right. The fact that the magnetic fields overlap in the curious alignment indicated is simply due to the proximity of the conductors carrying the current.

Fig. 14. Field about a Coil

Another simple method of demonstrating the identity of electricity and magnetism is to place an ordinary pocket compass above or below a wire which is running north and south and is carrying a current. If this is a direct current the needle of the compass will tend to set its axis at right angles to the wire, that is parallel to the lines of force; the direction of the deflection will depend upon the direction of the current. This test, therefore, not only indicates the magnetic field about the wire bearing a current, but shows its direction.

All of the arrangements which the filings assume under the influence of either a magnet or a current, as shown by the various illustrations, indicate that the stresses in the medium surrounding a magnet or current-carrying conductor follow certain definite lines, the lines showing the direction of stress at any point. These are termed lines of force.

Solenoids. It has been determined that the direction of the current and that of the resulting magnetic force are related to one another as the rotation and travel of an ordinary, or right-hand, screw thread. Consequently, if the conductor be looped instead of straight, the lines of magnetic force will surround it as shown in Fig. 15. The field of such a loop, if outlined with the aid of filings or explored with a compass needle, will be seen to retain the general character of the field surrounding a straight conductor, so that all the lines will leave by one face and return by the other, the entire number passing through the loop. Hence one face of the loop will be equivalent to the north pole of a magnet and the other face to the south pole. In fact, the loop will act exactly as if it were a thin disk magnetized perpendicularly to the plane. By winding a number of these loops to make a hollow coil, there is formed a solenoid, Fig. 16. Exploring its field shows that the lines of force pass directly through the center or opening of the hollow coil, leaving by one end and returning by the opposite end, as indicated.

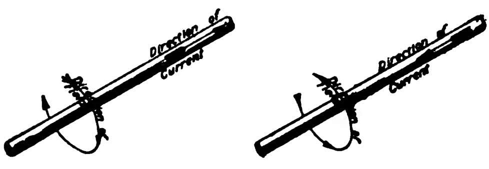


Fig. 15. Direction of Magnetic Lines about a Conductor

If such a solenoid is held vertically and a bar of soft iron placed so that it extends for an inch or so into the lower end of the solenoid, a current passed through the latter will cause the iron to be violently drawn up into the coil and held there. As long as the current flows, this rod is strongly magnetic and has all the properties already described. But the moment the current is shut off, the magnetism practically disappears and the rod immediately drops out of the coil by its own weight. Reversing the direction of the current reverses the polarity of the solenoid but makes the effect the same; increasing or decreasing the amount of current sent through it increases or decreases correspondingly the strength of its magnetic field. The principle of the solenoid is used in starting systems to operate electromagnetic starting switches

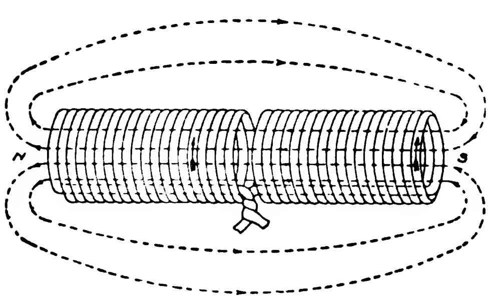


Fig. 16. Magnetic Field about a Solenoid

Effect of Iron Core on Strength of Solenoid. The magnetic flux or flow of lines of force through a solenoid is much greater when an iron core is present than when the coil is empty or a core of wood is inserted. The magnetism flows through the iron as a current would. Soft iron is said to have a high *magnetic permeability.* The magnetic permeability of air (or a vacuum) is taken as unity and other substances rated accordingly: for very soft iron it may be as high as 2500, while for substances such as silk, cotton, wood, glass, brass, copper, and lead, it is unity, the same as for air. Such metals are said to be non-magnetic. All insulators are likewise non-magnetic.

INDUCTION PRINCIPLES IN GENERATORS AND MOTORS

Induction. When a current suddenly flows in a wire placed close to another wire, a delicate measuring instrument such as a galvanometer will indicate a momentary current in the second wire. When the current in the first wire ceases, that in the second will likewise cease immediately. This phenomenon is known as induction, and a current is said to have been induced in the second wire.

Winding the first wire in the form of a coil and bringing this coil close to the second wire, will give the induced current considerably greater strength. The induced effect is still further increased in three other ways: *first,* by inserting an iron core in the coil; *second,* by winding the second wire in the form of a coil; and, *third,* by bringing these coils as close together as possible by winding one directly over the other.

Transformer Principle. The arrangement just discussed is termed an induction coil or transformer (step-up) and is universally employed in connection with ignition systems. The character of the induced current depends upon the relation that the first coil, termed the *primary,* bears to the second coil, known as the *secondary.* In the usual ignition coil the primary consists of a few turns of comparatively heavy wire, and a current of about 2 amperes (4 to 5 on starting) is sent through it at a low voltage, one seldom exceeding 6 volts. The secondary coil, however, consists of a great number of turns of exceedingly fine wire, and the current induced in this is proportional to the relative number of turns between the two and the value of the current in the primary. The secondary current is accordingly of extremely high potential but of low current value.

In the commercial step-down transformer, the relations described above are reversed, the primary being a coil of many turns of fine wire, while the secondary is a comparatively small coil of few turns. In this case, the current is received at the transformer at high voltage and correspondingly reduced amperage, and it steps the voltage down to the standard generally employed, 110 or 220 volts, and increases the amount of current proportionately.

Self-Induction. It has already been pointed out that electricity may be put under pressure or potential, and that the greater this pressure, the greater the amount of work a certain amperage of current will perform, thus affording a direct analogy with steam, water, or air under pressure. An electric current also possesses other characteristics corresponding to mechanical equivalents. Chief among these is inertia and it is the latter that is responsible for what is known as self-induction.

When a current is passed through a coil of wire, a strong magnetic field is set up in the coil owing to the concentration of a great many turns of wire in a small compass. By inserting a core of soft iron wires into this coil, the magnetic field is greatly strengthened, since the permeability of the iron affords a path of slight resistance for the magnetic circuit. There is, of course, a magnetic field surrounding every conductor in a circuit when the current is passing, but the iron core of the solenoid converts a certain part of this current into magnetism. An appreciable time is necessary after the circuit is closed for such a coil "to build up". This "building up" consists of saturating the core with magnetism.

When the circuit is suddenly opened, the current that has been stored in this core in the form of magnetism is as quickly retransformed and its value is impressed upon the circuit, causing a flash at the break. The flash is also aggravated by a certain amount of inertia which the current possesses. We may illustrate this by a stream of water flowing in a pipe. If the water is suddenly shut off by the closing of a valve, it tends to keep on flowing and momentarily causes a great increase in the pressure against the face of the valve, resulting in the familiar "water hammer". The same thing happens when a circuit is suddenly broken, and the higher the potential the more marked this effect will be. The current tends to keep on flowing, and the extra potential which this self-induction gives it will cause it to arc, or bridge, the gap at the break, unless a condenser is provided to take care of this. Every circuit possesses self-induction, but it is only marked in circuits having considerable inductance, that is, in coils, and especially those with iron cores, such as induction coils, circuit breakers, etc.

Capacity of Condensers. Every conductor of electricity has capacity to hold a charge just as a vessel holds water. But the capacity of a conductor is dependent upon its surface area rather than its cross-section, or cubic volume, and is also influenced by surrounding conditions. Where it is desired to accumulate a considerable charge, as for an ignition spark, a special form of capacity is utilized. This is known as a condenser (a detailed description of which is given later in connection with ignition coils). The ability of a condenser to absorb the rise in potential that occurs through self-induction whenever a circuit containing inductance is opened is also utilized to prevent sparking at contact points. Comparatively small condensers are necessary for this purpose, and they are shunted around the contact points, that is, connected in parallel with the latter. When the circuit is opened the excess energy of the circuit passes into the condenser instead of forming a hot spark at the contacts. The occurrence of any undue amount of sparking at contacts should accordingly be made the subject of an investigation of the condenser connections, or of the condenser itself.

Comparison of Generator Current to Water Flow. The comparison of air in a room has been made to illustrate the presence of electricity and its characteristics, since it may be made to partake of all the latter by being put under pressure, allowed to escape through various sized outlets, and made to perform work of differing nature by being utilized at varying pressures and volumes, exactly as electricity is. Where an electric current is produced by a generator, however, the older simile of water flowing under pressure due to the impulse of a pump may serve to make it much clearer. This comparison of a water pump and its piping with an electric generator and its circuits is known as a hydraulic analogue, and, it may be added, there is scarcely any characteristic or function of the electrical current that cannot be similarly compared.

Take, for example, a waterworks system of the type in which a large pump at the power house draws water from artesian wells or a reservoir and forces it into a closed system of piping. Located on this piping system are all the house outlets, street hydrants, and the like. The speed of the pump is regulated so as to keep a certain amount of pressure on the water in the pipes, based upon the average demand at different periods of the day. The pressure is reduced at night and is increased at any time, day or night, in case of fire.

Pressure and Voltage. This constant pressure in pounds per square inch that the pumps maintain on the supply of water in the entire piping system is the exact counterpart of the voltage, or electromotive force, produced by a dynamo, or generator, when running. Just as the pressure exerted on the water by the pumps depends upon the speed of the latter, so the voltage produced by the dynamo is proportional to its speed. In the case of the pump, the pressure depends upon the number of times that the pistons of the pump reciprocate; in the dynamo, upon the number of times that the coils, or windings, of the armature cut the lines of force of the magnetic field in which it revolves. This is explained in detail later in connection with generator principles.

When the pump moves very slowly, there is very little pressure produced in the pipes, and this is the case with the dynamo to an even greater extent, since dynamos are usually designed to run at very much higher speeds, and consequently their voltage, or pressure, drops off very sharply at low speeds. This will explain why the majority of lighting generators on automobiles do not begin to charge the battery until the motor of the car is running at a speed equivalent to ten to fifteen miles per hour, as explained later. At low speeds they do not generate sufficient voltage to overcome that of the battery.

Fall in Pressure. When either a pump or a dynamo is running at a constant speed, the pressure, or voltage, produced at the machine is practically constant. But in the case of the water system, the pressure is not the same at the outlet of a branch line a mile away from the power house as it is at the delivery end of the pump, nor is the voltage on a branch circuit at a great distance from the dynamo the same as it is at the terminals of the latter, consequently, the fall in pressure in the water piping is the exact counterpart of the drop in voltage on the electric circuit due to the resistance of the wires. In the case of the water supply, the friction encountered by the water in passing through the pipes is analogous to the resistance which the electric current must overcome, except that bends in a wire do not impose any greater resistance to the current than the same length of wire when straight, whereas bends in piping greatly add to the friction with a correspondingly greater drop in pressure.

Friction and Resistance. There is, in consequence, almost an exact parallel between the mechanical friction of water passing through a pipe and that of the electric current passing through a wire, as it is commonly said to do. Friction in water piping is inversely proportional to the size of the pipe in proportion to the pressure to which the water is subjected, and is directly proportional to the length of the pipe in exactly the same way that a wire opposes more resistance to the electric current the smaller the wire is, and the amount of resistance also increases with the length of the wire itself. In both cases, the product of this friction, or resistance, is heat; and it results in a drop in pressure, whether mechanical or electrical.

Current and Volume. So far the comparison has been limited entirely to the pressure exerted by the pump on the supply line as compared with the voltage of the generator imposed on the circuit. In a similar way the flow of water from the pipe line may be compared with that of the current in an electrical circuit. Assume, for example, that, in the case of the water-supply system, the pumps generate a pressure of 100 pounds to the square inch. Eliminating from consideration any drop in pressure between the pump and outlet as only tending to confuse the comparison, suppose a half-inch faucet to be opened at a distant part of the system. Then there will flow from the pipe an amount of water proportioned to the size of the outlet times the pressure, or head, back of it. Let us assume that this will be one cubic foot per minute, or, roughly, eight gallons.

In the same way, assume that the generator imposes a pressure of 100 volts on the line and, for purposes of comparison, there is no drop between the generator and the end of the line. So long as there is no outlet open there is pressure on the water in the supply system, but no flow. This is likewise the case with the electric circuit. The voltage is present as long as the armature of the dynamo is revolving, but there is no flow of current in the circuit. A small fan motor, corresponding to the half-inch faucet, is switched on at a distant part of the circuit. There is then a flow of current of, say one ampere. In this case, the hydraulic analogue reflects exactly the action of the current as compared with the water supply in a pipe. If, instead of opening a small house faucet, we open the valve of a branch main a foot in diameter, there is a correspondingly greater volume of water flowing, but the pressure remains the same. On the other hand, if, instead of a small fan motor, a five-horsepower motor is switched into the circuit, the outflow of current will be equivalent to five horsepower, though the voltage of the circuit will remain the same. (There is, of course, always a voltage drop with every piece of apparatus that the current passes through before completing the circuit by returning to the generator, just as there is a drop in water pressure for every additional length of pipe or open outlet in the system; but, to keep the comparison clear and simple, this is not taken into consideration here.) Thus, in one case, we have one cubic foot of water per minute flowing under a head, or pressure, of 100 pounds per square inch; in the other, a current of one ampere at a voltage of 100; also the fact that the volume of either water or electricity that will flow depends upon the resistance of the outlet. The fan motor is wound to a high resistance, and, consequently, only one ampere of current is required to operate it at its maximum speed. In the same way, the ½-inch outlet will permit only one cubic foot of water to escape per minute. Increasing the size of the outlet in either case increases the flow correspondingly. The simile holds good with the water system up to the point where the outlet becomes too large to permit the pumps to maintain the pressure; but, in the case of the electric generator, the resistance cannot be decreased to zero, since this would result in a short-circuit permitting the entire current output of the dynamo to flow. Unless the dynamo were protected by circuit breakers and fuses, the functions of both of which are explained later, the windings of the machine would be burned out.

Power Comparison. To go back to the simile between water and current flow, it will be noted that in one case there is a flow of one cubic foot per minute at 100 pounds to the square inch, and, in the other, a flow of one ampere of current at 100 volts. This flow of water represents power just as the flow of electric current does, and it may be utilized in a similar manner. The product of the volume times the pressure would give foot-pounds in the case of the water and watts in the case of the electrical energy, in other words, one ampere times 100 volts, or 100 watts—almost one-seventh of a horsepower.

Circuits. The simile of the water-supply system does not correspond exactly to any type of electric circuit, in that the water does not return to the pump in any case, as the current always must to the generator, to complete the circuit. But it does afford a comparison of the characteristics of both series and multiple circuits, showing to what an extent the illustration of electrical principles may be carried by means of a simple mechanical analogue. For instance, the opening of one outlet after another in a water system reduces the pressure in the entire system, just as the insertion of one piece of apparatus after another in a series electric circuit causes a corresponding drop in voltage for each addition, except, of course, that in case of the series electric circuit it must always be complete, regardless of whether one or a dozen different pieces of apparatus be included in it. In other words, the current must pass through each one of them in turn to complete the circuit. On the other hand, the water system has some of the characteristics of a multiple, or parallel, electric circuit, in that the opening of one outlet does not prevent the use of others, whereas in the series circuit, the breakdown of one piece of apparatus, such as a motor or a lamp, puts all the others out of action by opening the circuit.

The comparison may be carried still further to illustrate other attributes of the electric circuit. For example, if there be a bad break in one of the large mains of the water system, no water will reach smaller outlets beyond the break in the main, the entire volume flowing out of this opening. This corresponds very closely to a ground or short-circuit on an electric circuit. If one of the wires, instead of carrying the current to the motors, permits its supply to return to the generator by a shorter path, due to faulty insulation or a broken wire touching the ground, no useful work will be performed by the current. It will escape and be wasted just as the water is, with this important difference, however, that in the case of the water pumps, the break in the main will be evidenced only by a marked decrease in the pressure, and the pumps will run to no purpose, whereas the electric generator will still continue to generate its full voltage, and, unless the grounded circuit caused by the break has sufficient resistance, the circuit breaker, or fuses, must operate to protect it.

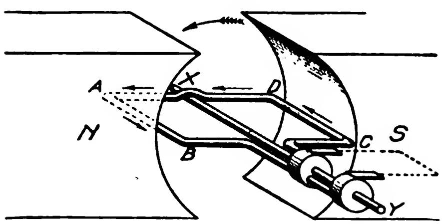


Fig. 17. Elementary Principle of Generator

GENERATOR PRINCIPLES

Classification. All dynamo-electric machines are commercial applications of Faraday's discovery of induced currents in 1831. They are all designed to transform the mechanical energy of a steam engine, a waterfall, a gasoline engine, etc., into the energy of an electric current. Whenever large currents are required—for example, in running street cars; in systems of lighting and heating; in the smelting, welding, and refining of metals; the charging of storage batteries, etc.—they are always produced by dynamo-electric machines.

There are two kinds of generators (1) d.c., or those producing a unidirectional (direct) current, that is, one which always flows in the same direction in the external circuit, and (2) a.c., or those producing an alternating current, that is, one which reverses in direction continuously throughout the entire circuit.

Elementary Dynamo. Whenever lines of magnetic flux are cut by a conductor, for example, by a wire passing through them, an e.m.f. (electromotive force) is produced in the conductor, and the strength of this e.m.f. is entirely dependent upon the speed at which the conductor passes through the magnetic field. If, at the time that this is done, the ends of the wire are brought together to form a circuit, a current will be induced in the conductor. The simplest form of generator would consist of a single loop of wire *ABCD* arranged to rotate in a magnetic field, as shown by Fig. 17. Having its plane parallel to the direction of the magnetic flux, the loop, if it be rotated to the left as shown, will have an e.m.f. induced in it that will tend to cause a current to flow in the direction shown by the arrows. The e.m.f.'s induced in *AB* and *CD* for the position shown will have their maximum values since the wires are then cutting the magnetic flux at right angles and are consequently cutting more lines of force per second than in any other part of the revolution. Note that as *CD* moves up, *AB* moves down (and vice versa) across the magnetic flux so that the induced currents in all parts of the loop at any instant are flowing in one direction. The value of this e.m.f. depends upon the speed, and as the loop approaches the 90-degree, or vertical, position, the e.m.f. decreases because the rate of cutting is diminishing, until when the loop is vertical both the cutting of the magnetic flux and the generated e.m.f. are at zero. If the rotation is continued, the rate again gradually increases, until at 180 degrees it is once more a maximum. The cutting, however, in the two quadrants following the 90-degree position has been in the opposite direction to that occurring in the first quadrant, so that the direction

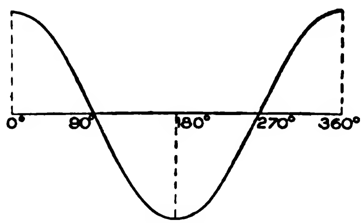


Fig. 18. Dynamo E. M. F. Curve

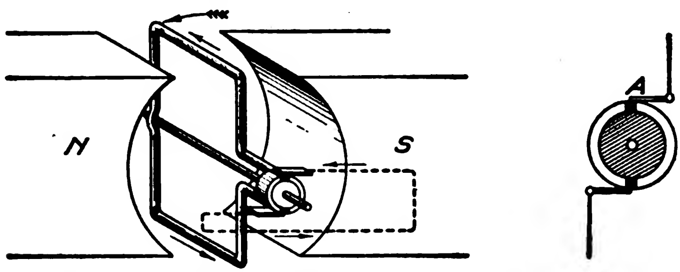


Fig. 19. Simple Form of Generator Showing Arrangement of Brushes in Contact with Commutator

of the e.m.f. generated is reversed. Plotting this through an entire rotation gives the curve shown in Fig. 18. Such an e.m.f. is termed alternating because of its reversal from positive to negative values, first in one direction and then in the other, through the circuit. It cannot be utilized for charging a storage battery, and hence it is not employed in connection with starting and lighting dynamos and motors. To convert an alternating current into a direct or continuous current, a commutator must be added.

Commutators. Fig. 19 illustrates a commutator in its simplest form. It may be imagined as consisting of a small brass tube which has been sawed in two longitudinally, the halves being mounted on a wooden rod. The wood and the two cuts in the tube insulate the halves from each other. Each one of these halves is connected to one terminal of the loop, as shown in the illustration, Fig. 20. Against this commutator, Fig. 19, two brushes bear at opposite points and lead the current due to the generated e.m.f. to the external circuit. If these brushes are so set that each half of the split tube moves out of contact with one brush and into contact with another at the instant when the loop is passing through the positions where the rate of cutting is minimum (as indicated in the enlarged end view of the commutator shown at A), a unidirectional current will be produced, but it will be of the pulsating character as indicated by the curve for one cycle shown in Fig. 21.

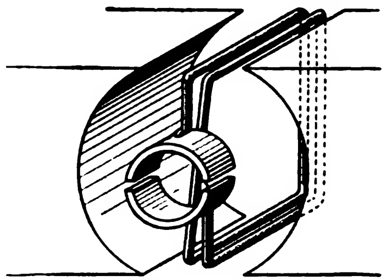


Fig. 20. Commutator with Double Turn

This would also be the case, if instead of the single loop, a coil wound on an iron ring be substituted, as in Fig. 22, the only effect of this being to increase the e.m.f. by increasing the number of times the electrical circuit cuts the magnetic flux. Now assume that two coils are connected to the commutator bars, instead of the single loop, shown in Fig. 22. This arrangement will give the simple device shown in Fig. 23, called an armature. The two coils are

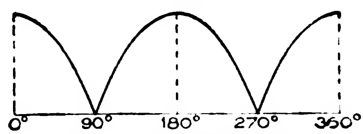


Fig. 21. E. M. F. Curve with Commutator

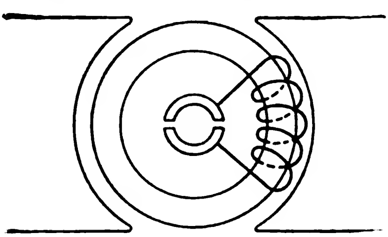


Fig. 22. Armature with Single Coil

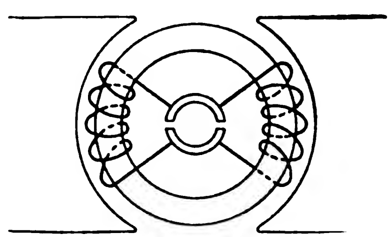


Fig. 23. Two-Coil Armature

in parallel and while the voltage generated by revolving this winding with two coils is no greater than with one coil, the current-carrying capacity of the winding is doubled. The current generated by this form of armature would still have the disadvantage, however, of being pulsating. As in the case of the automobile motor, the number of cylinders must be increased to make the power output a continuous unbroken line, so armature coils and their corresponding commutator brushes must be added that one set may come into action before the other "goes dead". By placing an extra pair of coils on the armature, at right angles to the first, as shown in Fig. 24, one set will be in the position of maximum activity when the other is at the point of least action. While this armature would produce a continuous current, it would not be steady, having four pulsations per revolution, and it is consequently necessary to increase the number of coils and commutator segments still further to generate a steady, continuous current. This is what is done in practice.

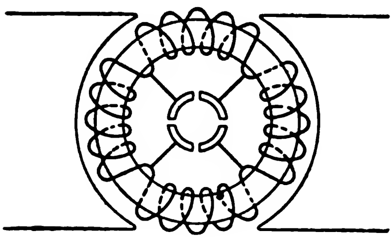


Fig. 24. Four-Coil Armature

A commutator consists of a number of copper bars or segments, equal to the number of sections in the armature. These bars are separated by sheets of insulating material, usually mica, and are

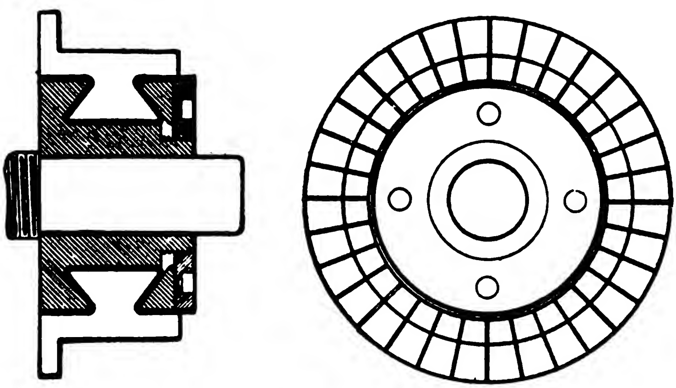


Fig. 25. Sectional and End Views of a Commutator
Courtesy of Horseless Age

firmly held together by a clamping device consisting of a metal sleeve with a head having its inner side undercut at an angle, a washer similar in shape to the head of the sleeve, and a nut that screws over the end of the sleeve, as shown in the left-hand or sectional view of Fig. 25. The sleeve is surrounded by a bushing of insulating material, and washers of the same material are placed between the assembly of commutator bars and the two clamping heads. Each bar is then completely insulated from every other bar and from the clamping sleeve. Commutators are also made by pressing the entire assembly of copper segments together, or molding them, in insulating material (Bakelite), which thus forms the hub or mounting of the commutator as well as the insulating material between the segments. After assembling, the commutator is turned down in a lathe to a true-running cylinder and then sandpapered on its outer cylindrical surface to present a smooth bearing surface for the brushes. At the inner end of the commutator which is closest to the armature windings, the commutator bars are provided with lugs as shown in the sectional view; these lugs are slotted and the armature leads are soldered to them. At the right, Fig. 25, is shown an end view of the same commutator.

From the repair man's point of view, the commutator is the most important part of the generator or the motor, since it is one of the first with whose shortcomings he makes acquaintance. Practically all lighting and starting motors now have their armature shafts mounted on annular ball bearings, so that the commutator and the brushes are the only parts that are subject to wear. If the time devoted in the garage to the maintenance of automobile electric systems were to be divided according to the units demanding attention, the battery would naturally come first, brushes and commutators next, then switches, regulating instruments, connections, and wiring, about in the order named. After all of these come, of course, burnt-out armatures or other internal derangements which necessitate returning the units to the manufacturer; but troubles of this nature are quite rare. While this list gives the order of precedence, it has no bearing on the relative importance of the troubles; with respect to the total time taken by each, the battery is responsible for not far from 90 per cent, the commutator for about 5 per cent, all other causes comprising the remaining 5 per cent.

Armature Windings. In the simple illustrations given to show the method of generating e.m.f. in the armature and leading the current to the external circuit, what is known as the ring type of winding is shown. This is inefficient because half the length of the conductor—the portion inside the ring—does not cut any lines of force and hence does not aid in generating the current. The design, moreover, does not lend itself to compactness, so that it would not be adapted to automobile work even if there were no objection to it on the score of inefficiency. A slotted type of armature core is very generally employed for the small generators and starting motors used on automobiles and the wire is either wound directly in the slots, or is "form wound", that is, the wire is placed on a wooden form shaped to correspond to the position the coil will take when in place on the armature. After winding the necessary length of conductor on this foundation, the wire is taped together, and varnished or impregnated with an insulating compound, and baked.

Owing to its high magnetic permeability, iron is universally employed for the core of the armature, since the function of the core is to carry the magnetic flux across from pole to pole of the field magnets, as well as to form a foundation for the coils. However, when a mass of iron is rotated in the field of a magnet what are known as "eddy currents" are set up in the metal itself, and these prevent the inner parts of the mass from becoming magnetized as rapidly as the outer and also cause the interior to retain its magnetism longer. As the efficiency of the generator depends upon the rapidity with which the sections of the armature become magnetized and demagnetized as they revolve, the lag due to these eddy currents is a detriment. To reduce this effect to the minimum, the armature cores are always laminated, that is, built up of thin disks of very soft iron or mild steel, these disks having the necessary slots punched in them to accommodate the windings when assembled on the shaft. The disks are insulated from one another either by varnishing them or by inserting paper disks between them. They are assembled on the shaft and are put together under considerable pressure, various means being employed to hold them in place. These disks are so thin that hundreds of them are required to make an armature core only a few inches long, and when pressed together in place they are to all intents and purposes a solid mass.

Armature winding, however, is something that is entirely beyond the province of either the car owner or the repair man, no matter how well equipped a shop he has. It is a job for the expert in that particular line, and on the rare occasions when an armature does go wrong, it should always be returned to the manufacturer, if possible, if not, to a shop making a speciality of such work.

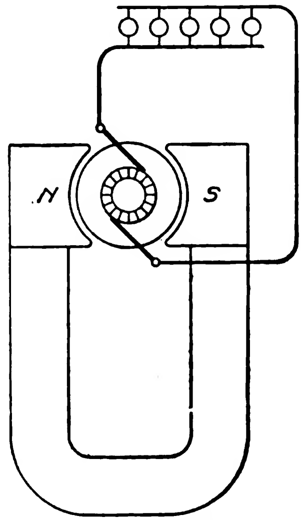


Fig. 26. Diagram of Magneto

Field Magnets. In the foregoing explanation of the generation of an e.m.f. in a conductor when rotated in a magnetic field and the leading out of the current through a commutator, the presence of the field has been assumed and nothing has been said regarding the method of providing it. The term field is applied interchangeably to the magnetic flux between the pole faces of the field magnets and to the magnets themselves, but it is more generally understood to refer to the latter directly and to the former by inference. There are various methods of maintaining the flux, usually described as "field magnet excitation", but only two of them are applicable to the electric generators employed on the automobile.

Permanent Field Used in Magneto. The simplest of these, and the first to be designed, employed permanent magnets, from which such a generator takes its name, *magneto*. Fig. 26 is a diagrammatic representation of an early form of the magneto-generator. Since magnetism cannot be maintained permanently at the high flux-density or strength which can be produced by an exciting coil fed by a current, this method is only employed in very small generators, as its bulk for large powers would be excessive. Its great advantage is its simplicity and constancy. The magneto-generator shown in Fig. 26, however, is designed to produce a continuous current, and is not the type in general use on the automobile today.

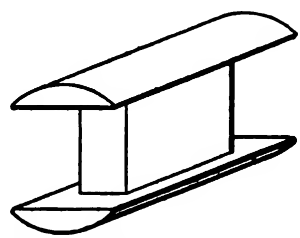


Fig. 27. Sketch Showing Shape of Armature Core
Courtesy of Horseless Age

The type usually installed is made with a two-pole armature, as shown by Fig. 27. This figure illustrates the core known as a "shuttle" type because the wire is wound around the center of the core in much the same manner as thread is put on a shuttle. These cores are laminated as already described, in all well-built magnetos. The space on the core is filled with a single coil of comparatively coarse wire on the majority of magnetos, which generate a low voltage current that is subsequently stepped up through an outside transformer. In some instances, in what may be termed the true high-tension type of magneto, there is a second winding of fine wire on the core so that the magneto generates a current

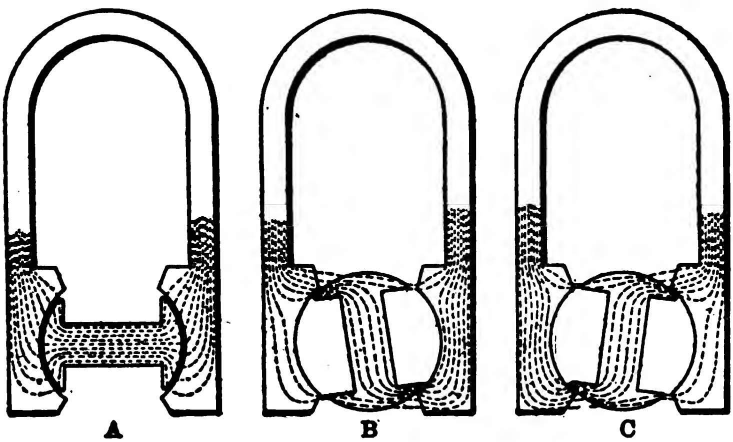


Fig. 28. Diagrams Showing Distribution of Magnetic Flux for Various Positions
Courtesy of Horseless Age

and steps it up without the aid of any outside devices. In either case, one end of the winding is "grounded on the core", that is, connected to it electrically, so that the core and other metal parts of the machine form one side of the circuit, while the other end is connected to a stud against which a spring-controlled carbon brush bears, to collect the current. Detailed descriptions of various types of magnetos are given later so that nothing further concerning the construction need be added here.

Principle of Operation of Magneto. Under "Generator Principles", the principle of the operation of the magneto has already been explained, the method by which the rotation of the conductors in the magnetic field generates an e.m.f. and a current is induced in them. But as the actual operation of the magneto as designed for ignition purposes is radically different from any other form of generator, it is given here. If unrestricted, the armature of the magneto will always assume the position shown at *A*, Fig. 28, and considerable effort will be required to turn it from this position as the magnetic flux through the armature is then a maximum. When the armature is rotated a little over 90 degrees from this horizontal position so that the armature poles leave the field poles, as at *B* in the same figure, the flux decreases, and when in a vertical position no lines of force pass through it. At this point, the direction

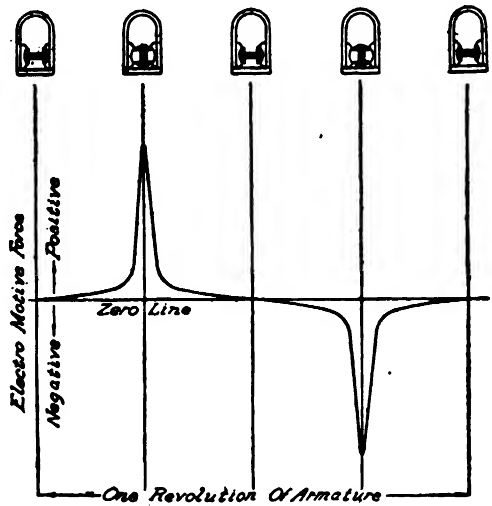


Fig. 29. Curve of Primary E. M. F. in Magneto on Open Circuit
Courtesy of Horseless Age

of the magnetic flux through the armature core reverses. Having a two-pole armature, the magneto produces an alternating current of one complete cycle per revolution, as shown by the curve, Fig. 29, which illustrates the electromotive force generated at the different positions in the rotation of the armature. The similarity between this curve and the one generated by the elementary dynamo, Fig. 17, will be noted. With the armature in the horizontal position there is a dead point, the e.m.f. curve only starting as the pole pieces of the armature begin to cut the edges of the field magnet poles. It then rises very sharply to a peak, and as sharply drops away to zero again, thus forming one-half cycle, which is then repeated in the opposite direction. As the present discussion comprises only an introduction to elementary principles and theories, further details of construction and operation of the magneto are given later in the section on "Ignition".

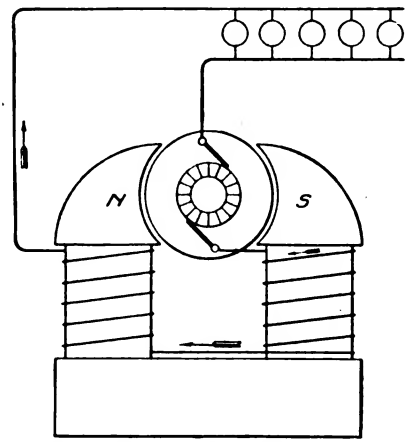


Fig. 30. Diagram Showing Series Generator

Self-Excited Fields. In a machine of the magneto type, the only method of varying the current output is to vary the speed of the armature, and it is therefore not well adapted to the majority of uses for which a generator is employed. Consequently, other methods of exciting the fields have been developed, which may be roughly divided into two classes: *first,* those separately excited, in which current from an independent source is supplied to the field windings. This is now practically restricted to large alternating-current generators and so need not be considered further here. *Second,* self-excited fields, which are now characteristic of all continuous current generators. In this method all or a part of the current induced in the armature windings is passed through the field coils, the amount depending on the type of generator.

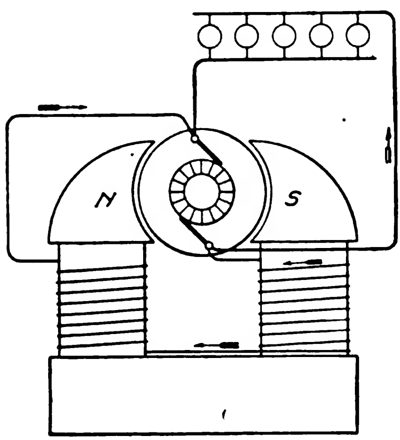


Fig. 31. Diagram Showing Shunt-Wound Generator

Series Generator. Where the entire current output is utilized for this purpose, the dynamo is of the series type, and a reference to the section on "Circuits", in connection with the illustration, Fig. 30, will make this plain. There is but a single circuit on such a dynamo and while it has the advantage of simplicity, it does not generate a current until a fairly high speed is reached, or unless the resistance in the external circuit is below a certain limit. It is also likely to have its polarity reversed so that it is not fitted for charging storage batteries. As the only series generators put into commercial use have been for supplying arc lamps in series for street lighting, they need not be considered further.

Shunt-Wound Generator. By winding the generator with two circuits instead of one and giving that of the fields a relatively high resistance as compared with the outside circuit on which the generator is to work, a machine that is self-regulating within certain limits is produced. As shown by Fig. 31, the main circuit of the generator is that through the armature with which the field winding is in shunt. The current accordingly divides inversely as the resistance and only a small part of it flows through the field coils, while the main output of the generator flows through the external circuit to light the lamps, to charge a battery, or the like, the resistance of this external circuit being much less than that of the fields. But in this type, as well as in the simple series form, the e.m.f. generated varies more or less with the load, and as the latter is constantly changing, it is necessary to provide some means of varying the e.m.f. generated to suit the load, in other words, to make the generator self-regulating. Of the several available methods of doing this, the only one applicable to the small direct-current generators used in automobile lighting and starting systems, is that of varying the magnetic flux through the armature.

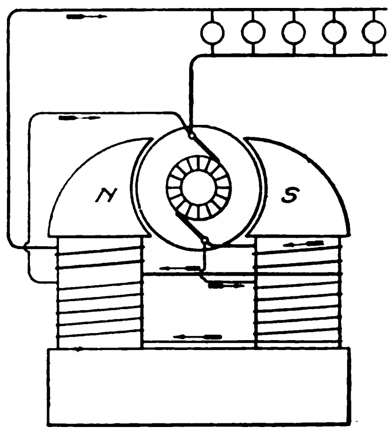


Fig. 32. Diagram Showing Compound-Wound Generator

Compound-Wound Generator. There are also several methods of effecting this variation of the magnetic flux, but the most advantageous and consequently the most generally used, is to vary the amount of current in the energizing coils on the field magnets.

By adding to the shunt winding a few turns of heavy wire in series with the armature so that all the current passes through them, the magnetic flux may be made to increase with the load as it is directly affected by the current demanded by the latter. This combination of the shunt and series is termed a compound winding, and the usual method of affecting it is shown by Fig. 32. Such a machine

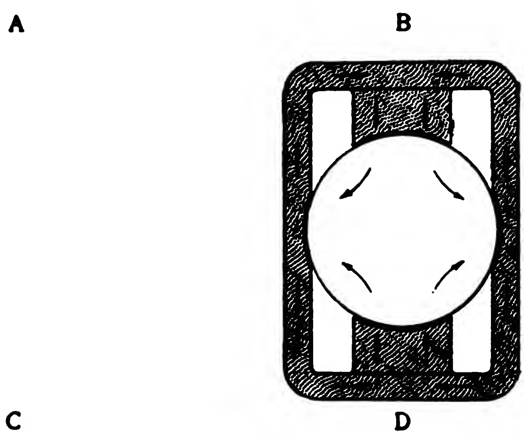


Fig. 33. Forms of Field Frames

is called a compound generator, and is sometimes used for lighting and for charging the storage batteries of automobiles.

In view of the great range of speed variation required of the automobile motor, the series wiring is sometimes reversed so as to act against the shunt instead of with it, in order to prevent an excessive amount of flux and a current that would be dangerous to the windings themselves due to a very high speed. The compound winding then opposes the shunt-winding and is termed a *bucking-coil* or winding. This is referred to later in connection with the discussion of methods of regulating the generator on the automobile.

Forms of Field Magnets. For greater simplicity, all of the illustrations shown in connection with the explanation of the various types of generators are of the old bipolar type in a form long since obsolete. The field frame, as it is designated may, however, take a number of different forms depending entirely upon the designer's conception of what best meets the requirements of ample power in the minimum of space and with the minimum weight. Fig. 33 shows some typical forms of field frames in general use on automobile generators, and it will be noted that in addition to providing a magnetic circuit the field frame also serves to enclose the windings. These are known as "ironclad" types from the fact that all parts are thoroughly enclosed and protected. The arrows in each case indicate the paths of the magnetic circuits, the number of the circuits varying with the number of pole pieces. The form at *A* has two opposed poles, each of which is designed to carry an exciting coil or winding. This is a bipolar machine. Field frame *B* is also of the bipolar type but only one pole carries an exciting winding, the other being known as a consequent pole. In both of these field frames, it will be noted that the magnetic circuits are long, which adds to the magnetic reluctance and tends to decrease the efficiency. To overcome this, multipolar types of field frames are very generally employed. One of these, with two wound or salient poles and two consequent poles, is shown at *D*, the extra poles making four short instead of two long magnetic circuits. *C* is a multipolar type with four salient poles.

Brushes. Brushes serve to conduct the current generated by the armature to the outer circuit and to the field coils in order that the excitation of the latter may correspond with the demand upon the generator. The brushes originally employed were strips of copper which bore on the commutator; as generators increased in size these brushes were built up of thin laminations of copper. Plain copper brushes in any form, however, cause an excessive amount of sparking which is ruinous to the smooth surface and true running of a commutator. Built-up copper gauze brushes were then adopted, and they were fitted to bear against the commutator. Though an improvement, these did not meet all the requirements and were in turn superseded by carbon brushes, which are now practically universal. The carbon brushes usually bear directly against the face of the commutator, either through a blunt, squared end, or one that is slightly beveled. The brush holders are generally attached to rocker rings, which allow adjustments to prevent sparking; in these holders are small helical springs under compression, which serve to press the brush against the commutator. Ordinarily, the brushes are composed of a uniformly smooth and homogeneous compound of carbon that soon acquires a glazed surface at its bearing end and wears indefinitely without requiring any attention, but at times a gritty brush will be found. Such a brush scratches the commutator surface, wears unevenly, and is generally a source of trouble.

Badly worn commutators frequently result from the use of improper brushes, or too heavy a spring pressure—also from too light a spring pressure. The manufacturer has found out by experiment and study just what character of brush is best adapted to his particular generator or starting motor and also the exact amount of spring pressure that is necessary to insure the best results. Consequently, much trouble will be avoided if brushes are replaced only with those supplied by the manufacturer of that particular machine, in connection with the brush springs that were designed for it. There are electrical as well as mechanical reasons for this, since both the resistance and current-carrying capacity of carbon brushes vary. This has been taken into consideration by the manufacturer who has provided a brush especially adapted to his machine.

ELECTRIC MOTOR PRINCIPLES

Theory of Operation. A machine that is designed to convert mechanical into electrical energy or the reverse, is known as a *dynamo-electric machine*. When its armature is rotated by an external source of power, such as a steam engine, hydraulic turbine, or gasoline engine, it is a *generator*. By sending a current through it from another generator or a battery it converts electrical into mechanical energy and is a *motor*. It is evident, then, that a generator and a motor are fundamentally one and the same thing, and that by a reversal of the conditions one unit may be made to serve both purposes. It will naturally depend upon how closely these purposes approach each other so far as their operating conditions are concerned, whether it will be practical to employ the same machine for both. In practice, operating conditions rarely approximate and so before the advent of the single-unit starting-and-lighting system on automobiles the use of the same machine for both generating current and converting it into mechanical energy was practically unknown. Space considerations were the chief factor which led to the development of the single system, as the demands on the machine for charging the battery and starting the engine are radically different.

How Rotation Is Produced. The operation of an electric motor will be clear if the essentials of a dynamo-electric machine and their relations are kept in mind. There is, first, the magnetic field and its poles—two or any multiple thereof, though for space reasons more than four poles are seldom used in starting motors; then the armature, which must also have an even number of poles corresponding to the number of segments in the commutator. Each separate coil in the armature winding magnetizes that section of the armature core on which it is wound, when the current passes through it, as its terminals, connected to different segments on the commutator, come under the brushes. In an electric motor having either two or four field poles, and eight, twelve, or sixteen armature poles, it is apparent that every few degrees in the revolution of the armature an oppositely disposed set of its poles is either just approaching or just leaving the magnetic field of two of the field poles. Bearing in mind that like poles repel one another and that unlike poles attract, and that the polarity of both the fields and the armature coils is constantly being alternated by the commutator, we see that each section of the armature is constantly being attracted toward and repelled from the field poles.

The fundamental law just stated can be easily illustrated by taking two common horseshoe magnets, such as can be bought for a few cents. Placing their north and south poles together it will be found that they have no attraction for each other and cannot be made to adhere in this relation. If they had sufficient force they would actually move apart when placed on a smooth surface in this position. But if one of the magnets is turned around so as to bring the north and south poles of the two opposite each other, the magnets will be immediately attracted and will hold together to the full extent of their force.

What may be called one cycle of the operation of an electric motor may be described as follows: the motor turns clockwise; it is of the bipolar type, that is, it has two field poles; and there are eight coils on the armature. At the moment assumed, the left field pole is the north, and the right south; consequently, the section of the armature just entering the field is of opposite polarity, presenting a south pole to the north pole of the field and a north pole to the south pole of the latter. The armature is therefore strongly attracted. This attraction is maintained by the current in the windings continuing in the same direction until the magnetic attraction reaches a maximum, at which point the stationary and moving poles are practically opposite each other. Unless a change occurred just at that point the armature would be held stationary and could be turned from it only by the expenditure of considerable force, that is, assuming that the field did not lose its exciting current. (This may be observed on a small scale by attempting to revolve the armature of a magneto by turning its shaft by hand.) But either at that point, or just before it is reached, the revolution of the armature brings a different set of commutator bars under the brushes and the direction of the current is reversed in that particular winding and with it the polarity of the armature poles. Instead of being mutually attracted the armature and field poles become mutually repellent. In brief, the armature is first pulled and then pushed around in the same direction by reason of the force exerted both by the field magnets and by its own magnets. The passing of one section of the armature through this change as it enters and leaves the zone of influence of a pair of pole pieces may be said to constitute a cycle of its operation, by analogy with alternating-current generation. The cycles are repeated as many times per revolution as there are coils on the armature and the number of coils miltiplied by the speed will give the number of changes per minute. For example, in a motor assumed to have eight armature coils, as in the present instance, there would be, at a speed of 1,000 r.p.m., 16,000 changes per minute, which makes clear the reason for the very smooth pull or torque that an electric motor exerts.

Counter E.M.F. Though being rotated by means of current obtained from an external source of power, it is apparent that the motor armature in revolving its coils in the magnetic field is fulfilling the conditions previously mentioned as necessary for the generation of an e.m.f. Experiment shows that the voltage and current thus generated are in an opposite direction to that which is operating the motor. It is accordingly termed a counter e.m.f. as it opposes the operating current. This, together with the fact that the resistance of copper increases with its temperature and that the armature becomes warmer as it runs, explains why the resistance of a motor is apparently so much greater when running than when standing idle. The counter e.m.f. approaches in value that of the line e.m.f., or voltage at which current is being supplied to the motor. It can, of course, never quite equal the latter for in that case no current would flow. The two opposing e.m.f.'s would equalize each other; there would be no difference of potential.

Types of Motors. Being the counterparts of electric generators, electric motors differ in type according to their windings in the same manner as already explained for generators. The plain series-wound motor is nothing more or less than the simple series-wound generator to which reference has already been made; the shunt and compound motors likewise correspond to the shunt and compound generators. But while the series-wound generator was of extremely limited application and has long since become obsolete, the series-wound motor possesses certain characteristics which make it very generally used. It is practically the only type employed for starting service on the automobile, and it is also in almost universal use for railway service. The reasons for this are its very heavy starting torque which increases as the speed of the motor decreases, the quick drop in the current required as the motor attains speed, and its liberal overload capacity. It is essentially a variable speed motor, and, just as the plain series-wound generator delivers a current varying with the speed at which it is driven, so the speed of the motor changes in proportion to the load. These are characteristics which make it valuable for use both as a starting motor for the gasoline engine, and for a driving motor on the electric automobile, though in the latter case it is seldom a simple series-wound type. As its speed is inversely proportional to the load, however, it tends to race when the load is light; in other words, it will "run away" if the load is suddenly removed, as in declutching from the automobile engine after starting the latter, unless the current is instantly shut off or very much reduced. This is provided for, as will be explained in detail later in connection with the various systems.

Shunt motors and compound-wound motors are the same as their counterparts, the generators of the same types, but as they are not used in this connection, no further reference need be made to them here.

Dynamotors. As the term suggests, this is a combination of the generator or dynamo and the electric motor, and it is a hybrid

Fig. 34. Dynamotor (Motor-Generator) of the Delco System

for which the automobile starting system has been responsible. It is frequently mistermed a "motor-generator" and while its assumption of the two rôles may justify the name, the use of the term is misleading as it becomes confused with the motor-generators employed for converting alternating into direct current. The latter consist of an a-c. motor on one end of a shaft and a d-c. generator on the other end of the same shaft. The two units are distinct except for their connection, whereas a dynamotor is a single unit comprising both generator and motor, and it can perform only one of these functions at one time. A motor-generator, such as is used in garages for transforming alternating into direct current for charging storage batteries, must carry on both functions at

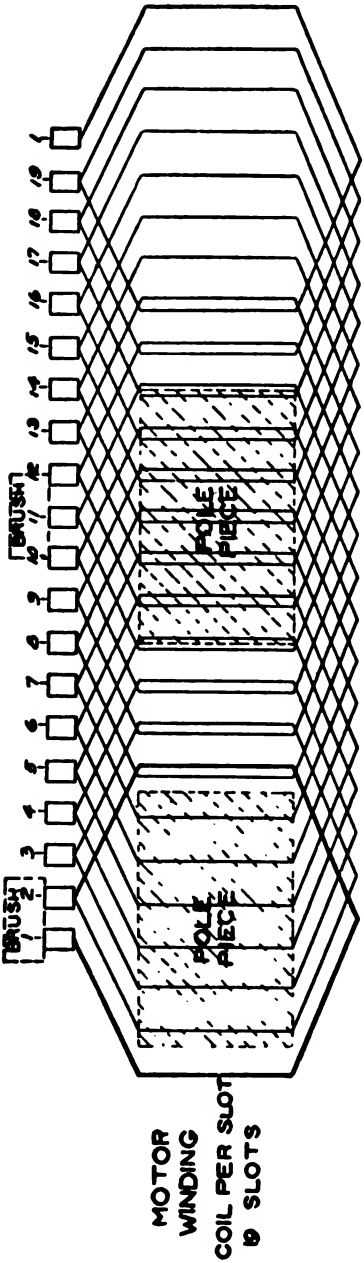


Fig. 35. Windings of Delco Dynamotor

the same time in order to operate. That is, the a-c. motor must run as a motor in order to drive the d-c. generator and cause it to generate a direct current. Hence, the term motor-generator as applied to the single-unit type of electric starting system for an automobile is not in accordance with the accepted meaning of the words and is likely to be confusing.

A typical example of the dynamotor is to be found in the Delco single-unit system, illustrated in Fig. 34. This is really the windings of two radically different machines, a shunt-wound generator and a series-wound motor, placed on the same armature core and field poles. As will be noted, the terminals of the two sets of windings on the armature are brought out in different directions and two commutators are employed, that at the right-hand end being for the generator windings, and that at the left for the motor. The method of winding the armature is illustrated by Fig. 35, which shows the generator and motor windings projected on a plane. In the preceding illustration the detail at the left shows the gearing and starting connection for coupling the starting motor with the flywheel of the engine, the one at the right an ignition distributor for the high-tension current. Both of these are later referred to at greater length.

Fig. 36. Typical Dry Battery

Batteries. The only other method known for generating a continuous, direct current is by means of chemical reactions in what are known as primary cells. With the exception of the so-called *dry cell,* a description of these and their workings could be of only historic interest and is accordingly omitted here. As no chemical reaction could take place in perfectly dry substances this part of the name is used simply to distinguish such cells from those using a liquid solution. The dry cell is a zinc-carbon couple, Fig. 36, the zinc acting as the container while the carbon is a heavy rod packed in manganese dioxide, together with some moisture-absorbing material. On the contents of the zinc container as thus filled is poured a solution of sal ammoniac and water which forms the active solution of the battery. The cell is sealed at the top to prevent evaporation, since, when the cell does actually become as dry inside as it is outside it is no longer of any use. Some of its other characteristics are mentioned under "Ignition", Part II.

The storage battery or accumulator does not generate a current in any sense of the word. By means of a much more complicated chemical reaction than that of the primary cell it absorbs a charge of electricity. Upon the completion of the circuit of a storage cell with a suitable load or resistance, such as driving a motor or lighting a lamp, a reversal of this chemical process takes place and the battery redelivers a part of the current which it has previously absorbed. Full details of the characteristics, construction, and working of the storage battery are given in the article on "Electric Automobiles". The storage battery and the dry cell are the only two forms of battery employed on the automobile so that no mention of the other types is necessary, particularly as all but very few of them are practically obsolete.

SUMMARY OF ELECTRICAL PRINCIPLES

GENERAL PRINCIPLES

The importance of a knowledge of the fundamental principles of electricity and of its characteristics to the man who wishes to familiarize himself with the electrical apparatus on the automobile to the point where he can readily diagnose and remedy its ills has already been dwelt upon. To bring these out more clearly and make them easier to memorize, they are repeated here in the form of a brief résumé in questions and answers.

Q. What is electrical pressure, and to what may it be compared?

A. Electrical pressure is electromotive force, usually termed e.m.f., or voltage, also potential, and may be likened to water under pressure in a pipe or to compressed air in a container.

Q. Of what does this electrical pressure consist, and how is it measured?

A. It is represented by the difference of potential between two points in a circuit, and it is measured in volts.

Q. What does the unit volt represent?

A. The volt is the amount of e.m.f. required to force a current of one ampere through a resistance of one ohm.

Q. What is the ampere?

A. It is the unit of current flow.

Q. What is the ohm?

A. The unit of resistance represented by a length of wire that will pass one ampere under a pressure of one volt.

Q. In what unit is the volume of current flow measured?

A. In the coulomb, which is the equivalent of one ampere per second.

Q. Are the factors of electrical quantity, flow, and pressure related, and how?

A. They are all closely related, and their relation is governed by the factor of resistance.

Q. What is resistance, and of what may it consist?

A. Any element which tends to retard the flow of the current is resistance. It may consist of the wire of the circuit itself; the windings of different apparatus in the circuit, such as an induction coil or a motor; the filament of a lamp; a switch; or the like.

Q. Are these the only forms that resistance takes?

A. No. Poor joints in wires, dirty and loose connections, dirty switch blades, all produce increased resistance in the circuit. These are undesirable increases in the resistance. In addition to these, there are special resistances intentionally inserted in the circuit to serve a definite purpose. These are known as rheostats, resistance coils, windings, or grids, according to the form they take.

Q. Why is it desirable to keep the resistance of the circuit, outside of that produced by the apparatus itself, at a minimum?

A. Because any resistance other than that interposed by the windings of the motor, the filaments of the lamps, or other useful apparatus in the circuit, not only means waste current, but also prevents the full amount of current required from reaching the desired points.

Q. How does this waste occur?

A. In a poor joint, a loose connection, or a dirty switch blade, the current is dissipated as heat and accordingly represents that much energy passing off into the air.

Q. Can undesirable resistance be interposed in a circuit in any ways other than those already mentioned?

A. Yes, by the use of wire too small to carry the amount of current required by the apparatus.

Q. What is the effect of using wires too small for the current?

A. The wires waste a great deal of the current in heat and, if much too small for the purpose, are likely to become overheated to a point at which they will burn the insulation off or to actually become fused by the current.

Q. What determines the voltage in an electrical circuit?

A. The potential, or voltage, of the source of supply, such as a storage battery, in which case the voltage will be constant less the drop caused by the resistance of the circuit; or, in the case of a lighting generator, it will depend upon the design of the latter (winding, etc.) and the speed at which it is running.

Q. How may the voltage be varied?

A. In the case of a battery, by varying the number of cells, each cell of a storage battery giving approximately 2 volts. In a generator, by varying the windings of the field and the armature and by increasing or decreasing the speed at which it runs. On a circuit having a higher voltage than desired, by the insertion of an amount of resistance calculated to give the drop required.

Q. Can lamps of a certain voltage be burned on a circuit having a higher voltage?

A. Not if inserted directly in such a circuit. For example, the standard 6-volt lamp cannot be used directly on a 6- or a 12-cell storage-battery circuit as employed for the lighting and starting systems of many cars. The filament would immediately burn out, as its thickness is calculated to a nicety to become incandescent when current of the voltage for which it is designed is passed through it, and anything in excess of this voltage will fuse the wire.

Q. How can lamps of lower voltage be used on such circuits without the employment of a wasteful resistance to cut the voltage down?

A. By cutting down the number of cells employed for the lighting, as, for example, where 12 cells are used to operate the starting motor, the battery is divided into four groups of 3 cells each for the lighting, these groups delivering current at 6 volts, while the complete battery has a potential of 24 volts. This is termed putting the battery into *series-multiple* connection, which is explained further under the head of "Circuits".

Q. When the voltage is lower than that required by the lamp, what happens?

A. The lamp filament will give only a dull red glow with a voltage drop of but 20 per cent or less of the total, since there is insufficient potential to cause the current to bring the filament wire to incandescence.

Q. Is the insertion of any apparatus, such as lamps, a motor, etc., in a circuit having a voltage higher than that for which they are designed likely to damage them?

A. Yes, it will burn them out if, for instance, 110-volt lamps or motors are connected to 220-volt current, or 6-volt lamps put on a 12-volt circuit.

Q. Does the opposite also hold true?

A. No. The apparatus will merely fail to function properly if put on a circuit of a voltage lower than that for which it is designed.

OHM'S LAW

Q. What is Ohm's law?

A. It is the basis of all computations concerning the flow of an electric current. It is stated as *current equals voltage divided by resistance* and may be transposed to find any of the three factors, as, *resistance equals voltage divided by current*, so that, given any two of the factors, the third may be readily determined.

Q. How is the power equivalent of an electric current expressed?

A. Power equals current times voltage, the product being watts, as one volt times one ampere equals one watt.

Q. How many watts are there in a horsepower?

A. 746. Electrical horsepower, however, is usually figured in kilowatts, or units of one thousand watts, generally abbreviated to KW.

Q. Given a 6-volt storage battery fully charged and a circuit including a starting motor, the total resistance of which (idle) is .1 ohm, how much current will pass through the motor?

A. As current equals voltage divided by resistance, we have $6 \div .1 = 60$ amperes.

Q. If, instead of a heavy stranded cable between the battery and motor, we substitute a fine wire having a resistance of 10 ohms, how much current will pass?

A. Only .6 ampere.

Q. What would happen if a very small wire were employed to connect the starting motor with the battery?

A. Not sufficient current would reach the motor to operate it, and the wire would probably be fused by the heating effect of the heavy current.

Q. If one horsepower be required to turn the engine over at 100 r.p.m., and the car is equipped with a 6-volt battery, how many amperes will be necessary to start?

A. As power divided by voltage equals current, $746 \div 6 = 124\frac{1}{3}$ amperes.

Q. How is the power equivalent usually expressed?

A. Power equals current times voltage.

Q. As the voltage is one of the chief determining factors, what effect does doubling it have?

A. Reduces by one-half the amount of current required, exactly the same as doubling the pressure of a steam boiler reduces correspondingly the volume of steam necessary to perform the same amount of work.

Q. If the voltage be cut in half, what will be necessary to perform the same amount of work?

A. The number of amperes, or amount of current, must be doubled.

MAGNETISM

Q. What is magnetism?

A. It actually is electricity in another form and is evidenced by the attraction or repulsion that one magnet exerts on another, or that any piece of magnetized metal has for objects of steel or iron.

Q. How is this relation between magnetism and electricity shown?

A. By the fact that they are interchangeable. By passing a current of electricity through a coil surrounding an iron or steel bar, it becomes magnetic; upon moving a magnetized piece of metal close to a coil of wire, a current of electricity is induced in the wire.

Q. What is meant by the polarity of a magnet?

A. Upon being magnetized, a bar of steel will attract other pieces of metal (iron or steel) indiscriminately, but upon being brought close to another magnet, it will display an attraction at one end and a repulsion at the other for the second magnet. In other words, the magnetic attraction at both ends is not the same. These ends are termed the poles, one north and the other south, by analogy with the compass which is merely a magnetized needle having a natural tendency to point north and south.

Q. What other characteristics do the poles of a magnet display?

A. They show that the force of the magnet is practically concentrated at these poles, as the magnetic attraction is very much less at any other part of the bar.

Q. What is the law of magnetic attraction and repulsion?

A. Like poles repel one another and unlike poles attract. In other words, if a bar magnet be suspended, and the north pole of a second magnet be held close to the north pole of the suspended magnet, the latter will swing away; if the south pole of the second magnet be approached to the north pole of the suspended magnet, the latter will swing toward the former until they touch.

Q. How does the force of this attraction or repulsion vary?

A. Inversely as the square of the distance, i.e., separating the poles by twice the distance reduces the force acting between them to one-fourth its value. For example, if two magnets exhibit a strong attraction for each other at a distance of one-half inch, the attraction will be four times stronger when they are separated by only one-fourth inch.

Q. What are the chief magnetic substances?

A. Iron and steel.

Q. What is meant by the magnetic field?

A. The space immediately surrounding the poles and at which the magnetic force is most plainly apparent, as shown by the experiments with filings which graphically illustrate the field of influence of the magnet, and from which the term in question originates.

Q. What is a magnetic circuit?

A. The path followed by the magnetic flux, or flow, from one pole to the other.

Q. What analogy is there between the poles of a magnet and the flow of a current in an electric circuit?

A. The current is said to flow from the positive, or north, pole of a battery or generator, to the negative, or south, pole to complete the circuit, exactly as the lines of force in a magnet flow to complete the magnetic circuit.

Q. How can the polarity of a current flowing in a wire be determined by a simple experiment?

A. Hold a small pocket compass close to the wire. If the needle of the compass is attracted at its north pole to the wire, the current flowing in the latter is negative (south pole), as unlike poles attract, and *vice versa*. This will be true only when a direct current is flowing in the wire, since an alternating current, as the term indicates, alternates in polarity with every cycle.

Q. What are lines of force?

A. The invisible flow of magnetic influence from the north to the south pole of a magnet or about any conductor carrying an electric current.

Q. What is a solenoid?

A. A hollow coil of wire through which a current may be passed to produce a magnetic field.

Q. What is the difference between a permanent magnet and an electromagnet?

A. When a piece of hard steel has been magnetized, either by being rubbed on another magnet or by being placed in a solenoid through which a current is passed, the steel retains a large percentage of its magnetism when removed from this magnetic field and is said to be a permanent magnet. An electro magnet consists of a soft iron or steel core on which a coil of wire is wound. When a current passes through the wire, the coil becomes strongly magnetic, but when the current ceases, the magnetism does likewise.

Q. When a bar of iron is placed partly in the coil of a solenoid through the winding of which a current is passed, what takes place?

A. The bar is strongly attracted to the center of the coil and held there.

Q. How is this principle taken advantage of in electric starting and lighting systems on the automobile?

A. It is employed for the operation of electromagnetic switches for the starting motor, and it is also the principle upon which the electromagnetic gear shift depends for its operation.

Q. What effect has the insertion of an iron core in a solenoid?

A. It greatly increases the flow of magnetism through the solenoid, with the same amount of current passing through the winding of the latter.

Q. What effect has reversing the direction in which the current is passed through the winding of a solenoid?

A. It reverses the polarity of the latter so that if the core were a bar of hard steel, it would be drawn into the opening of the solenoid with the current in one direction, and expelled from it when the current was reversed.

Q. What bearing have the principles of magnetic attraction and repulsion and of magnetic polarity on electric generator and motor operation?

A. They are the fundamental principles upon which the operation of all electric generators and motors are based.

INDUCTION

Q. What is the principle of electric induction?

A. If a circuit carrying an electric current be opened and closed quickly in the case of direct current, and a coil of wire be held close to this circuit, a current will be induced in the coil. If the latter be wound on an iron core, the induced current will be very much stronger, and if both the active circuit and the coil are on the same magnetic core, the maximum inductive effect will be produced. The latter is, in effect, a transformer, and if an alternating current be sent through the first circuit, or coil, there is no need to make and break the circuit as where the current is direct.

Q. Why will a transformer not operate on direct current without making and breaking the circuit constantly?

A. It is necessary to magnetize and demagnetize the core, or, where there is no core, to produce a magnetic field and then destroy it, in order to produce an inductive effect.

Q. Why will it operate on alternating current without making and breaking the circuit?

A. Because the alternating current intermittently rises to its maximum in one direction, then drops to zero and rises to its maximum in the opposite direction, that is, the direction or the polarity of the current changes with every cycle. The transformer core is accordingly magnetized to full strength with a certain polarity, is then demagnetized and again remagnetized with the opposite polarity, and it is this rise and fall in the strength of the magnetic field from zero to maximum, first in one direction and then in the other, that causes the inductive effect.

Q. What is a cycle?

A. It consists of one alternation from zero to maximum in one direction, back to zero and then to the maximum in the opposite direction, and back again to zero. The ordinary house-lighting supply current is 60 cycles, i.e., it alternates 60 times per second, or 3600 times per minute. It is owing to this extreme rapidity in alternation that no flickering is apparent in an incandescent lamp fed by alternating current.

Q. Where alternating current is not available, how can a transformer be operated?

A. By making and breaking the circuit at a high rate of speed, as with a vibrator used on automobile induction coils.

Q. In general, why is no vibrator necessary on a coil when fed with current from the magneto?

A. Because the magneto supplies an alternating current.

Q. On the so-called dual system of ignition, the same coil without any vibrator is used with both the battery and magneto as a source of current. How is this effected?

A. The circuit breaker, or interruptor, of the magneto takes the place of the vibrator when the battery is used for starting, while the alternating current from the magneto operates the induction coil, or transformer, when the engine is running on the magneto.

Q. What relation does the induced current bear to the current from the source of supply?

A. This depends upon the transformer and the purpose for which it is intended. On the automobile where it is desired to raise the current to a high voltage to enable it to bridge the gap of the spark plugs, the transformer is known as a *step-up* type, i.e., it takes current at a low voltage and transforms it to one of high voltage, or tension. The original, or primary, current passes through a winding of a comparatively small number of turns of coarse wire on a core of soft iron wires. Directly over this winding is a second one consisting of a great number of turns of very fine wire. This is known as the *secondary* *winding,* and the current induced in it is termed a *secondary current.* The voltage of this secondary current depends upon the voltage of the source of supply and the proportion that the number of turns in the secondary winding bears to that of the primary winding.

Q. Is the transformer used in any other form or type on the automobile?

A. In the so-called true high-tension type of magneto, the transformer is made integral with the armature, the fine wire, or secondary winding, being placed directly over the coarser winding that serves to generate the current. The step-up is the only type of transformer used on the automobile.

CONDUCTORS

Q. Do materials differ greatly in their ability to conduct electricity, and which are the most efficient in this respect?

A. They vary all the way from absolute insulators to those metals which will pass the electric current with the minimum resistance, such as silver, copper, and aluminum.

Q. Do the characteristics of a material affect its current-conducting ability?

A. Very greatly. The harder copper is, the poorer its conductivity, and this is likewise the case with steel.

Q. Name the different materials in the order of their current-conducting ability.

A. Silver in pure state, soft copper, brass, aluminum, iron, steel, carbon, German silver, etc.; also water, depending upon how alkaline or acid it is.

Q. Is German silver a good conductor?

A. No. It is known as *high-resistance* conductor and is accordingly used chiefly for winding resistances and not for the wires of a circuit.

Q. What are some good insulators?

A. Wood, glass, resin, paraffin wax, silk, cotton, asbestos, rubber, and similar mineral or vegetable substances.

Q. Are they always equally good insulators, regardless of their condition?

A. They are efficient as insulators only when dry. The presence of moisture on any of them affords a path for the current to cross them.

Q. What effect on the ability of the conductor to carry a current has the amount of material used?

A. The resistance is increased with a decrease in size and is also increased directly as the length of the conductor.

Q. Where, for mechanical or other reasons, it is not practical to use copper or aluminum, how can an equally efficient conductor of some other material be provided?

A. By increasing the amount of material employed in the same proportion that its conductivity bears to that of copper. For example, assuming that steel is only one-thirtieth as good a conductor as copper, thirty times as much of it must be employed to give the same conductivity.

Q. Give an example of this?

A. The single-wire system of connecting the starting and lighting outfit on an automobile. A small copper cable forms one side of the circuit, while the entire chassis forms the other. The ordinary trolley-road circuit is another, the small overhead wire forming one side of the circuit, and the rails on which the car runs, the other.

Q. Name some of the materials which are employed for their high resistance to the current.

A. German silver, iron wire, cast iron in the form of grids of small cross-section, and carbon. Very fine copper wire is also employed where the resistance desired is not very great, and space considerations permit its employment.

Q. What is meant by the "specific conductivity" of a material?

A. Its ability to conduct the current as compared with that of pure silver which has a specific conductivity of one.

Q. Does this ability of a conductor to convey the current vary particularly with a great increase in voltage?

A. Yes. The so-called high-tension current which has been stepped-up in a transformer from the 6-volt potential of the 3-cell storage battery to many thousand volts for ignition purposes will cross surfaces and penetrate materials that are perfect insulators to the low-tension current. For example, the high-tension current will leak across a moist wooden surface or it will sometimes puncture the one-fourth inch of rubber and cotton insulation of the secondary cable.

Q. What is one of the chief effects of transforming a current at a low voltage to one of high potential?

A. It enables the current to leap an air gap, the width of which is proportioned to the voltage itself. The greater the voltage the greater the width of the gap it will jump. This is the principle on which the spark plug is based.

HIGH-TENSION CURRENTS

Q. When a current of 2 amperes at 6 volts, such as would be consumed by the ordinary ignition coil from a storage battery, is transformed to a high potential, is the amount of current still the same? In other words, can 2 amperes at 6 volts be transformed or stepped-up to 2 amperes at 10,000 volts?

A. No. The current decreases as the voltage increases. For example, to make the comparison more clear, consider a current of 10 amperes at 100 volts. This is passed through a step-up transformer, of which the ignition coil is a type, and is given a potential of 1000 volts. The current, however, would then be 1 ampere, that is, the current decreases in the same proportion that the voltage is increased. The opposite is also true. By passing this current of 1 ampere at 1000 volts through a step-down transformer, it may be converted into a current of 100 amperes at 10 volts. It will be noted that the product of volts times amperes in any of the above instances cited, or of any possible combinations that can be made, is always the same. In other words, a certain amount of energy is sent through the transformer, and the same amount, barring losses due to the transformation process itself, is taken out.

Q. Is there any mechanical analogue of this process of transforming a current up or down to impress upon it a greater or lesser potential?

A. There is nothing in mechanics that corresponds exactly to this peculiar property of electricity. The resulting change in the form in which the energy is applicable as a result, however, may readily be compared with mechanical standards. For example, we may have in a very small boiler, a pressure of 1000 pounds to the square inch, but a volume of only one cubic foot of steam. This small amount at its high pressure represents the equivalent in energy of 10 cubic feet of steam at a pressure of 100 pounds.

Q. What is the object of stepping the current up to such high voltages?

A. On the automobile, simply to enable it to jump the gap of the spark plug and fire the charge. In ordinary commercial service, to permit of sending it long distances with a minimum expenditure for copper wire and a minimum loss in the amount of energy transmitted.

CIRCUITS

Q. What is meant by an electric circuit?

A. The path by which the electrical energy, or current, is said to flow from and return to its source.

Q. Is a circuit absolutely necessary in order to permit of utilizing electricity?

A. Unless there is a circuit or complete path for the current, it does not flow.

Q. Must a circuit be comprised completely of wires leading from, and returning to, the source, such as the battery or generator?

A. No, it is not necessary that wire be used for both sides of the circuit. One side or the other may be composed of a *ground*, such as the tracks of a trolley system, the overhead wire constituting the other side of the circuit, or in the case of a single-wire lighting and starting system in which one cable is employed to conduct the current from the battery to the starting motor and lights. and the chassis itself forms the ground return for both.

Q. How many forms of circuits are there in general use?

A. Three: the series, the multiple, and the series-multiple. In the first, all apparatus in the circuit is in series. That is, all the current from the source must pass through each instrument or light in turn to complete the circuit. In the multiple type of circuit, every instrument or light on it is independent of all the others. Lights may be turned on or off, motors started or stopped, without interfering in any way with any of the others. As its name indicates, the series-multiple is a combination of the two forms of circuits. For example, in using incandescent lamps to cut down the current for charging a storage battery from the lighting mains, the lamps themselves are in multiple, but the whole bank of lamps is in series with the storage battery. See illustration on charging storage battery direct from lighting mains.

Q. Which of these forms of circuit is in most general use on the automobile?

A. All three will be found on practically every car equipped with a starting and a lighting system. For instance, the starting motor is operated in series with the battery, while the lamps are wired in multiple for the side and head lights, and the speedometer and tail light are wired in series as a branch of the multiple-lighting circuit, thus giving a series-multiple circuit. The ignition distributor, coil, and battery are in series.

Q. What is meant by a grounded circuit?

A. This is ordinarily used to indicate that through lack of insulation at some part of the wire, or similar injury, the circuit has been shortened, owing to this bare wire touching a *ground,* thus permitting the current to return to its source without passing through whatever instruments there may be on the circuit. A *grounded circuit,* however, is also one in which one side consists of a ground return instead of having two wires. This is frequently distinguished by being termed a *ground-return* circuit.

Q. What is a short-circuit?

A. As the term indicates, a completion of the circuit short of the point or apparatus which the current is intended to reach. The example just cited is a short circuit as well as a ground, sometimes termed a *grounded short-circuit.* In other words, the abrasion of the insulation of one of the conductors has permitted the current to escape by a convenient path of return which, being of less resistance than the one it is intended to take, prevents any current from reaching the apparatus in the circuit. A ground is practically always a short-circuit, but the reverse is not always true, that is, a short-circuit need not necessarily be a ground, as in a double-wire circuit, but the two conductors may come together at a point where the insulation is worn, or winding of a coil may break down and cause a short-circuit.

Q. What are some typical examples of grounded circuits on the automobile?

A. Both the primary and secondary sides of the ignition circuit and the starting and lighting circuits of the so-called single-wire systems in which the chassis is always used as a ground return for all the circuits employed.

HYDRAULIC ANALOGUE

Q. What is a hydraulic analogue, and what bearing has it on an electrical system?

A. It is a comparison of the electrical system with a hydraulic or water-pressure system and serves to make clear the resemblance or analogy that exists between the principles upon which both operate.

Q. What type of hydraulic system is similar to an electrical system consisting of a generator, external circuits, and lamps, motors, or the like, as a load?

A. A constant-pressure system in which the pumps keep the water in the pipes under a certain amount of pressure corresponding to the demand. When the demand increases, the supply does likewise and *vice versa*. (In the case of the pumping system, this is not automatic, but is controlled by the attendant.)

Q. To what does the pressure of such a pumping system correspond in the electrical system?

A. To the voltage, or electromotive, force.

Q. Can there be voltage, or potential, in an electrical system without a flow of current?

A. Yes, exactly as in the pumping system in which there is always a constant pressure on the water in the pipes whether the water is escaping through any of the outlets or not. In other words, there may be pressure but no flow. The same thing is true of the generator. If it be turning at its normal speed and is wound to produce current at 100 volts, there will be a potential of 100 volts across its terminals, even though there are no lamps or motors switched on in the external circuit.

Q. How does the resistance of the pipe lines in the water system compare with the resistance of the wires in a circuit to the electric current?

A. It is nearly the same. It varies inversely as the size of the pipe and directly as its length. The smaller the pipe the greater the resistance per foot; the longer the pipe the greater the total resistance. In the same way, the resistance to the electric current increases with the decrease in the size of the wire and increases with the length of the wire, the chief difference being that bends or turns in the wire do not add to the electrical resistance, whereas bends in the pipe impose greatly added resistance to the flow of water.

Q. What comparison may be made between the speed at which the generator and the pumps run?

A. The greater the speed, the greater the pressure in the case of the pumps, and of the voltage in the case of the generator. Below a certain speed, usually termed the normal speed, there is a sharp falling off in the pressure in both. Neither can be operated safely at an excessive speed.

Q. What is the cause of the increase in voltage with increasing speed in the case of the generator?

A. Voltage, or electromotive force, is generated by the coils, or windings, of the armature cutting the magnetic lines of force of the field of the generator. The greater the number of times that these coils pass through the lines of force per minute, the greater the voltage will be.

Q. How does fall in pressure correspond to voltage drop?

A. To reach the end of the piping system, the water must overcome the resistance of the latter to its passage, and the friction involved robs it of some of its pressure in overcoming this resistance. Consequently, there is less pressure at the outlet a mile away from the pumps than there is at the pumps themselves. The same thing is true of the electric circuit. The current must force its way through the wires by reason of its voltage or pressure and, in so doing, some of the voltage is lost in overcoming the resistance of the wires, joints, switches, and the like. In both cases allowance for this loss is made by increasing the pressure at the source by an amount equivalent to the loss in transmission. For example, in electric street-railway work the motors are wound to operate on current at 500 volts, while the generators in the powerhouse produce current at 550 to 600 volts, the difference being known as the *voltage drop*.

Q. Is this an important matter on the automobile where the circuits are so short?

A. It is of considerable importance, particularly in connection with the starting motor circuit. The circuits are very short, but the initial voltage is likewise very low, so that the percentage available for voltage drop is correspondingly limited. For example, a drop of one volt in a 110- to 115-volt lighting circuit is negligible, being less than 1 per cent, but a drop of one volt in a 6-volt circuit represents almost 17 per cent and would accordingly be prohibitive. As poor connections, dirty switch contacts, dirty commutator, and worn brushes are apt to increase the resistance to a point where the voltage drop is in excess of this, the importance of properly maintaining these parts of the system may be appreciated.

Q. How does the flow of water correspond to the flow of current?

A. In both cases, the amount is proportionate to the resistance of the outlet and to the pressure back of the current, whether water or electricity. In other words, the volume of water that will flow depends upon the size of the outlet (the smaller the outlet the greater the resistance to the flow) times the pressure back of it. In the same way the number of amperes that will flow when the circuit is closed depends upon the voltage of the circuit divided by the resistance (Ohm's law). For example, the ordinary 16 c.p. carbon-filament lamp for a 110-volt circuit has a resistance of 220 ohms, which, divided by 110, gives ½ ampere as the current that will flow when the lamp is switched into the circuit.

Q. Can the piping system properly be compared with an electric circuit?

A. In practically every way except that of the return required for the latter. For example, the opening of a series of outlets in the piping system reduces the pressure in proportion to the number opened; so in connecting a number of different pieces of apparatus in series in an electric circuit, the voltage through each will decrease as another is added. It may also be compared with a parallel or multiple circuit in that the opening of one outlet does not prevent drawing water from another. A break in a main corresponds to a short-circuit or a ground in that no water can then be drawn from any outlet beyond the break. The comparisons between the piping system and the circuit are not exact, owing to the lack of any necessity for a return in the case of the water piping, but they serve to make clearer some of the fundamentals of the electric circuit.

GENERATOR PRINCIPLES

Q. What makes it possible to generate a current of electricity by mechanical means?

A. The fact that electricity and magnetism are different manifestations of the same force and that, given one, the other may be produced. Also the fact that they are readily interchangeable, i.e., one may be readily converted into the other.

Q. On what fundamental principle does the generation of electricity in this manner depend?

A. That of induction.

Q. How is it utilized?

A. By revolving a coil of wire in the field of a magnet.

Q. What occurs when this is done?

A. An e.m.f. is generated in the coil.

Q. Describe the simplest form of generator.

A. Such a generator consists of a horseshoe magnet between the poles of which a coil of wire is revolved.

Q. What governs the strength of the e.m.f. or potential, thus generated?

A. The speed with which the conductor or wire revolves, or is said to "cut the lines of force" of the magnetic field.

Q. How can this potential be further increased?

A. By winding the coil of wire on an iron core, as the iron becomes strongly magnetic and greatly increases the inductive effect.

Q. What is this simplest form of generator consisting of horseshoe magnets for the field and of a single winding on an iron core termed, and for what is it employed on the automobile?

A. It is known as a *magneto* and is generally employed for producing the current needed for ignition purposes.

Q. Can such a generator be directly employed for charging a storage battery or for lighting lamps?

A. No, it cannot be used for charging purposes, since it generates an alternating current. Moreover, owing to the small number of poles (two), its single winding, and the high speed at which it is driven, it produces very little current but a high e.m.f., as this is desirable for ignition. It cannot be used for lighting purposes for the same reason, i.e., the simple winding produces an alternating current with a very perceptible interval between the alternations, or cycles, so that a lamp would flicker very badly. As its e.m.f., or voltage, is proportionate to its speed and as there is no method of controlling it, the lamp would be burned out as soon as the magneto was speeded up.

Q. What are the essentials of this simple form of generator?

A. The field consisting of the horseshoe magnets, and the armature consisting of a soft iron or steel core, usually in the form of an H, in the slots of which, the single winding of comparatively coarse wire is wound.

Q. Why is the field of a magneto usually referred to as a "permanent field?"

A. Because it consists of so-called permanent magnets. Naturally, they are not permanent in the real sense of the word, but their magnetism is constant while it lasts and it decreases only very gradually under the influence of heat and vibration.

Q. Why does heat affect the magnetism of the field of a generator of this type?

A. Because a piece of hard steel that is strongly magnetic when cold loses its magnetism altogether when raised to a sufficiently high temperature. In other words, if heated to a bright red and then cooled, it is no longer a magnet, and the steel must be remagnetized. Constant vibration has the same effect, but it is much slower.

Q. Is there any other way of increasing the voltage of such a generator besides running its armature at a higher speed?

A. Yes, by increasing the number of turns of wire in the winding, which has the same effect as revolving a single coil at a higher speed.

Q. How is the current produced by a simple form of generator, such as the magneto, conducted to an outside circuit?

A. Ordinarily, this would be done by means of slip rings, i.e., plain bands of copper mounted on the armature shaft with narrow copper brushes bearing on these rings, as is the case with large alternating-current generators. But as the ignition system of the automobile is a grounded circuit, one end of the armature winding of the magneto is connected directly to the core of the armature, and the other is led to a small V-shaped ring or to an insulated stud on the end of the shaft against which either a copper or a carbon brush is held by a small spring.

Q. What is the cause of the alternating cycle of the magneto, and at what points in the revolution of the armature does it occur?

A. In revolving in the field of the magnets, the armature passes successively from the field of influence of a north pole to one of opposite polarity, so that the direction of the e.m.f. is reversed.

When the armature is in a horizontal position in the field, the e.m.f. curve is at zero; as it turns, the edges of the armature core pass the ends of the pole pieces of the field, and the e.m.f. rises sharply to a maximum as the central line of the core passes the ends of the poles, when it is said to be cutting the maximum number of lines of force. It drops off again quickly from this point and again reaches zero, when the armature is in a vertical position. As its ends come under the influence of opposite poles, the curve again rises, but is now in the opposite direction, or of opposite polarity. In other words, it passes from zero to maximum and back again in every half revolution, or 180 degrees.

Q. How can a generator be made to produce a direct, instead of an alternating current?

A. The current is always alternating as generated in the armature, but it may be conducted to the outside circuit as a unidirectional, or so-called direct, current by the addition of a commutator.

Q. Can such a current be produced by the addition of a commutator to the simple single-coil winding already mentioned in connection with the magneto?

A. Yes, but as the commutator would have but two parts, the e.m.f., while passing in one direction, would be strongly pulsating.

Q. What is a commutator and how does it convert the alternating current produced in the armature to a direct current in the outside circuit?

A. It consists of a number of segments of copper, one for each coil terminal of the armature, i.e., two for each complete coil of the winding. These segments are insulated from one another, and brushes bear at opposite points of the conducting hub thus formed by the segments. As the terminals of the armature coils are connected to segments that are opposite one another (in the simplest forms of winding), and as the brushes, also opposite one another, are set at points so that they pass from one segment to another when the rate of cutting is at a minimum in the armature winding, their relation to the latter is changed each half revolution. In other words, at the point in the revolution where the polarity of the e.m.f. generated reverses, the relation of the brushes to the winding is also reversed, so that the direction of the e.m.f. is accordingly always the same. See Figs. 20 and 21.

Q. How is the pulsating nature of the direct current thus generated overcome?

A. By adding coils and commutator bars to the armature so that new coils come into action before the e.m.f. produced in those just preceding them under the brushes has an opportunity to drop much below the peak or maximum. Thus, only the peak of the wave is utilized, and the e.m.f. of a direct current consists of a series of these wave peaks overlapping one another.

Q. Are permanent magnets used for the fields of all generators?

A. No, only for those of magnetos. In other types, an electromagnetic field is used.

Q. What are the advantages of the permanent field for use in connection with the magneto?

A. It is always at its maximum strength, so that the magneto generates a powerful e.m.f., even though turned over very slowly. Regardless of the speed of the armature, the strength of the field remains the same, so that no controlling devices are necessary to prevent the armature from burning out, owing to excessive speed.

Q. What is an electromagnetic field and how is it produced?

A. It is based on the fact that when a current of electricity is sent through a winding surrounding an iron core, the core becomes strongly magnetic. It accordingly consists of windings on the fields of the generator, in addition to those on the armature. Depending upon the particular type of generator in question, either all or only part of the current produced in the armature is sent through the windings of the field. The latter is then said to be *self-excited* in that it depends upon no outside source.

Q. Is the self-excited field characteristic of all generators except the magneto?

A. Yes, of all direct-current generators. Large alternating-current generators are said to be separately excited, a smaller direct-current generator being employed solely for the purpose of rendering the fields of the larger machine magnetic.

Q. What is a series-wound generator, and why is this type not used on the automobile?

A. It is one in which the entire current generated in the armature is passed through the field windings. It does not generate until a high speed is reached. Its voltage varies sharply as its speed, and it may have its polarity reversed by the battery if its speed drops below a certain point, consequently, it is not fitted for charging storage batteries. (In fact, the series-wound generator is practically obsolete, except for some special uses.)

Q. What are shunt- and compound-wound generators?

A. In the former, the windings of the armature and of the fields are in multiple, or shunt, so that only a certain amount of current, depending upon the difference in the resistance of the outside circuit and that of the fields, passes through the windings of the latter. As the load and consequently the resistance of the outside circuit increases, more current passes through the shunt, and the fields become more strongly magnetic, thus increasing the output so that the generator is, to a certain extent, self-regulating.

In the compound type, there is, in addition to the main shunt winding on the fields, an auxiliary winding of heavier wire (lower resistance) which is connected in series with the armature. As in a series-wound generator, the amount of current exciting the fields is directly proportional to the speed, more current in proportion passes through the compound winding than through the shunt winding as the load is increased, and the generator is self-regulating to a much greater degree. The compound-wound type of generator is in practically universal use on the automobile as well as for general power purposes. See Figs. 31 and 32.

Q. What is meant by the term "self-regulating" as used in the preceding paragraphs?

A. The generator automatically produces more current in response to the demand occasioned by an increase in the load, without any change in its driving speed.

Q. How is this accomplished?

A. The amount of current produced by the generator depends upon the strength of its magnetic field in which the armature revolves. The magnetism of this field represents the so-called lines of force. The greater the number of lines, or the more powerful they are per unit of pole-piece surface, the greater the volume of current that will be generated. In practical usage, this is referred to as the *magnetic flux*, or flow, through the armature. By increasing or decreasing the amount of this magnetic flux through the armature, the current output can be controlled within close limits.

Q. What is meant by the "load" on a generator?

A. The lamps, motors, storage battery, or similar apparatus to which it is supplying current.

Q. As the speed of the generator itself does not increase, how does it provide for an increase in the load?

A. By absorbing more power from its driving unit. For example, if a generator be operating with only ten 100-watt lamps in the circuit, it is requiring approximately one and one-half horsepower to drive it. Now, if another group of ten lamps of the same size be switched on, the amount of power demanded by the generator of its engine will be doubled. This may be very readily demonstrated in a rough way by fitting a handcrank to any small automobile generator and turning the machine over with one lamp in the outside circuit. It will be found very easy to spin the generator very rapidly by hand, as practically no resistance is felt. Now connect in the circuit a discharged storage battery, and the additional power required to turn the machine will at once be very perceptible.

Q. What are the brushes and what purpose do they serve?

A. They are strips of copper or carbon (the latter is now almost universally used), which serve to conduct the current generated in the armature to the outside circuit and to the field windings by bearing on the revolving commutator. Except where an additional brush is employed for regulating purposes, there is usually one brush for each pole of the field, i.e., a bipolar generator is fitted with two brushes, a four-pole with four brushes. The brushes are held against the commutator by springs. Soft copper embedded in carbon is also employed, especially for low-voltage generators, such as the lighting generator on the automobile.

ELECTRIC MOTORS

Q. Is there any difference in principle between the electric generator and the electric motor?

A. Fundamentally, they are the same, as is evidenced by the fact that either is reversible, that is, an electric generator, when supplied with current from an outside source (of the proper voltage, of course), will operate as a motor, and a motor, when driven by an outside source of power, will generate an electric current. They are naturally not interchangeable in practice, owing to differences in design and winding. The generator is wound to produce the maximum amount of current at a certain voltage with a given horsepower, while the motor is designed to produce the maximum amount of power with the minimum current.

Q. What is the operative principle of the electric motor?

A. That of magnetic attraction and repulsion.

Q. How is it applied?

A. As in the generator, both the fields and the armature of the motor consist of electromagnets. The brushes and the commutator serve the same purpose of reversing the direction of the current through the armature coils every time a different pair of commutator segments passes under the former. As has already been explained, reversing the direction of current flow through the winding of an electromagnet reverses the polarity of the magnet itself. To simplify the illustration, take a bipolar motor with a two-pole armature having but a single winding. When the current is switched on, the armature is at a 45-degree angle, so that its poles are just under the poles of the field. As the commutator causes the current to flow through the armature winding in a reverse direction to that of the fields, unlike poles will be created. They will attract each other, and the armature will revolve a small part of a revolution, until it is directly in the strongest part of the field of the influence of the field magnets. Just as this point is reached, however, the brushes pass on to new segments of the commutator, and the direction of the current in the armature coils is instantly reversed. The polarity of the armature core is also reversed, so that there are now like poles opposed to one another, and they repel, causing the armature to complete another part of its revolution, when the former conditions are again established and the armature is again attracted. In a bipolar motor with a simple two-pole armature, there would be two phases of attraction and repulsion per revolution. In larger motors this is multiplied by the number of poles in the field and the number of coils on the armature.

Q. As an electric motor in running fulfills all the conditions necessary for the generation of an e.m.f., what becomes of this voltage?

A. It constitutes what is termed a *counter e.m.f.* and serves the useful purpose of increasing the resistance of the motor when in operation, thus reducing the amount of current necessary to drive it. For example, when the motor is standing idle, the resistance of its windings is low. It is for this reason that large direct-current motors (one h.p. or over) cannot be started without the aid of an outside resistance to cut down the starting current, otherwise the armature would be burned out. As the armature speeds up, the counter e.m.f. generated opposes that of the driving current and accordingly increases the resistance. The heating of the windings in operation further serves to increase the resistance, as the resistance of most metals increases with a rise in their temperature.

Q. How many types of motors are there, and what type is most generally used for automobile starting?

A. As they correspond exactly to generators, there are the same number of types, i.e., series, shunt, and compound wound. The series type is almost universally employed on the automobile and is also very largely used on trolley cars.

Q. If the series-wound generator is of so little practical application, how is it that the series-wound motor is found so advantageous?

A. The same characteristics that are a disadvantage in the generator are correspondingly valuable in a motor, which explains why generators and motors are not interchangeable in practice, as already mentioned. A series-wound machine is essentially a variable-speed machine, and this is not desirable in a generator, while it is in a motor. The series type of motor has a very heavy starting torque, or pull, which increases as the speed of the motor decreases. This is exactly what is wanted to overcome the inertia of the gasoline engine. Its current consumption falls off very quickly as its speed increases, and it has a very liberal overload capacity, being capable of carrying loads up to five times the normal, for short periods.

Q. As the speed of the series motor decreases in proportion to the load, what happens when the load is suddenly relieved as in the starting of the gasoline motor?

A. The electric motor tends to race, or *run away.*

Q. How is this prevented on the automobile?

A. The method employed differs in different systems, but, as a rule, the starting of the gasoline engine automatically opens the starting motor circuit, or means are provided for greatly reducing the amount of current it receives the moment the load is removed.

Q. Are either shunt- or compound-wound motors used on automobiles?

A. They are employed on electric vehicles, but not often in connection with the starting systems used on gasoline cars.

Q. What is a motor-generator, and what is it employed for?

A. As its name indicates, it consists of two units, a motor and a generator, the former having an alternating current, and the latter a direct current. It is employed for converting an alternating current into a direct current, so that it may be utilized for charging storage batteries. The alternating-current supply is used simply for running a motor of that type to which is directly coupled a direct-current generator. There is no electrical connection between the two machines.

Q. Are motor-generators ever used on automobiles?

A. No, but the combination of a direct-current generator and a starting motor in one machine, as in the single-unit systems, is frequently so-called through error. This single unit is variously termed a *dynamotor* and a *genemotor* to distinguish it from a motor-generator.

Q. How are the two radically different purposes for which the generator and the motor must be designed combined in one machine?

A. By putting independent windings on the fields and the armature, and, in some instances, by employing two commutators at different ends of the armature shaft.

BATTERIES

Q. What other method is there of producing an electric current besides that of driving a dynamo?

A. The use of batteries known as primary and secondary cells.

Q. What is the difference between these two types?

A. In the primary cell, the current is generated by means of the chemical reaction taking place between electrodes of different materials in an acid or alkaline solution, one electrode being dissolved in the solution as the chemical action continues.

The secondary cell is the storage battery. This does not generate a current of electricity as in the case of the primary cell, nor does it actually store electricity as its name would indicate. The passing of a current through its elements brings about a chemical conversion of the latter, which is reversed when the current flows out of the cell.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

GASOLINE AUTOMOBILES

PART IV

1. How is gradual engagement secured in a cone clutch?

2. What are the disadvantages of the inverted cone clutch?

3. Sketch a typical contracting band-clutch.

4. What type of clutch is used in the 8-cylinder V-type Cadillac?

5. What is the coefficient of friction between cork and leather used dry in a clutch?

6. What are the parts used in a magnetic clutch?

7. When a metal-to-metal oiled clutch slips, what is the cause of the trouble?

8. What are the causes of clutch spinning?

9. What is the difference between the progressive and the selective transmission; why has the former been discarded?

10. What transmission is used on the Winton?

11. What is an interlocking device?

12. How are transmission adjustments made?

13. Describe the Manly drive.

14. Sketch and explain the Owen magnetic transmission.

15. What troubles may be expected in the planetary type of transmission?

16. Why is the worm gear generally used in steering devices?

17. What is the maximum efficiency obtainable with a worm gear?

REVIEW QUESTIONS

ON THE SUBJECT OF

GASOLINE AUTOMOBILES

PART V

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1. Explain the action of the Winton steering gear.

2. Describe the action of a correct steering arrangement in turning a corner.

3. What are the double requirements of a correct steering gear?

4. Name the different forms of steering gears now in use and describe one form.

5. Why is the worm utilized in nearly all steering gears?

6. Give the special advantages of the Hindley worm over other forms.

7. How does the drag link used in the Ford steering gear differ from conventional designs?

8. Give the test for backlash in an irreversible type of steering gear.

9. Why is it necessary to use at least one universal joint in a steering rod?

10. Discuss steering in 4-wheel drive types.

11. What is the difference between the Elliott and the Reversed Elliott front axles?

12. Describe the Marmon self-lubricating axle.

13. Why are sub-frames used?

14. Discuss wood frames and name American car that has its frame made of wood.

15. What is the peculiarity of the Marmon frame?

16. Explain the Hotchkiss drive.

REVIEW QUESTIONS

ON THE SUBJECT OF

GASOLINE AUTOMOBILES

PART VI

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1. Discuss the advantages of flexible joints when used in place of universal joints.

2. Give the advantages and disadvantages of the shaft drive

3. Why are torque rods necessary?

4. Into what classes may rear axles be divided?

5. What percentage of 1917 cars use the three-quarter floating axle?

6. Describe the rear-axle construction of the Case car.

7. Explain the action of a gearless differential.

8. How may a sagging axle be adjusted?

9. How many sets of brakes should be used on a chain-driven car?

10. Describe the action of the brake used on the Knox tractor.

11. Why have substitutes been sought for the ordinary differential?

12. What are the advantages of silent chains?

13. What system of final drive is used in the Metz?

14. How may chattering be eliminated in internal-expanding brakes?

15. What is meant by "checking up" axles?

16. What are the advantages of double-brake drums?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRICAL EQUIPMENT FOR GASOLINE CARS

PART I

1. What is an electromagnet; how is it used?

2. Explain what is meant by (a) a short-circuit; (b) a ground

3. A certain 12-volt starting motor required an average current of 80 amperes to turn the automobile engine over fast enough to start it. How many horsepower is developed by the starting motor?

4. Describe the process of generating an e.m.f. wave by a dynamo.

5. If pure water is an insulator, why is it necessary to keep the spark plugs and other parts of the secondary circuit dry?

6. What is a dynamotor?

7. Give the rule for determining the direction of current flow in a solenoid winding.

8. What is meant by "voltage drop"?

9. Give the diagrams of series, shunt, and compound generator windings.

10. Explain how rotation is produced in an electric motor.

11. Give diagram of a lighting circuit for an automobile, showing lights in multiple.

12. What are the differences between shunt-. series-, and compound-wound generators?

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