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COMMERCIAL ELECTRICAL TESTING

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BY

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Introduction

THE following chapters on commercial electrical testing, by Mr. E. F. Collins, Technical Superintendent of the General Electric Company's Schenectady Works, cover a branch of engineering, the study of which is of great importance at the present time. The rapid growth of electrical engineering has necessitated a corresponding development in testing practice to keep pace with engineering and commercial needs; and therefore a description of the arrangements, methods and apparatus used by the Schenectady Works of the largest electrical manufacturing company in the world cannot but prove instructive, not only to the engineering student, but also to all electrical engineers, besides being of considerable aid to those schools and colleges which give a course of instruction in electrical laboratories.

The testing department of a large company is, of necessity, one which employs only those methods which have been found by experience to combine accuracy, efficiency and economy. The subject can be naturally divided into two classes; *viz.*, tests made to obtain engineering information to serve as a basis for future design or for other purposes, and commercial testing. In the latter case, which forms the greater part of the testing work, commercial considerations require that each job be finished as quickly as possible. The machines supplying power and the switchboards must therefore be located and designed from this point of view, and all connections and wiring laid out with the greatest possible care. The personnel must be thoroughly drilled and instructed in their work by experienced men, and each job as it comes along must be assigned to a small group who assume the responsibility for the proper completion of the test. The switchboards must be wired so that a large number of connection combinations can be readily obtained. The instruments used must be of the highest quality to insure accurate results, and must frequently be compared with reliable standards—work for which a standardizing laboratory is necessary. All these matters must be kept in mind and a system provided for enforcing testing regulations for obtaining clear records of the work done. In short, the testing department is a complex organization whose keynote is efficiency. Economy of labor and power, and the arrangement of apparatus are of equal importance with accuracy; with the latter, of course, a *sine qua non*, since the majority of apparatus tested must meet specification as regards performance, heating, efficiency, and the like. When, as often happens, more than one method can be employed in a given case, the test must be chosen which yields the maximum of accuracy practicable, consistent with the character of the work.

These questions are fully considered in this little book and will appeal to all those having charge of similar departments, college laboratories, etc. To the student of engineering, however, the description of the various tests, their preparation, how they are carried out, the instruments used, and the diverse calculations required will appeal most strongly. Nearly all types of electrical machinery have been covered, and many examples have been given showing the kind of results that actually obtain in the more important cases, and the means employed for discovering electrical or mechanical faults.

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The demand for the first edition of this book was so great that the supply was soon exhausted. We have felt it imperative, therefore, to have a second edition printed, thus enabling those who were disappointed in securing a copy to avail themselves of this new opportunity. As stated on the cover, this later edition is not a mere reprint of last year's book for it contains additional material and, so far as has been brought to our attention, has had those minor errors corrected which it seems are unavoidable in all first editions.

EDITOR, GENERAL ELECTRIC REVIEW.

CHAPTER I

MEASUREMENT OF RESISTANCE, VOLTAGE, CURRENT AND POWER

RESISTANCE MEASUREMENTS

Unit employed	(Primary Std.)	(Coils from N.B S.)
(International Ohm)	(Working Std.)	(Current Carrying Stds.)
Medium 0.01 to 1000000	Wheatstone Bridge Slide Wire	P.O. Dial or Decade Ohm Meter Special Bridges
Low Below 5	Thomson Bridge Drop Method	Voltmeter and Ammeter Quick Period Galvanometer Low resistance Outfit
High above 50000	High Resistance D.C. Voltmeter Insulation Measuring Outfits	

Unit Employed

The unit employed is known as the "International Ohm." It is represented by the resistance offered to an unvarying electric current by a column of mercury at 0 deg. C., 14.4521 gm. in mass, of an uniform cross-sectional area, and 106.3 cm. in length." The cross-sectional area of this column is approximately 1 sq. millimeter.

Primary Standard

The primary standards against which the working standards of resistance may be checked are standard resistance units of the National Bureau of Standards or Reichsanstalt form. In order, however, to be assured of their continuing accuracy, they should be compared occasionally with the Government standards at Washington and certified to by the Bureau of Standards. The certificates give the temperature at which the units are correct and also the temperature coefficient, *i.e.*, a correction factor to apply when the temperature of the unit differs from the standardizing temperature.

Working Standards

These consist of several current carrying units of various current capacities and resistance values. They are frequently compared with the primary standards referred to and also with each other.

CLASSES OF RESISTANCE MEASUREMENTS

There are three general classes into which resistance measurements may be divided. These are "Medium," covering a range from 0.01 to 1,000,000 ohms; " Low," covering a range below 5 ohms; and "High," covering a range above 50,000 ohms. It will be noted that the division line between the classes is not very definite, *i.e.*, the several ranges overlap each other.

Medium

For the measurement of medium resistance the "Wheatstone Bridge" and the "Slide Wire Bridge" are used.

WHEATSTONE BRIDGE

Two types are in use, the "Post Office" pattern and the "Decade" type. Both operate on the same principle. In the "Post Office" type the resistances composing the rheostat are all connected in series and the reading is obtained by adding *all* the values of the plugs that are *out* when a balance is obtained. In the "Decade" type (also the dial type) only one plug is used for each decade, and the reading is obtained directly, by noting the values against the plugs that are *in* when a balance is obtained. It is, of course, understood that in both cases proper account must be taken of the ratios as plugged in the "arms" of the bridge. Also, in both cases, only one plug in each arm must be used and the values must be taken from the plugs that are *in*. The following remarks will apply to both types of bridge.

Good Contacts

All plugs and other contacts should be kept clean and bright. The plugs should be cleaned every time the bridge is used or, if in constant use, at least every day. This may be done by wiping them with a piece of soft cloth or waste applied with the finger. *Never* use emery cloth nor polishing powder. The key contacts may be cleaned by putting a piece of heavy paper between them, pressing the key and pulling the paper out. If very much corroded, a piece of worn *crocus* (not emery) cloth may be used.

It is essential that all plugs should be tight. It is not necessary to use much force, in fact this should not be done. The plug should be given a slight rotary motion, at the same time applying a gentle pressure. In removing the plugs, give them a rotary motion in the *same direction* as when they were inserted. The rotary motion should be in a clockwise direction, to prevent unscrewing the plug heads.

Using Keys

To open the keys (if they are in proper condition) only a firm steady pressure is necessary. Pounding the keys must not be allowed, since it ruins them. This applies to all testing keys, as well as to bridge keys.

Choice of Ratios

In using the Wheatstone Bridge, it is best that the resistance in the arms and the resistance in each of the four bridge arms should be as nearly equal as possible, as this gives the most sensitive arrangement.

Most bridges have a capacity of 1 to 9999 or 10,000 ohms in the rheostat, with ratios for multiplying or dividing the rheostat plugging by 1000. It is not advisable where other means are at hand to use the 1/1000 or 1000/1 ratios, except on a bridge of unusually accurate resistance adjustments, as the 1 ohm coils are not as accurate as those of greater resistance. Avoid using 1 ohm coils as far as possible.

TEMPERATURE COEFFICIENT

For ordinary bridge work in the factory and in general work (outside of the laboratory) the temperature coefficient of the bridge may be neglected, as it is too small to be appreciable within the limits of the work under consideration. The temperature coefficient of the material in test, however, must always be considered, *i.e.*, it must be decided whether it should be allowed for or not; in the former case make the proper allowance. Apparent disagreement between different departments frequently arises which on investigation will often be found to be due to a disregard of the temperature coefficient of the apparatus in question.

Should it be necessary to make a temperature correction for the bridge, great care must be taken to measure the temperature of the bridge coils correctly. A thermometer placed in the bridge box often does not nearly indicate the correct temperature of the coils, especially if the surrounding temperature is rapidly changing. The bridge should be kept in a nearly constant temperature and the indications of the thermometer in the box should remain substantially constant for an hour at least, better for two or three hours.

SLIDE WIRE BRIDGE

This is a modification of the Wheatstone Bridge, the slide wire forming two arms of the bridge and corresponding to the ratio arms in the Wheatstone.

Ohmmeter

The so called "Sage" Ohmmeter is essentially a slide wire bridge arranged for portable use where approximate values are sufficient.

This instrument is useful for special jobs and is found very convenient, especially on outside work, *i.e.*, where no fixed bridge is available, such as in a power station, car barns, etc. Its sensitiveness and consequently its degree of accuracy is largely dependent on the hearing of the observer and the condition of the dry cell batteries forming a part of the instrument and supplying the necessary current for making a measurement. A telephone receiver of the "watchcase" pattern is used on this bridge in place of a galvanometer to determine when balance is obtained.

Instructions already given regarding contacts and plugs apply. In addition the slide wire and "contact finger" should be given proper attention. The wire can be wiped off with the finger or a soft cloth when dirty. The contact finger may be cleaned with crocus cloth.

Under no circumstances use any emery or crocus on the slide wire as this will ruin the bridge. The bridge should be tested before starting on an outside job, to see if it is in working order, as the batteries deteriorate even when standing idle. Never leave the bridge connected, as metallic dirt or conducting material sometimes collects in the plug holes which may short circuit and spoil the battery if the receiver switch is not in working order, as occasionally happens. This switch should receive occasional attention.

LOW RESISTANCE MEASUREMENTS

Under this heading are included the "Thomson Bridge," sometimes called "Double" Bridge, and the "Drop Method," using an ammeter and voltmeter or their equivalents.

The Thomson Bridge

This is a modification of the Wheatstone Bridge and is suitable for use with low resistances, as its arrangement removes the objection to the former, *viz.*, the resistance of connections and plugs. It is also a modification of the "Drop Method" discussed later, but the accuracy of the results is not directly dependent on the value of the current employed. As this device is in the nature of a permanent fixture and a special operator is generally employed for its use, further explanation is not considered necessary.

The instructions, already given, in reference to contacts, plugs, slide wire, etc., also apply here. If a slide wire bridge is not provided with a roller the contact *must not be moved* until it is released from the wire. Failure to observe this will soon ruin the wire, especially if of small diameter.

Drop Method (Direct Current)

For this method current and potential measuring instruments of suitable ranges are required, *simultaneous readings* being taken on each; from these readings the resistance is calculated by Ohm's Law ($R=\frac{E}{I}$).

The principal points for consideration are those relating to the location of the instruments, their influence on each other, etc., and also relating to the proper choice of the capacity of the instrument for a given purpose. The Current Standard must be connected in series with the resistance to be measured, and, where practicable, a suitable adjustable resistance for controlling the current. The volt standard is connected across the resistance to be measured, so as to measure its potential drop. A non-inductive resistance may be connected in series with the voltmeter to alter its sensitiveness if required. This resistance should have a current capacity equal to that of the voltmeter.

The instruments should be so chosen that the deflections obtained are reasonably large, in order to reduce the error of observation as much as possible. The current used should be sufficient to give a good deflection on the ammeter. It must not, however, be great enough to heat the resistance under test and thereby change its resistance. This point is very important and frequently overlooked; the greater the temperature coefficient of the material of the resistance the more important it becomes. If the current employed in making the measurement is not steady, two observers should make observations, one reading the ammeter and the other the voltmeter. Simultaneous readings should be taken, each reading being repeated several times, the average reading being used to determine the final result. Neglect in considering the ratio of the resistance of the voltmeter used to that of the apparatus under test sometimes introduces errors. If the ratio is large (2000 or more) the law of divided circuits can be neglected and result obtained from Ohm's Law as previously stated. If the ratio is small, allowance must be made, since a part of the current is shunted through the voltmeter, which is also measured by the ammeter.

HIGH RESISTANCE MEASUREMENTS

Under this heading "High Resistance D-C. Voltmeter," and "Insulation Resistance Measuring Sets," are considered.

D-C. Voltmeter

A high resistance instrument (50,000 ohms or more) is generally used for high resistance measurements. For lower resistances, lower voltages and a lower resistance voltmeter may be used. The Weston ohmmeter belongs to this class. In these cases the deflection on the voltmeter is directly proportional to the current flowing through it, and inversely proportional to the resistance of the circuit with constant potential across it.

A constant potential of about 500 volts is usually employed. This voltage reading is determined by connecting the terminals of the supply directly to the voltmeter and a second reading made and noted. The resistance X is then given by the formula $\frac{R_m}{R_m+X}=\frac{D_m}{V}$; where $R_m+X=\frac{VR_m}{D_m}$; R_m = resistance of the voltmeter used; D_m the deflection of the voltmeter with resistance in series; V the voltage of the supply when taking reading D_m; and X is the resistance sought.

If the value of X is large relative to R_m it is not generally necessary to subtract R_m to get X, and this is not done.

In making these measurements do not attempt to use a voltmeter which reads lower than the voltage of supply, as in case the resistance is omitted the instrument is likely to burn out. Do not try to get results by this method unless the supply is steady and constant or a second instrument is available connected directly to the line all the time with a second observer for taking simultaneous readings. When two instruments are used do not get their resistance values mixed; the resistance of the instrument reading the voltage is immaterial.

A suitable reflecting galvanometer calibrated to read in volts may be used in place of the voltmeter. The method and calculations are the same as described above.

INSULATION RESISTANCE TESTING SETS

The principle of operation is similar to that of the D-C. voltmeter, a shunt box being added to increase the range of the galvanometer which is used in place of the voltmeter in the other method.

The galvanometer constant $K=\frac{D\times S\times R\times C_2}{10^6\times C}$ and the resistance $=\frac{K_2}{D_2S}$ where D = deflection of galvanometer when taking constant; D_2 when making observation; S = multiplying factor for shunt; R = resistance in series when taking constant; C and C_2 = number of cells used when taking constant and observation respectively.

Complete instructions are furnished with the portable outfit when sent out. The permanent outfits work on the same principle and are generally installed with other testing apparatus where a special operator is available.

The following points should be mentioned. The various parts of the entire outfit, including the connecting wires (both internal and external), must be properly insulated from each other and from earth to prevent leakages. If this is not done, leakage currents may pass through the galvanometer and not through the resistance being measured, thus falsifying the results.

If the resistance being measured lies between the earth and some conductor, as is the case with a lead covered cable, one side of the galvanometer should be connected directly to earth taking precaution to insulate the rest of the circuit well. To form an earth, a bare wire may be used grounded to earth, to which one side of the galvanometer is connected. With this arrangement, if any leakage occurs, the leakage current is shunted by the galvanometer and does not affect the readings. Where possible, leakage should be eliminated, but reasonably correct results can be obtained by testing, changing over the corrections and averaging the results.

When making insulation tests on cables tests should be made for earth currents. To do this, disconnect the battery and short circuit the terminals to which the battery was connected. Then, connect to ground and to line and observe the galvanometer deflection. If there is no deflection no leakage currents exist, if there is a deflection of constant direction and amount a dead resistance equal to the internal resistance of the battery can be substituted in place of the short circuiting wire and the amount and direction of the galvanometer deflection can again be observed. This deflection is added or subtracted from the deflection obtained when making the test, before dividing into the constant. Since the battery resistance is small compared to the resistance under test, it can usually be neglected and the deflection used as obtained with the short circuiting wire. If the earth currents are very appreciable or unsteady in amount or direction the test should not be taken until the conditions are more suitable.

Chloride of Silver Dry Cell Batteries are generally used to supply the current for these resistance measurements.

These cells are very quickly ruined by short-circuiting or using them on too low a resistance. The cells should never have less than 5000 ohms per cell connected in series with the circuit connected to them.

Never put wires or other material into the battery covers, which could short circuit the cells. The space between the covers and cell tops may seem to be a convenient place to carry spare wire but this practice causes trouble. Abrasion of the insulation on the lead wires supplied with the batteries may short circuit the cells, and must not be allowed.

The cells should be tested before using to see that they are in good order (giving about 0.8 to 1 volt). In any case the e.m.fs. of the two cells must be sufficient to allow the operator to get correct results. The resistance of the voltmeter used should be at least 5000 ohms, or if several cells in series are tested at once, the voltmeter resistance in ohms must be at least 5000 times the number of cells tested in series.

It frequently happens that some of the cells in a battery give only a fraction of their proper voltage; in such cases the voltage of each individual cell must be considered when making a test, and the total voltage must not be estimated merely from the number of cells in use.

Wherever possible, cells below normal voltage should be rejected and replaced by new cells.

When an outfit is permanently installed, the Marcusson portable testing battery is satisfactory for insulation work if a considerable number of tests have to be made or heavy currents are required, as they will withstand rough usage. As the voltage of these cells are higher (being about 2¼ volts per cell) than that of the Chloride of Silver cell, fewer are required.

Measurement of Electromotive Force

The primary standard of e.m.f. as established by the National Bureau of Standards is the Weston Normal Cell which has a voltage of 1.0183 volts. However, for practical work the Weston Standard Cell is used, whose e.m.f. should be determined and certified to by the National Bureau of Standards. To compare an e.m.f. directly with the standard, the potentiometer is used.

In the potentiometer the e.m.f. of the standard cell is balanced against the drop of potential caused by passing current through the potentiometer shunt from a storage cell. This shunt consists of a series of adjusted resistance coils and a slide wire marked to scale. By setting the contacts of the circuit containing the galvanometer and the standard cell at scale points indicating the exact voltage of the standard cell, and adjusting the storage battery until the circuit balances and the galvanometer reads zero, the potentiometer becomes direct reading. Any external voltage not exceeding 1.5 volts may then be read by balancing it against the drop across a suitable part of the potentiometer shunt. For extreme accuracy a small correction is made to allow for known variations in the resistance of the various sections of the slide wire. To measure higher voltages a multiplier is used which will reduce 15, 150 or 750 volts to the 1.5 volts required for the potentiometer.

For a working standard of direct voltage a G.E. laboratory standard voltmeter is used, and for alternating voltage a Weston standard voltmeter. These are frequently calibrated to the primary standard. In the case of the A-C. instrument, reversed readings are made in calibration, to insure agreement between A-C. readings and D-C. calibrations. The instruments to be calibrated are compared with the working standards, by means of a system of multipliers which give the necessary range to the working standard.

For the measurement of direct voltages, two kinds of voltmeters are used, Weston, and Thomson D-T. These give a range from 1 to 750 volts with full scale reading. Both operate by the torque produced on a movable coil carrying current located in the field of a permanent magnet. A very powerful stray field may, however, partially demagnetize or cross magnetize the instrument and permanently change its calibration. Some voltmeters are shielded and some are not. The non-shielded meters are easily affected by stray fields. Weston instruments are ironclad and D-P. are not easily affected. Both types are also made as millivoltmeters with low resistances, reading from .200 millivolts up.

Never connect any instrument marked "Millivoltmeter" or "Special Meter" across higher voltage than it reads otherwise the instrument will burn out. To measure voltage higher than the capacity of the instrument a multiplier may be placed in series with it. Then if E is the corrected reading of the voltmeter, V the voltage to be measured, R_v and R_m the resistances of the voltmeter and of the multiplier,

$$V = E \times \frac{R_v + R_m}{R_v}$$

or, two voltmeters may be placed in series and careful simultaneous readings taken; the sum of the two corrected readings is the voltage to be measured. One of the two voltmeters may be considered as a multiplier for the other; then if E_1 and E_2 are the corrected readings on the two instruments at one point, and E is the corrected reading on the first instrument at any other point,

$$V = E \times \frac{E_1 + E_2}{E_1}$$

For all D-C. instruments, the Standardizing Laboratory gives a constant K, such that if V = corrected voltage and E = reading of the instrument,

$$V = K \times E$$

From this $E = \frac{V}{K}$

Therefore, to obtain the reading on the instrument which corresponds to the voltage required, divide the correct voltage by the constant of the instrument. Since these constants are never far from unity, the equation

$$E = (2 - K) \times V = V + (1 - K) \times V$$

is nearly true. This is the most convenient method for getting the proper reading.

Illustration: 110 volts required $K = 1.003$

$$\begin{aligned} E &= V + (1 - K) \times V \\ &= 110 + (1 - 1.003) \times 110 \\ &= 110 - .003 \times 110 \\ &= 109.67 \end{aligned}$$

Most instruments used in the test are provided with a mirror under the needle. To eliminate parallax and obtain the correct reading, sight the needle when it exactly covers its mirror image, then without altering the position, read the intersection of the needle with the inner scale circle. It should be remembered that while the scale on most D-C. instruments is equally divided, so that the errors of observation are nearly the same in actual amount in all parts of the scale, the percentage error varies inversely with the deflection. Hence when accuracy is required, the instrument must not be read at a low point on the scale.

Before using any instrument, it should be carefully inspected to determine whether the needle is free and rests at zero. No instrument which sticks at any part of the scale should be used nor should an instrument be used which has a zero error. D-C. voltmeters should be disconnected from field circuits while the field switch is being opened, because of the inductive kick, which frequently bends the needle. They should also be disconnected from synchronous motor or rotary fields, while the machines are starting from the A-C. side because of the high alternating voltage developed by transformer action in the field windings during starting. This voltage will sometimes puncture or burn out a voltmeter.

A voltmeter should always be connected through a double-pole switch, and should be kept out of circuit when not in use, as its readings may change with long continued heating. The cover glass should never be rubbed before reading on account of the electrostatic effect on the needle. If a cover glass shows electrification. it may be discharged by moistening it with the breath. No moisture should be allowed to reach the inside of the instrument.

Cables carrying heavy currents, whether D-C. or A-C., should be kept close together. They must never pass on opposite sides of a machine standing on an iron floor. If an instrument reads alike in four positions 90° apart, it is unaffected by stray fields. Protection from stray fields is sometimes obtained by placing the instrument in an open topped iron box. This is an efficient protection as far as the stray fields are concerned, but the readings of the instrument may be slightly changed by the proximity of the iron to the field of the instrument.

For all A-C. instruments the Standardizing Laboratory furnishes curves of calibration, in which the instrument reading is plotted against the reading of a correct standard. These curves should be used to correct readings and to determine the proper reading for any voltage required.

Potential Transformers

For most commercial alternating voltages a 130 or 150 volt voltmeter is used in connection with a potential transformer.

Transformers are designed for use from 25 cycles upward. They are calibrated with a load of a single instrument, and should not be loaded with more than two instruments nor used, at 25 cycles, above the normal rated transformer voltage of the particular connection employed if accurate results are desired. When used below 25 cycles, the voltage at which reasonable accuracy may be secured varies directly with the frequency. The transformer primary must be connected to the lines and the secondary to the instruments.

The cases of iron potential transformers should always be grounded. No changes should ever be made in connections with the high potential on.

Care should be taken that voltage leads are always connected to the points between which the difference of potential is to be read. Thus, in reading volts across the armature on a compound wound D-C. machine, the leads should be attached to the brushes, while in reading volts across the machine they should be attached the outer end of the series field and the·brush ring of opposite polarity. In any circuit where voltage drop is measured, the resistance of an extra connection in the main current circuit included between the voltmeter contacts is often sufficient to cause serious error. Only the voltmeter current should flow through the voltmeter leads.

Measurement of Current

The primary standard of current is the silver voltameter, which is used for comparison occasionally. The practical standard used is a set of standard resistances very accurately calibrated. The voltage drop across these resistances is measured by the potentiometer, the result being a direct measure of current. Slight corrections are made for the slide wire and the resistance of the external shunt.

A special standard millivoltmeter with a set of shunts attached constitutes the working standard of direct current. The working standards for alternating current include a series of Kelvin balances covering a wide range of currents. The working standards are calibrated from the potentiometer, reversed readings being used for the balances. The portable instruments are compared with the working standards.

In reading a special meter attached to a shunt, assume the end of the scale to represent the rated amperes of the shunt, and read the result accordingly. To correct for instrument error, multiply by the instrument constant. To correct for the shunt error, multiply by $\frac{E}{IR}$, where E = rated volts drop of the shunt, I = rated current of the shunt, and R = actual resistance of the shunt. This correction is very small, and may usually be neglected.

For measuring current beyond the capacities of the instruments at hand, two ammeters may be placed in multiple; but both instruments must be read simultaneously at every point. If two shunts are used in multiple, special meters must be connected to each and readings taken on both.

For the measurement of alternating current, Types P and P3 are used. The general statements as to voltmeter and P3 are used. The general statements as to voltmeters apply equally to ammeters of the same type. The ammeters are somewhat more likely to produce stray fields, especially the high current instruments. Ammeters should be protected by a short circuiting switch, which is kept closed except when reading.

The usual method of measuring high alternating currents is by using current transformers in connection with low reading ammeters. The standard commercial G. E. transformers have a 5 ampere secondary. The secondary should not carry more current than that required by two instruments. The secondary circuit of a current transformer must never be open while current flows through the primary. If this precaution is not taken, there is danger of the transformer overheating and thereby breaking down the insulation. There is also danger to anyone handling the secondary, owing to its now high voltage. All these transformers can be used on circuits operating at 25 to 125 cycles.

To measure the currents in a three-phase circuit, two equally rated current transformers and three ammeters are necessary. The primaries of the two transformers are placed in two of the lines, connecting one lead of one secondary to the lead of corresponding polarity of the other secondary and joining the two remaining leads with a short-circuiting wire. One ammeter is placed in each of the two separate transformer secondary circuits; the third ammeter goes in the short-circuiting line, and reads the current in the third phase.

Measurement of Power

There is no primary standard of electrical power in practical use. Wattmeters are used which are calibrated from the standards of current and electromotive force. For D-C. calibration, 100 volts, as given by a laboratory standard voltmeter, is applied to the potential circuit of the wattmeter, and current measured on a standard ammeter is sent through wattmeter current circuit. The product of the volts and amperes gives the true watts, which are plotted against the readings of the instrument. For A-C. calibration at unity power factor, readings are taken direct and reversed and the average reading is used. If a calibration at low power factor is required, the phase position of the voltage on the instrument is regulated by means of a phase shifter while the readings are compared with those of a calibrated dynamometer.

Never apply more than the rated voltage to the potential circuit. The current circuit will carry up to three times the rated amperes for a short time. The accuracy of the wattmeter depends but slightly on the ratio of current and potential applied. To correct a reading of a wattmeter, compare with the calibration curve. Current and potential transformers may be used with wattmeters where current or potential is larger than rated. If R_w is the reading of the wattmeter, C the ratio of the current transformer, and P the ratio of the potential transformer,

$$\text{True watts} = P \times C \times R_w$$

When wattmeters are used with current or potential transformers, the potential circuit, current circuit, and case of the wattmeter should be connected together with a light fuse wire, to prevent differences of potential between the coils and case. If a wattmeter potential circuit is not absolutely noninductive, the current in it will have a slight phase displacement relative to the voltage across the wattmeter terminals. This is equivalent to a change in the phase angle between the voltage and current of the main circuit as read on the wattmeter. Hence, wattmeters are subject to an error, from which ammeters and voltmeters are free. If a current and a potential transformer are used there is usually a further phase difference between primary and secondary current in the former, and between primary and secondary voltage in the latter. The result of these three angular changes is a change in the phase relation in the wattmeter. The The total change rarely exceeds 2°, and is frequently less than 30′. At or near unity power factor its effect on the reading is inappreciable; but at a very low power factor large errors may result. Where special accuracy on wattmeter work on low power factor is required, the matter should be referred to the laboratory.

In measuring the watts in a two-phase circuit, each phase should be considered as a separate single-phase circuit. The sum of the readings on two wattmeters gives the total watts.

In a three-phase circuit two wattmeters should be used. The current coils should be placed in two of the lines and each potential coil connected from that line in which its current circuit is placed, to the third line. The algebraic sum of the wattmeter readings gives the total watts. The higher reading wattmeter is always positive; the lower reading is positive if the power factor is above 0.5, negative if it is below 0.5. To determine by test whether this latter reading is positive or negative, open the line to which the wattmeter in question is not connected. This leaves a single-phase circuit on the wattmeter; if the wattmeter still reads forward, it will give positive values on the three-phase connection. If it reads backward, it gives negative readings on three-phase.

The watts in a three-phase circuit may also be read with three wattmeters. In this case a Y-box consisting of three equal resistances starting from a common or Y point is connected to the three lines. The Y point then becomes a netural point for the three lines. A wattmeter is connected in each line, and its potential circuit is connected from its own line to the Y point.

When reading a small power at a moderately high voltage on a wattmeter, the wattmeter reading may be affected by the losses in the instrument itself. If the current flowing in the voltage circuit of the wattmeter passes also through the current coil, the wattmeter reads the losses in its potential coil. If a voltmeter is similarly connected, the wattmeter reads its losses also. If E is the applied voltage and R the resistance of the loss circuit, then, since the circuit is practically noninductive, loss $= \frac{E^2}{R}$.

If the wattmeter and voltmeter are so connected as to prevent the current in the potential circuits from flowing through the current coil, the wattmeter reads the losses in its current coil, and the voltmeter reads the drop through the wattmeter current coil in addition to the voltage across the load. These errors are nearly always negligible. If the wattmeter reads the losses in potential circuits, a measure of the amount of the losses may be had by reading the wattmeter, after opening the load circuit so as to leave all instruments connected to the main lines. This is called reading stray power, and is a good check for leakage losses.

Measurement of Power Factor

The power factor of a single-phase circuit $= \frac{\text{Watts}}{\text{volts} \times \text{amps.}}$. There is no single-phase power factor meter which is independent of frequency through any considerable range. The power factor is therefore usually obtained by the use of voltmeter, ammeter and wattmeter.

In a balanced three-phase circuit, the power factor may be obtained from the two wattmeter readings. If a is the phase angle, the power factor $= \cos a$, and R is the ratio of the smaller to the greater wattmeter reading,

$$Tan\ a = \frac{1-R}{1+R}\sqrt{3}$$

The principle of the G-E. balanced three-phase power factor meter uses this fact. The elements of two wattmeters are so combined into one instrument that the position of the pointer depends on the ratio of the watts. The instrument is quite accurate, and practically independent of frequency.

The volt amperes in a balanced three-phase circuit are equal to the product of the amperes per line, the volts, between lines, and the square root of three.

CHAPTER II

TESTING FOR OPEN-CIRCUITS, SHORT-CIRCUITS, POLARITY, AIR-GAP

In the manufacture of armatures and fields for electrical apparatus, possible defects in material and errors of workmen can often be disclosed by what may be termed "stationary testing." Defects and errors may arise as follows: Through a wrong application of, or mechanical faults in, insulation; the use of wrong material for conductors, leads, etc.; wrong assembly of connections (workmen's mistakes).

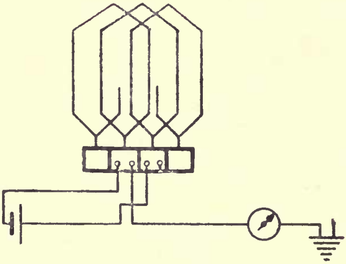


Fig. 1. Testing for Grounds

Direct corrent armatures are tested for grounds, short circuits, open circuits, and high resistance joints before being sent to the Testing Department. In testing for grounds a high potential is applied between winding and core; the potential depending upon the class of apparatus tested. When a ground develops in test it can usually be located by smoking the insulation at the breakdown point.

If a low resistance ground has developed it may be quickly and accurately located by the following method:

A low voltage current sufficient to give a readable deflection on a galvanometer or millivoltmeter (Fig. 1) is passed through the armature winding from a commutator bar to one adjacent to it. A connection is made from one side of a galvanometer "to ground", the lead from the other terminal of the galvanometer being placed on one of the commutator bars. The supply leads and galvanometer lead are then passed from segment to segment, until first a full deflection is obtained and then zero reading when the leads are removed one segment further. The grounded coil then lies *between* the bars for which full deflection was obtained.

A bar to bar test is usually made to disclose short circuits, open circuits, and other similar faults. For this test the windings connected to two adjacent commutator segments have their resistance measured by the "drop of potential method," as indicated in Fig. 2. Storage batteries and a special electro-magnetic d'Arsonval galvanometer should be used. With this arrangement readings can be obtained rapidly, as the instrument is "dead beat."

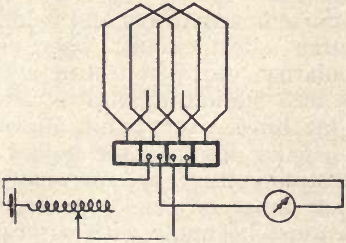


Fig. 2. Testing for Open Circuit

Measuring the ohmic resistance of the winding will sometimes reveal a wrong connection, which, on a bar to bar measurement, would give a uniform deflection all around the commutator. Series or wave windings may sometimes have all the conductors joined in series, but in the wrong order, so that the armature is inoperative. In the case of multiple or lap windings, double, triple or even quadruple spiral re-entrant windings are possible, whereas a single spiral is what is wanted. In taking a resistance measurement for brush to brush, or running resistance of the armature, see that the measurement is made from the proper commutator segments. For multiple or lap windings, the resistance measured from diametrically opposite points divided by half the number of poles squared will give the true running resistance, while with a series or wave winding the resistance should always be taken at points 180 electrical degrees apart. For example, take a four-pole armature with a lap winding and 360 commutator segments. This armature should have its resistance measured between bars No. 1 and No. 181. This resistance divided by four will give the running resistance. With a wave winding on the same armature, the resistance measurement should be taken between bars No. 1 and No. 91, this resistance being the true running resistance.

Alternating current armatures and fields are similarly tested for grounds, short circuits, open circuits, wrong connections, polarity, etc. In testing for grounds the same methods and similar apparatus are used as for direct current machines, except that alternating current machines are usually designed for higher voltages, and consequently testing voltages are correspondingly higher, and greater care must be taken in testing. All high potential tests must be made with carefully calibrated electrostatic voltmeters that have been checked with a spark gap. The testing equipment should be as near the apparatus as possible, since the additional capacity of testing lines may raise the voltage at the receiving end much above that at the generating end. Unless this precaution is taken, excessive voltages may be applied which may damage the insulation. In case a ground develops, a resistance measurement will generally locate the point at which it occurs, unless each phase has two or more multiple circuits. In the latter case it may be more readily located by opening one or more cable joints and separating the circuits.

A measurement may be taken in the following manner: First, measure the total resistance of the grounded circuit or phase; second, measure the resistance of the winding from one terminal to ground, by connecting one side of the measuring line to the terminal and the other side to ground; third, measure the resistance from the other terminal to ground, by shifting the measuring line from the first terminal to the second. If all measurements have been accurately made, the sum of the second and third will be equal to the first, and the location of the ground will be as far from one terminal, expressed in terms of the total strength of the winding, as the measured resistance from that terminal to ground is to the total resistance of the circuit.

This test is outlined in Fig. 3, which represents a single circuit, or phase, of an alternating current machine,

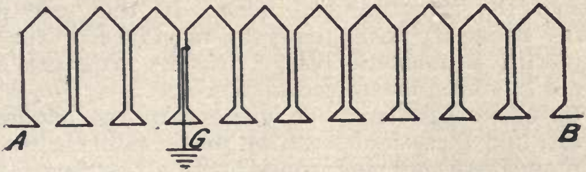


Fig. 3. Test for Grounds on an A-C. Armature

with a ground as shown. If the resistance between A and B is one ohm, between A and G 0.35 ohm, and between B and G 0.65 ohm, the location of the ground is 35/100 of the distance between A and B, from A. As 10 coils are in the circuit, the measurements show that the fourth coil is grounded, counting from A.

In the case of an alternating current winding the ohmic resistance measurement will not always detect a wrong connection, such as a reversed coil, pole section, or phase; the copper resistance measurement would be correct, although the total winding might be partly reversed and therefore, inoperative. Such faults may be discovered by a polarity or impedance test with alternating current. For this purpose a single-phase current can be used, since a reading may be taken on the different circuits, or between pairs of terminals successively, by shifting the testing lines until the whole winding has been tested.

Short circuited coils on moderate size machines can be readily detected by using a wound electro-magnetic yoke excited with alternating current. This yoke is dropped over a portion of the armature coil after the coils have been placed in their slots. The yoke and armature form an alternating current transformer, with the yoke winding as primary and the armature coil as secondary. If there is a short circuited turn, layer, or coil in the armature, the magnetizing current in the yoke winding rises. If the current is maintained a short time, the insulation on the short circuited section will warm up appreciably, or burn sufficiently to indicate the defective coil.

On larger size alternator armatures, tests may be made for short circuits by passing alternating current through the armature coil itself. In this case it is usually necessary to increase the reactance of the coil by placing a magnetic bridge over its armature slots after it has been assembled in the core.

The above tests may be made with the apparatus at rest, and these faults can be more readily corrected when apparatus is being wound, with a resulting saving in time and cost. However, the test may be equally well employed after the apparatus is completed.

Practically all direct current machines are delivered to the Testing Department unassembled, with few exceptions.

To assemble a machine, the field spools are first mounted upon the frame and connected up in accordance with the connection print which is furnished for each machine. As soon as this is done, the windings are tested electrically for resistance and insulation; the polarity of the poles is also tested by exciting the field coils. These tests check the assembly of spools and their position upon the frame.

In testing field coils for polarity, all field windings must be tested separately to ascertain if the series and shunt commutating pole windings are wound and assembled correctly. Polarity may be tested by means of a compass, in which case the compass must not be carried too near to the pole, otherwise it may be demagnetized or even reversed. To test for opposite polarity of alternate poles, two pole tips may be bridged with a piece of soft iron. If the polarity of the poles differ, the piece will be strongly attracted; whereas, if the poles are of like sign, a much less attraction will be exerted.

On direct current machines, the voltage drop per spool with a given current flowing through the field should not vary more than a few per cent (maximum to minimum) from the average voltage drop per spool The field spools for alternating current apparatus are assembled on the field spider in the Armature Department; hence, it is only necessary to take a resistance measurement per spool before starting a test. The variation between maximum and minimum drop per spool should not differ materially from the average drop per spool. In recording the drop on spools, the spools should be numbered in a clockwise direction, beginning at the spool next to the opening in the shunt field when facing the commutator. When testing a machine, a very careful record must be kept of all winding resistances. Many armatures are fitted with equalizing rings, and it is impossible to obtain the true armature resistance without disconnecting the equalizer taps.

The shunt field resistance is obtained by the "drop method," using an ammeter and voltmeter. This measurement is required on each machine before a test is started. For measuring the series field resistance a special galvanometer measuring set is used. As a considerable amount of the resistance of a series field may consist of the contact resistances of the joints between the spools, all connections must be carefully cleaned and clamped tightly together before measuring the resistance.

The measurement of air gaps on all apparatus is important. Air gaps on direct current machines are measured in the following manner: With the armature stationary, the gap under all poles should be measured at both the commutator and pulley ends, the measuring scale being inserted under each pole tip, without including the chamfer of the tip. A mark should then be placed on the armature circumference under the center of a given pole, and the armature revolved through one pole span. The air gap measurement adjacent to the position of the mark on the armature should then be taken on the commutator end and so on for succeeding poles. The first set of measurements is known as the "stationary gap"; the second set as the "revolving gap."

The maximum air gap on direct current machines, when measured from iron to iron, should not differ from the minimum air gap by more than a few per cent of the average measurement, and but little more when measured from the armature binding wire to the iron of the pole piece.

On commutating pole machines the air gap measurement is taken under the center of the commutating pole. It is also necessary to measure the distance between the tip of each commutating pole and the adjacent tip of the main pole. This spacing should be uniform.

Air gap measurements are taken on alternating current machines in a manner similar to that described above for "stationary" and "revolving gap" on direct current machines; except that the air gap measurement on a-c. machines is taken at the center of the pole piece, both on the front and back ends. In measuring the "revolving gap," it is not necessary to take the air gap measurement under each pole. The measurement need only be taken at points spaced 45 degrees apart. That is, eight (8) sets of measurements are required for the "revolving gap."

Since the air gaps of induction motors are small, and a uniform gap is important, they are measured by special gauges provided for the purpose. These gauges are passed completely through the motor air gap from end to end of the punchings, measurements being taken at several points about the circumference of the rotor while stationary and while revolved in a manner similar to that described above.

When air gap measurements are taken, a critical inspection should be made of the clearance between the rotor and windings or other parts, to insure that it is sufficient to allow the machine to operate without any surfaces striking or rubbing together. This difficulty may occur if the windings project beyond the punchings unnecessarily far. In no case should the machines be started until proper clearances are obtained.

When apparatus is first started it should be brought to speed very slowly and carefully watched to see that everything is correct as the speed increases to normal value. Reliable tachometers, or speed indicating devices should be used in starting to prevent a dangerous increase of speed. Oil rings must be examined at slow speed to see if they are carrying sufficient oil to the bearings. In the majority of cases, oil rings should turn at ¼ speed, and properly lubricate the bearings.

The balance of the rotating parts should be carefully noted until the machine has reached its normal rated speed. If the apparatus does not run without vibration the matter must be remedied before the test proceeds. Vibration due to the running of the machine may indicate lack of balance, whereas it may really be due to improper alignment, or to springing of the shaft. When unbalancing occurs in operating machines running above 1200 r.p.m., correction must be made by dynamic balancing.

CHAPTER III

SATURATION TESTS, GENERATOR, MOTOR, BALLISTIC

In order to ascertain the characteristics of the magnetic circuit, a test known as "saturation" is made. The characteristic curve may be obtained by any of the following methods: "generator saturation," "motor saturation," and "ballistic saturation."

The test usually made is "generator saturation." To obtain a saturation curve by this method, the machine is driven as a generator, preferably at constant speed. If, however, a set of readings is known for one speed, they can be obtained for any other by direct proportion. Hence a saturation curve taken at any constant speed at once gives the saturation curve at any other speed. On direct current machines the brushes should always be set on the neutral point when taking a no-load saturation.

In taking a saturation curve on polyphase alternating current generators, a reading of the voltage across each phase must be taken at normal field current, to ascertain if the phases are properly balanced. If they do not balance, an error in the armature is indicated, which must be corrected. On rotary converters careful readings should be taken of the direct current voltage, as well as the alternating current voltage between all phases, with the field excitation giving normal voltage. The phase voltages must be also closely balanced.

Generator Saturation

The usual method of taking a generator saturation curve is to hold the speed constant and increase the field current step by step until at least 125 per ecnt of the normal voltage of the machine is reached, taking simultaneous readings at each step of volts armature, volts field, and amperes field. After reaching the maximum value of the field current, without opening the field reduce the current gradually in four or five steps, again taking readings to determine the value of the residual magnetism at various points along the curve. Special care should be taken to insure accurate readings at and above normal voltage, since with alternating current generators, this is the portion of the curve used for calculating the regulation under load. Whenever saturation curves are taken, a record of the air gap from iron to iron should be made upon the record sheet. The length and circumference of spools should also be entered, together with the armature and field specifications.

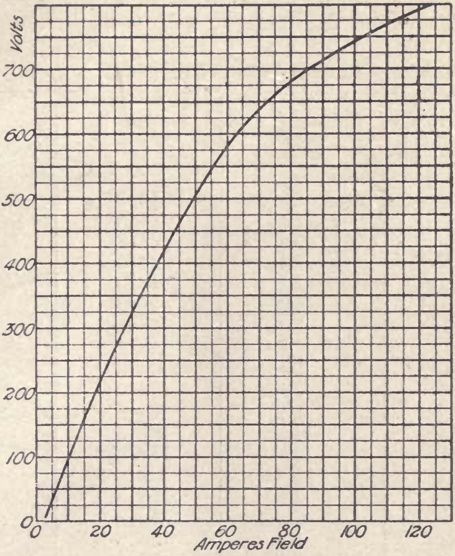


Fig. 4. Saturation Curve on a 500 Kw., 600 Volt, 20-Pole, 360 R.P.M. 3-Phase, 60 Cycle, A-C. Generator

Motor Saturation

When it is inconvenient or impossible to drive the machine as a generator, a motor saturation may be made. In this case the machine is operated as a free running motor. The driving power must be furnished from a variable voltage circuit. A certain voltage is impressed upon the armature, and the motor field weakened or increased in the case of direct current machines until normal speed is obtained, when a record is made of the volts armature, amperes armature, amperes field, volts field, and speed. The starting voltage should be at least 50 per cent lower than the normal voltage of the apparatus. The applied voltage at the armature should be increased by steps to 25 per cent above normal value, and the field increased correspondingly to keep the speed constant; the same readings being recorded at the various steps as before. Readings should also be taken at three or four points as the impressed voltage and field current are lowered to approximately the value at the beginning of the test.

TABLE I—SATURATION

Votls Arm.	Volts Field	Amps. Field	Speed R.P.M.
192	25	18.0	360
228	29	21.0	360
253	32	23.2	360
304	38	29.0	360
416	52	40.0	360
495	62	48.9	360
542	70	55.1	360
579	75	59.8	360
597 597	79	62.0	360
597	79	62.0	360
614	83	65.4	360
707	110	87.5	360
785	146	117.0	360
755	130	102.0	360
555	74	55.5	360
453	57	43.6	360
287	35	26.3	360
178	26	16.1	360

When testing direct current apparatus in the above manner care should be taken to see that excessive speeds do not result from unstable electrical conditions, and the circuit breaker controlling the motor should therefore be so arranged that it can be readily operated by the tester reading the speed.

On alternating current apparatus, the machine is run as a motor and the impressed voltage varied as already described. The speed is independent of the motor field in this case, and instead of regulating the motor field for speed, it should be regulated to give minimum input current at each voltage. Readings should be taken of voltage impressed, amperes armature, amperes field, and volts field. With induction motors it is only necessary to impress variable voltages at constant frequency and record readings of volts armature, impressed amperes armature, and speed.

The calculation of saturation tests is very simple, as it only consists of applying instrument correction factors and ratios, and plotting upon coördinate paper, volts armature as ordinates and amperes field as abscissæ. Fig. 4, which is plotted from the values given in Table I, shows the results of a saturation test made by one of the above methods.

Ballistic Saturation

In order to make a generator or motor saturation test, the machine must run at, or near, its normal speed. Sometimes it is desirable to test for saturation without the delay and expense of setting up and operating the machine. In this case a test known as "ballistic saturation" can be used, obtained as follows:

First, a machine of given armature winding, armature core, and field structure is operated for a running saturation test as already described. The machine is then shut down and its brushes shifted 90 electrical degrees from their no-load neutral position when the machine was running. The shunt field of the machine is wired to a source of excitation and provided with a field reversing switch so that the field circuit may be quickly opened and reversed. This permits of the field current being interrupted at any value, quickly reversed, and allowed to rise to the same value again. Leads from a ballistic galvanometer are then connected to the armature directly under the center of the brushes of two adjacent studs, all other brushes being removed. The galvanometer circuit should have a resistance such that the voltage induced in the armature, when the field is broken at a maximum current value and reversed, is just sufficient to give the maximum scale deflection on the ballistic galvanometer.

A ballistic curve may then be obtained, from which the running saturation curve can be readily derived. Galvanometer readings are taken at a number of field current values, as in the running saturation tests. The magnetic flux due to each current value is proportional to the induced voltage in the armature when the field is broken and reversed by means of the reversing switch. Hence, if the galvanometer deflections are plotted with the field current, with the former as ordinates, a curve similar to the running saturation curve will be obtained.

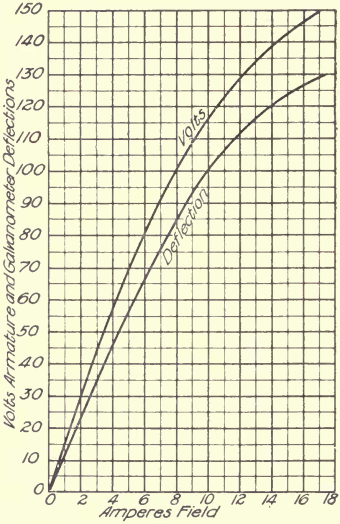


Fig. 5. Ballistic and Running Saturation on a 75 Kw., 125 Volt, 6-Pole, 375 R.P.M. Compound Wound D-C. Generator

This curve bears a definite relation to the running saturation curve, depending upon the armature windings, leakage, coefficient, galvanometer constant and resistance of the galvanometer circuit. Before taking galvanometer readings at a given field current value, the field current should be reversed one or more times in order to obtain the same magnetic conditions as were obtained in the running saturation curve. Unless this precaution is observed, the saturation curve will not agree closely with the running saturation test of the same machine.

The running saturation for any machine may be calculated from the machine constants and this test, without further information. Such a calculation is, however, somewhat involved, and uncertain. It is best to take the ratio of the galvanometer deflection for a given field current, to the armature voltage generated when the machine is running at normal speed with the same field current for excitation. This ratio will hold with sufficient accuracy for all practical purposes throughout the ballistic test, and hence allows of a ready determination of a running saturation curve being obtained on any machine which is a duplicate as regards armature winding and core, and field structure. This method may be used to great advantage to check up individual standard machines and insure that the magnetic circuit and windings are correct. Similar machines should be tested with the same galvanometer and resistance values.

To obtain the ballistic curve, the armature need only be wedged central with the field bore by wooden or composition wedges to obtain a uniform air gap. Fig. 5 shows the results of a ballistic test and running saturation test.

CHAPTER IV

CORE LOSS TESTS, OPEN-CIRCUIT, SHORT-CIRCUIT, DECELERATION

Three methods are used to measure the core losses on rotating direct current apparatus and alternating synchronous apparatus. They are known as follows: "running light core loss," "belted core loss," and "deceleration core loss." The "running light" test is made on all direct current generators and motors which are given a running test. It is occasionally, though not frequently, employed with alternating current synchrouons apparatus.

The following conditions must obtain with direct current apparatus in order to give satisfactory results: Brushes must be shifted on the commutator to the no-load neutral point; the spring tension must be normal, and the commutator clean, so that the normal operating commutator and brush friction values are obtained. This test, wherever possible, should be made after all the others have been finished, in order to have a glossy commutator, with its surface in good operating condition. The driving power should be supplied from a variable voltage circuit that is not subject to sudden fluctuation. Since the power input required to drive the machine running free as a motor must be obtained, its value must not be read when the rotating parts are either accelerating or decelerating. A steady voltage must be kept on the armature and the field current must have a constant value.

When "running light" tests are made on direct current generators, the observations must be made with full load field flux. The potential applied to the armature must be equal to the normal rated voltage of the generator, increased by the CR drop in the armature at full load. With this voltage impressed, the field current is varied until normal speed is obtained, when careful readings must be made of armature current, armature voltage, field current, field voltage and speed.

If the machine in test is a direct current motor, the voltage applied to the armature should be equal to the normal rated voltage of the motor, less the CR drop in the armature under full load. The field current is then adjusted to give normal speed, and electrical and speed readings taken as outlined above for direct current generators.

The power supplied to machines running free will equal that absorbed in bearing friction, brush friction, windage, and core loss, when the armature C^2R losses have been subtracted.

In making records of these tests, the testing record should clearly show whether the running light current consists of the armature current plus the shunt field current, or whether it is the armature current alone. To check this point, open the armature circuit with the shunt field circuit closed, and note whether any current is indicated on the ammeter, reading the power supplied. If no current is indicated, the reading indicates the armature current alone; otherwise, the running light current is equal to the sum of the armature and field currents. To obtain "running light" core loss tests, only a single field winding must be used for excitation; this must be a shunt field winding.

In order to obtain running light core loss upon alternating synchronous machines (in which class rotary converters are not included, as the core loss test on these machines is similar to that on direct current machines), they should be operated as synchronous motors at the proper frequency and rated voltage. For the best results, both frequency and voltage must have a steady value.

With normal voltage on the armature, the direct current field should be varied until minimum armature current is obtained. Readings should then be taken of amperes and voltage on all the phases. At minimum input current unity power-factor obtains, and therefore the power to drive such machines will be the volt-ampere input. Wattmeters may be used in addition to check the volt-ampere readings. This measurement includes friction and windage losses, together with open circuit core loss plus the C^2R loss in the armature. If the value of the core loss need not be separated from the other losses, the test is useful for checking up full load efficiencies. For direct current apparatus this test is obtained quickly and at less expense than by other more elaborate methods, and the results are just as accurate and satisfactory.

The "belted core loss" method separates the core loss from the bearing friction, brush friction and windage. A small direct current motor is used to drive the machine under test as a generator at its rated speed. A belt drive between these machines is most commonly used. However, wherever great accuracy or a high speed is necessary, direct driving by a coupling is often used.

The driving motor for this test must be carefully chosen. It must be operated with good commutation and with a fixed setting of the brushes, through the range of load required for the core loss test. Ordinarily, a safe rule to follow is that the motor should be of approximately 10 per cent of the capacity of the machine under test. The maximum load which this motor should carry with the heaviest field on the machine under test, should not exceed 50 per cent of its normal rated capacity. The driving motor should be operated as nearly as possible at its rated speed and field strength; the brushes should be carefully set at the best position for good commutation at all the loads required by the test; and the commutator surface should be in first class condition.

The weight and width of the belt must be selected to give minimum loss. When testing motor-generator sets, rotary converters, and other apparatus that do not use belts, the tension of the belt must be kept as low as practicable, so that the bearing friction is not increased due to the belt pull. Endless belts should be used in preference to laced belts.

The driving motor must be wired so that readings may be taken of amperes armature, amperes field, and speed. A reading should be taken on the motor corresponding to normal speed of the machine under test. The machine under test should be wired with its field separately excited and provision made for reading amperes field, volts field, and volts armature. Careful resistance measurements of the armature of the driving motor must be made previous to starting the test.

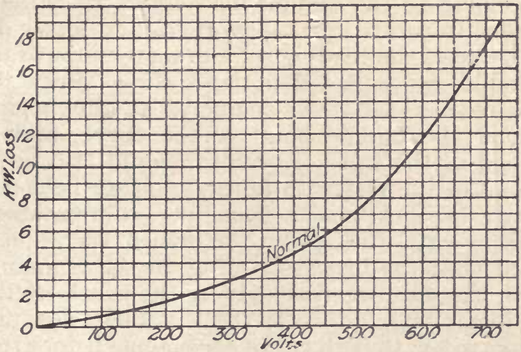


Fig. 6. Open Circuit Core Loss on a 500 Kw., 600 Volt, 20-Pole, 360 R.P.M. 3-Phase, 60 Cycle, A-C. Generator

The test is then carried out as follows: The field of the driving motor is adjusted to about normal value and excited from a source of constant voltage, so that its value may be held constant throughout the test. The speed of the driving motor is regulated by varying the voltage applied to its armature terminals. First run the driving motor and the machine under test a sufficient length of time to allow the friction to reach a constant value. This will obtain when the input on the driving motor becomes constant while driving the machine under test without any field excitation. Careful readings should then be taken, first of the input to the driving motor with the machine under test unexcited and all brushes down on the commutator; and second, with all brushes raised from the commutator of the machine under test. The difference between these two sets of readings will give the brush friction on the machine being tested. Starting with zero field on the machine under test, observations of the input to the driving motor should be made at various values of the field current, up to that which will give 125 per cent normal load voltage. Correcting the motor input at these various field strengths by subtracting the C^2R loss of the armature of the driving motor and the power input to the driving motor for zero field, the core loss corresponding to the various field strengths is found.

In order to insure constancy of friction losses during the entire test, the readings of the motor input for zero field should be repeated at least three times during the progress of the test; namely, at the beginning, again near the middle point of the curve, and lastly at the end of the test. Readings should also be taken at the end of the test with normal voltage field current and with brushes raised from the commutator, for comparison with the reading in which the same field was used with the brushes resting on the commutator, and with the set of readings giving the brush friction.

The tester should check these values, one against the other, to see that they are consistent, before turning in the results of the test. To check the results of the core loss as the test proceeds, the power input to the driving motor required by the core loss at a given excitation should be plotted against volts armature generated. This should give a curve similar to Fig. 6. If a satisfactory curve is obtained, the driving motor should be unbelted and a running free reading taken upon it, holding the same amperes field as were used during the test. The bearing friction and windage losses of the machine under test can be separated, if desired.

For a successful core loss test, all readings must be made at absolutely constant speed, when the rotating parts are neither accelerating nor decelerating. All values of field current must be held constant while taking readings. No pulsation or sudden variations must occur in the armature current of the driving motor, as these would vitiate the power readings.

In making out reports of core loss tests, the following data should be recorded in addition to the electrical readings already mentioned: Circumference of commutator; circumference of shunt and series field spools; height of shunt and series field spools; number and width of commutator bars; size and material of brushes; number of studs and brushes per stud; brush pressure per brush; rating of driving motor together with its armature and frame number; and the type, rating and number of the machine under test. On series motors core loss tests should be taken at several different speeds covering the range of the speed curve. The method used is identical with that described above, and will be considered in connection with railway and series motor tests.

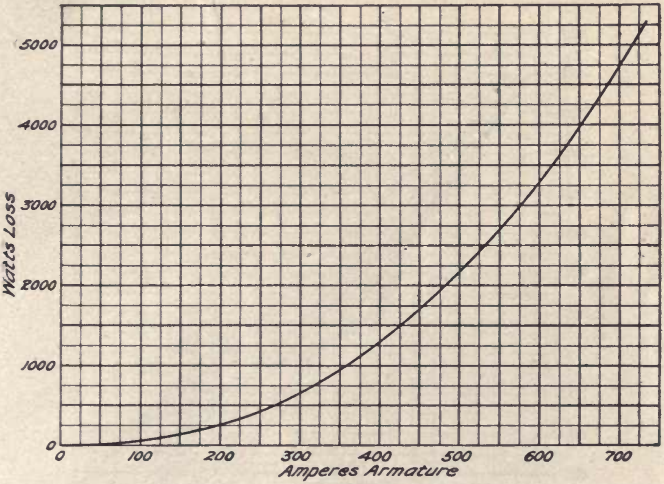


Fig. 7. Short Circuit Core Loss on a 500 Kw., 600 Volt, 20-Pole, 360 R.P.M 3-Phase, 60 Cycle, A-C. Generator

Synchronous alternating machines generally have loss measurements taken on open circuit as outlined above, and also with the armature of the machine under test short circuited. In the latter case, the increase in power supplied by the driving motor over that required by the friction loss is plotted as ordinates against the amperes armature as abscissæ or the open circuited armature voltage due to a given excitation. A curve is obtained similar in character to the open circuited core loss curve. Such a test is commonly known as "short circuited core loss." Fig. 7 shows the results of such a test after all correction factors have been applied. In making this test careful measurements must be made of the resistance of the short circuited armature circuit including all leads, before and after the test, since to obtain the true short circuited core loss, the C^2R loss must be subtracted. Observations should be made with the short circuited armature

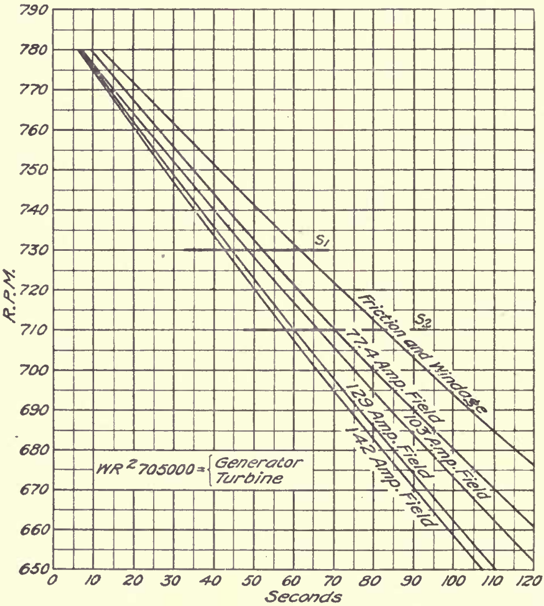


Fig. 8. Deceleration Curves on a 3000 Kw., 2300 Volt, 720 R.P.M., 60 Cycle 3-Phase, A-C. Generator

current at a value at least 200 per cent of its normal full load current.

It is often necessary to determine the core loss, friction and windage losses of large machines when it is impracticable to employ the belted core loss method. The running light reading alone does not allow the separation of the core loss from friction and windage. A method known as the deceleration core loss is used for this purpose. Such tests are employed regularly on turbine-driven units, and it is often very convenient to use them in connection with certain vertical water-wheel-driven generators and other exceptionally large horizontal alternators and direct current machines possessing a considerable flywheel capacity.

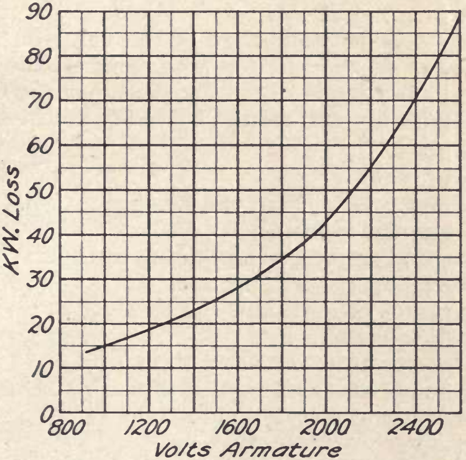


Fig. 9. Open Circuit Core Loss Curve taken from Deceleration Curves of Fig. 8

A running light reading at normal speed and normal voltage should be taken to give the driving power necessary under that condition. Where this is not practicable, the moment of inertia of the rotating part must be known. This can be very accurately calculated for the majority of machines from their mechanical dimensions, as given by the working drawings. The test is as follows: First drive the machine with full field at a little above normal speed, and then suddenly cut off the driving power and observe the deceleration; then do the same thing with full field on the machine. In the first case the deceleration is due to the retarding force—to friction and windage—and in the second case to these factors plus core loss. Readings of the speed of the rotating parts should be taken at sufficiently frequent intervals to obtain a uniform and reliable curve. A set of these curves is shown in Figs 8 and 9. With the aid of these curves, together with a "running light" test or a calculation of the kinetic energy of the rotating parts, a determination of the value of the core loss, and also of the friction and windage, is readily made. The following is a brief deriviation of the formulæ used in calculating such results by either method.

If M = mass.
W = weight.
v = linear velocity at radius of gyration.
ω = angular velocity.
S = speed r.p.m. corresponding to angular velocity
g = 32.2 ft. per sec. per sec.
r = radius of gyration.
Wr^2 = flywheel effect.
E = power at speed s and time T
E_1 = power at speed S_1 and time T_1
E_2 = power at speed S_2 and time T_2

Then $\frac{E_1+E_2}{2}$ = average power from T_1 to T_2

The kinetic energy of a rotating body at any instant is equal to $\frac{1}{2}Mv^2$

$$\frac{1}{2}\, Mv^2=\frac{W}{2g}v^2=\frac{W}{2g}\,(r\omega)^2 \text{ where } \omega=\frac{2\pi s}{60}$$

The energy consumed in decelerating from

$$\omega_1 \text{ to } \omega_2=\frac{Wr^2}{2g}(\omega_1{}^2-\omega^2{}_2)=0.00017\ Wr^2\ (S_1{}^2-S_2{}^2)$$

foot pounds.

Since the average power during the interval multiplied by the time required to decelerate from S_1 to S_2 is equal to the energy loss in deceleration from S_1 to S_2,

$$\frac{E_1+E_2}{2}(T_2-T_1)=0.00017\,Wr^2\,(S_1^2-S_2^2)\text{ or}$$

$$E=0.00017\,\frac{Wr^2\,(S_1^2-S_2^2)}{T_2-T_1}\text{ ft. lbs. per sec.}$$

$$\text{Therefore, kw.}=\frac{0.00017\,Wr^2\,(S_1^2-S_2^2)}{T_2-T_1}\times\frac{746}{550}\times\frac{1}{1000}$$

$$=\frac{2308}{10^{10}}\times\frac{Wr^2\,(S_1^2-S_2^2)}{T_2-T_1}$$

If T_3 and T_4 are respectively the times at which the speeds S_1 and S_2 occur with no field on the machine,

$$\text{then kw. in this case}=\frac{2308}{10^{10}}\;\frac{Wr^2\,(S_1^2-S_2^2)}{T_4-T_3}$$

The kw. core loss is then the difference between the kws. obtained by the formulæ given above.

If the kw. running light has been obtained,

$$\text{kw. running light}=\frac{2308}{10^{10}}\;\frac{Wr^2\,(S_1^2-S_2^2)}{T_2-T_1}=\frac{KWr^2(S_1^2-S_2^2)}{T_2-T_1}$$

$$\text{Therefore } Wr^2=\frac{\text{kw. running light }(T_2-T_1)}{K\,(S_1^2-S_2^2)}$$

$$\text{Also kw. friction}=\frac{K\,Wr^2\,(S_1^2-S_2^2)}{T_4-T_3}$$

Or substituting for Wr^2

$$\text{Kw. friction}=\frac{T_2-T_1}{T_4-T_3}\times\text{kw. running light.}$$

Hence knowing "running light," the friction can be calculated and the core loss separated from the "running light."

In making "deceleration core loss" tests, the same data should be recorded that are required in connection with the "belted core loss" method. Tables II and III show the standard method of calculating test results, open circuited and short circuited, taken by the "belted core loss" method. Table IV shows the method employed in calculating results of deceleration "core loss" by using either the value of the moment of inertia of rotating parts, or by "running light" test.

TABLE II

Open Circuit Core Loss on a 500 Kw., 600 Volt, 360 R.P.M., 60 Cycle, 3-Phase Generator

	DRIVING MOTOR							GENERATOR				
	Volts Arm.	Amps. Arm.	Amps. Field	Speed R.P.M.	C.E. Input	C^2R	C.E. $-C^2R$	Core Loss	Volts Arm.	Volts Field	Amps. Field	Speed R.P.M.
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.2	62.0	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	114.0	85.0	2.5	500	9700	55	9645	1060	152	20.0	3.9	360
	114.2	90.0	2.5	500	10280	62	10218	1633	204	25.8	18.7	360
	114.3	95.5	2.5	500	10900	70	10830	2245	262	32.2	24.0	360
	114.5	103.0	2.5	500	11800	82	11718	3133	322	38.8	29.6	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	114.5	112.0	2.5	500	12820	96	12724	4139	386	46.9	36.4	360
	114.6	126.0	2.5	500	14420	122	14298	5713	453	54.6	42.6	360
	115.0	145.0	2.5	500	16700	162	16538	7953	515	63.7	50.2	360
	115.4	160.0	2.5	500	18450	200	18250	9665	562	71.2	56.2	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	115.5	166.0	2.5	500	19200	212	18988	10403	570	74.0	58.0	360
	115.8	173.0	2.5	500	20000	230	19770	11185	594	78.0	61.0	360
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.5	62.0	360
	116.5	185.0	2.5	500	21580	263	21317	12732	624	84.6	65.7	360
	116.8	212.0	2.5	500	24800	345	24455	15870	684	100.5	78.4	360
	117.0	238.0	2.5	500	27850	435	27415	18830	721	117.5	90.9	360
	Motor Running Light											
	113.0	15.4	2.5	500	1780		1780	6905	Friction and Windage			

Driving Motor MP–4–60–550–125 V. Res. Hot. = 0.0077 Ohms.

TABLE III

Short Circuit Core Loss on a 500 Kw., 600 Volt, 360 R.P.M., 60 Cycle, 3-Phase A-C. Generator

	DRIVING MOTOR						GENERATOR					
	Volts Arm.	Amps. Arm.	Amps. Field	C.E. Input	C^2R	C.E. —C^2R	Core Loss + Gen. C^2R	C^2R	Core Loss	Amps. Arm.	Amps. Field	Speed R.P.M.
	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
Friction	113.5	76.0	2.5	8630	45	8585	0	0	0	0	0	360
	114.0	93.0	2.5	10600	66	10535	1950	1320	6630	236	12.4	360
	113.8	94.0	2.5	10710	68	10640	2055	1680	375	266	14.0	360
	113.5	106.0	2.5	12050	86	11965	3380	2540	640	328	18.0	360
	114.2	115.0	2.5	13130	102	13030	4445	3440	1005	382	19.8	360
	115.0	125.0	2.5	14380	120	14260	5675	4130	1545	418	21.6	360
Friction	113.5	76.0	2.5	8630	45	8585	0	0	0	0	0	360
	114.2	130.0	2.5	14850	130	14720	6135	4540	1595	438	22.6	360
	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
	115.2	158.0	2.5	18200	192	18010	9425	6780	2645	536	27.6	360
	114.2	176.0	2.5	20100	238	19860	11275	8350	2925	594	30.6	360
	115.0	204.0	2.5	23450	320	23130	14545	10400	4145	662	34.0	360
	116.0	232.5	2.5	27000	415	26585	18000	12700	5300	732	37.5	360

Driving Motor MP–4–60–550–125 V. Res. Hot. = 0.0077. Generator Res. between Lines = 0.0158 Av.

TABLE IV

Deceleration Core Loss

Amps. Field Held	T_1	T_2	T_2-T_1	S_1	S_2	$S_1^2-S_2^2$	Friction	Core Loss and Friction	Core Loss	Volts from Saturation
0	61.6	82.4	20.8	730	710	28800	226	226	0	0
77.4	52.1	70.6	18.5	730	710	28800	226	254	28	1570
103	48.2	88.1	17.9	730	710	28800	226	266	40	1990
129	44.4	60.5	16.1	730	710	28800	226	292	66	2350
142	42.8	58.2	15.4	730	710	28800	226	306	80	2500

Calculations of Deceleration Core Loss on a 3000 Kw., 2300 Volt, 10-Pole, 60-Cycle, 3-Phase Generator

Moment of inertia is equal to 705,000.

The normal speed of the turbine being 720, S_1 is taken equal to 750 and S_2 equal to 710.

First curve (top), Fig. 8, is taken with no field on the machine.

T_1 or time corresponding to $S_1=61.6$ seconds.

T_2 or time corresponding to $S_2=82.4$ seconds.

$$\begin{array}{rlrl} T_2 = & 82.4 & S_1^2 = & 532900 \\ T_1 = & \underline{61.6} & S_2^2 = & \underline{504000} \\ \text{Diff.} = & 20.8 & & 28900 \end{array}$$

Substituting these values in formula

$$\text{Kw.Loss} = \frac{2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{T_2 - T_1} = \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{20.8}$$

$$= 226$$

Second curve, taken with 77.4 amperes field current.

$T_2 = 70.6 - T_1 = 52.1 = 18.5$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{18.5} = 254$$

Third curve, taken with 103 amperes field current.

$T_2 = 66.1 - T_1 = 48.2 = 17.9$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{17.9} = 263$$

Fourth curve, taken with 129 amperes field current.

$T_2 = 60.5 - T_1 = 44.4 = 16.1$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{16.1} = 292$$

Fifth curve, taken with 142 amperes field current.

$T_2 = 58.2 - T_1 = 42.8 = 15.4$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28200}{15.4} = 306$$

From the saturation curve the volts armature corresponding to the various field currents used can be obtained and a core loss curve plotted between volts armature as abscissæ and core loss as ordinates.

CHAPTER V

FIELD COMPOUNDING TESTS AND MAXIMUM OUTPUT TESTS

Field Compounding

Field compounding tests determine the additional ampere turns field necessary to overcome armature reaction and CR drop in a machine from no load to full load. The test is made by separately exciting the field of the machine under test, in order to hold the voltage at the armature terminals constant as the load is increased from no load to full load. Readings of amperes field, volts field, amperes armature, volts armature, and speed are taken at no load and at least three intermediate points between no load and rated load. It is generally required and usually advisable to take an observation at 25 per cent overload, if the power is available. All readings should be made with a rising field current. On polyphase apparatus the phases should be loaded equally so that their currents will be properly balanced. Fig. 10 shows a curve of field compounding in which amperes field or ampere turns are plotted as ordinates and amperes armature as abscissæ. This curve is plotted to the values given in Table V.

TABLE V

Field Compounding on a 150 Kw., 250 Volt, 225 R.P.M., 6-Pole, D-C. Generator

(6 Bar Brush Shift)

Volts Arm.	Amps. Arm.	Volts Field	Amps. Field	R.P.M.
250	0	226	10.8	225
250	150	240	11.65	225
250	300	270	12.90	225
250	450	300	14.3	225
250	600	334	15.9	225
250	750	370	17.6	225

Maximum Output

The maximum output of direct current compound wound generators is dependent upon their commutation, or heating limitations; hence the maximum output test on these machines is usually a commutation test, which will be described later. Since in shunt wound generators the voltage falls with the load at constant field excitation, the maximum output is not always limited by commutation. It is not usual to make maximum output tests, however, on compound wound machines, since they possess little practical interest.

In the case of induction motors, the maximum output, or breakdown point, is a matter of considerable importance. If sufficient power is available, the motor is loaded in successive steps up to the breakdown point, beginning at zero load. During this test readings of volts armature, amperes armature, speed, and motor output are taken and plotted. It is essential that the voltage and frequency of the power circuit from which the motor is operating be held constant. It is also important that the readings be taken quickly at overload, and that the motor be allowed to cool between such readings, else it will overheat. Where sufficient power is not available to take a breakdown test with normal voltage impressed on the armature of the motor, a voltage considerably below normal is used; *viz.*, $\frac{3}{4}$, $\frac{1}{2}$, or even $\frac{1}{4}$ voltage. It is then necessary to calculate the full voltage results from those obtained at the lower voltages. This may be done by increasing the power output in proportion to the square of the ratio of normal voltage to the lower voltage.

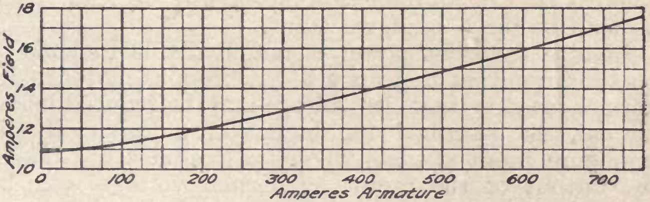


Fig. 10. Field Compounding Curves on a 150 Kw., 250 Volt, 225 R.P.M., 6-Pole, D-C. Generator (6 Bar Brush Shift)

The load at which a synchronous motor breaks from synchronism when operating at its normal rated voltage and frequency is often necessary. All maximum output tests on synchronous motors, unless stated to the contrary, should be made with a field excitation giving minimum input armature current for a given load. Readings must therefore be taken of volts armature, amperes armature, amperes field and volts field, with various loads from no load to that load which will cause the motor to break from synchronism, the field strength being adjusted for each reading to give minimum input. The speed of a synchronous motor will be constant until the point of breakdown is reached, whereas that of an induction motor will decrease from no load to the breakdown point.

In case sufficient power is not available to make a maximum output test upon a synchronous motor at its normal rated voltage, its voltage may be reduced below normal, as described for induction motors. If the minimum input obtains when the readings are taken, the output of the motor at normal voltage may be determined in the manner described for induction motors.

The wiring for this test must be arranged so that the armature circuit of the motor can be opened immediately when the motor breaks from synchronism.

CHAPTER VI

HEATING OF ELECTRICAL MACHINES—ACTUAL LOAD TESTS

The test to determine the heating of a machine is a very important one and great care must be taken to obtain reliable temperatures. Any large machine requiring a considerable amount of floor space should have the room temperatures taken at four different points nearby, and at a sufficient distance away from the machine to be unaffected by heat from the latter. Two thermometers, one in air and one in a specially designed metal cup containing oil, are used at each point to measure the room temperature. Before starting a heat run, thermometers should be placed on all important accessible stationary parts, such as series and shunt field spools, pole tips, frame, etc., in the case of a direct current machine. In addition, thermometers should be placed between pole tips to register the temperature of the air thrown off from the surface of the armature and from the air ducts. Each thermometer should be attached with the bulb in contact with the part of which the temperature is required, the bulbs being covered with putty. Thermometers which are to register the temperature of air ducts should be so placed that the bulb cannot make contact with the iron laminations while the machine is running.

The machine should be shielded from currents of air coming from adjacent pulleys and belts. Unreliable temperatures are obtained when the machine is located so that another machine blows air upon it. A very slight current of air will cause great discrepancies in heating; consequently either a suitable canvas screen should be used to shield the machine under test, or the machine causing the draught should be shut down.

Overload heat runs require considerable attention. Where an overload is applied for one or two hours, it should be certain that normal load temperatures have been reached before applying the overload. The overload must be carried only for the specified time, since, in many cases, the temperature rises rapidly throughout the whole period of the overload. Hence lengthening or shortening the overload period a few minutes may make several degrees difference in the overload temperatures obtained. To avoid continuing an overload run for a longer time than that specified, arrangements for a sufficient number of thermometer and resistance measurements must be made well in advance of the end of the run.

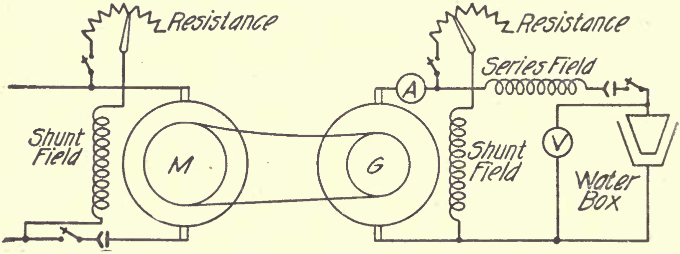


Fig. 11. Connections for Loading a D-C. Generator on a Water Box

During the heat run all conditions should remain normal, and the machine should be watched carefully for any undue heating of bearings or field spools, or for the appearance of defects. The wiring, holding-down bolts, belt lacing, etc., must also be watched.

In making heating tests two methods may be used; i.e., *actual load tests* and *equivalent load tests*. Several different means for obtaining actual load tests may be employed, such as "water box," "circulating," "feeding back," "shifting the phase" and "induction generators."

The "water box" method, as the name implies, consists in driving the machine by either a motor or engine and loading it upon a "water box," or rheostat. (Fig. 11.) This method entails considerable expense, since all the power generated is lost. To obviate this loss and reduce the cost of testing, the "feeding back" method is used when possible, especially in the case of large direct current machines and motor-generator sets. In this method the total machine losses are supplied either mechanically or electrically from an external source. In the mechanical loss supply method, two machines of the same size and voltage are belted or direct connected together and driven by a third machine large enough to carry the losses of the set. Connections are made as shown in Fig. 12. If the machines have series fields, these should be connected to boost one another. Both machines should then be started up as generators and thrown together by closing the switch between them when the voltage across this switch is zero. The field of the machine that is to act as motor should then be weakened, which operation throws load on both machines. The speed is held constant by the loss supply motor. After running at the proper load for the specified time, temperatures should be taken and tests finished according to standard requirements.

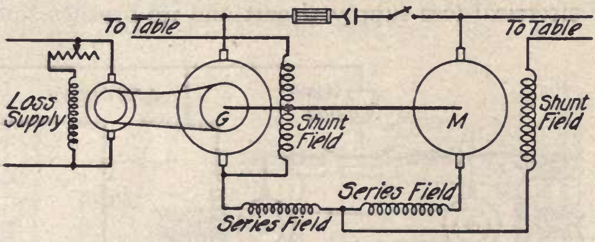


Fig. 12. Connections for Mechanical Loss Supply Pump Back

If the machines are motors, the same connections should be made and the machines thrown together as before. The voltage of the system must be held by the machine running as generator. The only correct way of obtaining load is by changing the speed of the set, the brushes having previously been set in the running position. Usually the speed will have to be decreased, and the difference between full load and no load speed will be the normal drop in speed for the motors. Cases sometimes occur when the speed of the motor, due to armature reaction, increases with increase of load. In pumping back, this condition is shown by the motors taking an overload at no load speed, in which case the speed of the loss supply must be increased.

In the method of electrical loss supply, two machines are direct connected or belted together and the losses supplied electrically. Should two shunt motors be tested by this method, one machine should be run at normal voltage, current, speed and full field; the other motor to be run as a generator with a little higher current and slightly stronger field than for normal conditions. The fields of the generator may have to be connected in multiple. Connections should be made as in Fig. 13. The motor should be started first from the electrical loss supply circuit and its brushes shifted for commutation and speed. After exciting the field of the generator and adjusting the voltage between the machines to zero, the circuit is closed. The machines are loaded by increasing the field current of the generator. Care should always be exercised when shifting the brushes while the machines are under load, since a slight change in shift will at once change the load. After the heat run has been finished and all motor readings taken, the wiring should be changed and motor

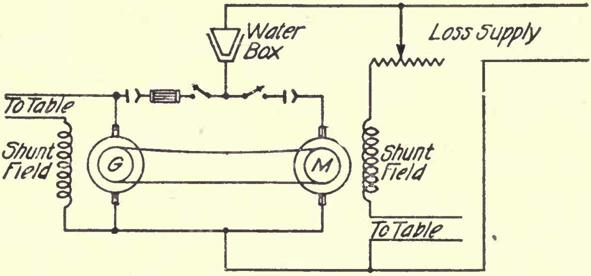


Fig. 13. Connections for Electrical Loss Supply Pump Back

readings taken on the machine which ran as a generator.

When compound wound generators are being tested by this method the series field of the motor must be included or the load will be unstable.

Another method of "feeding back," often used, is to feed the entire load back on the main supply circuit from which the motor is run that drives the generator under test. If the main supply circuit is likely to vary in voltage, it may be necessary to insert resistances between the generator and supply. It sometimes happens that the no-load voltage of the generator is below that of the supply. As changing the line resistances will have no effect at no-load, the generator voltage must be increased until it is equal to that of the main supply circuit. Having previously calculated the full-load field current from the no-load current and the ratio of compounding voltages, the machines are thrown together and full load put on the generator by cutting out the variable resistance.

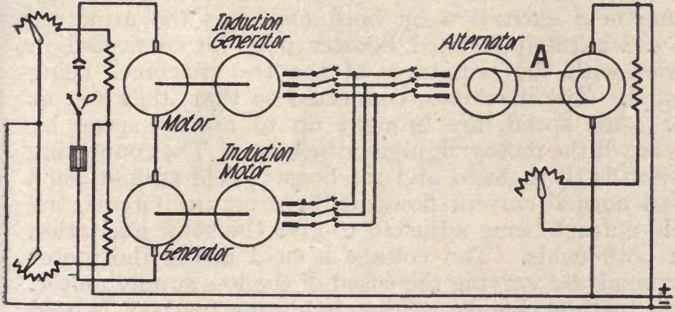


Fig. 14. Connections for Induction Motor-Generator Set Pump Back

Two similar motor-generator sets can be tested very readily by the "feeding back" method. As an illustration, suppose each set consists of an induction motor and a direct current generator. In this case connections are made as in Fig. 14. The alternating current and direct current ends of the sets are respectively connected together, one set being run normally, and the other inverted. The induction generator feeds back on the induction motor, both taking their exciting current from the alternator (A) which supplies the losses. The sets are started one at a time from the alternating current end and the direct current ends paralleled by means of a voltmeter across switch P. The direct current motor field is weakened until the ammeter in the direct current line indicates that normal current is flowing. The weakening of the motor field allows the speed of the inverted set to increase just enough to load the induction generator, while it also decreases the counter e.m.f. of the motor a sufficient amount to allow full load current to flow in the direct current circuit. This load must be closely watched, as it is unstable. Load unstability is a rather common occurrence in "feeding back," due to either variations in shop voltage or speed.

It will be noted in the "feeding back" tests described, that it is necessary to weaken or strengthen one of the fields to obtain the load. To conduct the test with the same field excitation on both machines the armature of a separately excited booster may be connected in series with the armatures of the two machines being tested. The machines, connected so that they run at the same speed, are brought up to normal speed by means of the motor supplying the losses. The connecting switch is then closed and the booster field strengthened until normal current flows in the armature circuit, the field current being adjusted to give the same excitation on both fields. The voltage is held across the motor terminals by varying the speed of the loss supply motor. This method, known as the circulating method, is used particularly in the testing of series or railway motors. In the latter case the machines are geared to the same shaft.

Another method known as "shifting the phase" is used in testing two similar alternators or frequency changer sets. Two similar alternators may be direct connected by means of a coupling and driven by a motor to supply the losses. For example, let a three-phase machine be considered, the phases of which are shown diagrammatically in Fig. 15. The machines should be run at normal speed, the fields connected in series and separately excited to a value corresponding to the load at which it is desired to make the test. The value of this excitation should be calculated from the saturation and synchronous impedance curves. With phases A and A′ connected together, the voltage across phases b and b′ is read, the circuit closed, and the value of the current flowing observed. Knowing the voltage between phases a and b, a′ and b′ and b and b′, the angle of phase displacement may be readily obtained. Should the resulting armature current be considerably greater or less than that desired, a further trial will be necessary.

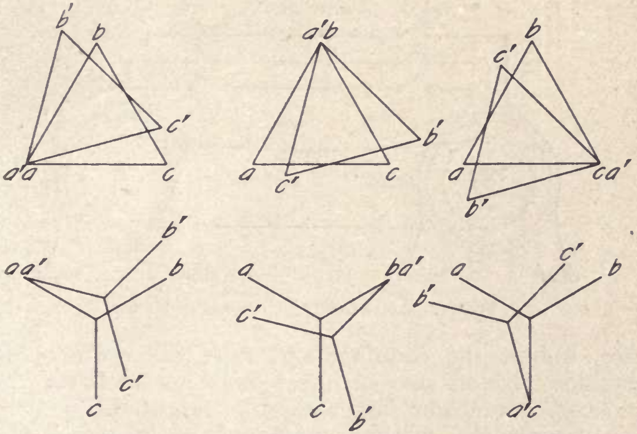


Fig. 15. Shifting of Phases Shown Diagrammatically

The current value will vary nearly as the angle of displacement, so that an approximate value of the angle desired can be found from the value of current and angle previously ascertained. When the value of this angle has been ascertained, the phase displacement should be changed, so as to obtain as closely as possible the desired value of current. With the machines still connected together as they were originally, the angle of phase displacement previously found will be increased

120 electrical degrees by connecting a′ and b If a′ and c are connected, a still further displacement of 120 degrees is obtained. If with any oft hese connections, the field of one machine be reversed, a still further displacement of 180 degrees is made. With the connection which gives the nearest value of armature current to that required, a further adjustment may be made by shimming the stator of one or both machines up on one side and taking shims out on the other side. The circuits should then be closed and the heat run made for the specified time. Even with the angles of phase displacement possible with the various combinations of connections and field rheostats it may not be practicable to get the desired armature current. In this case, unbolt the coupling and shift the rotor of one machine around one or more bolt holes. The "cut and try" operations should then be repeated.

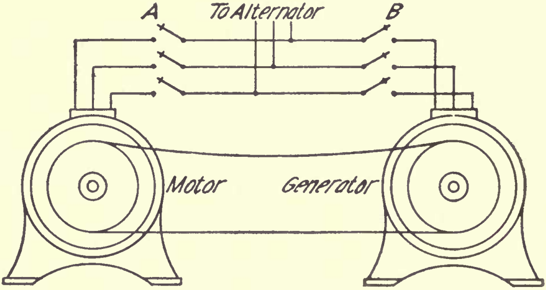


Fig. 16. Full Load Test on Induction Motors

Although the method employed in this test may seem long and tedious, the results obtained are very satisfactory, especially where it is necessary to make an actual full load test.

The induction generator method is sometimes employed in making full load tests on induction motors. Two similar induction motors are belted together and run in parallel from the same alternator which supplies the losses. (Fig. 16.) In order to get full load on both machines, the diameter of the pulleys must differ by a percentage equal to double the full load per cent slip.

In starting, the switches A are closed and the motor allowed to come up to speed, until the speed of the motor running as a generator is above synchronism. The alternator field is opened momentarily, while the switches B are closed. The circuit in the alternator field is then closed again, and full load crurent flows through the two machines. No changes in load can be made without changing the pulley ratio and it is absolutely necessary that this ratio be correct in order to obtain full load.

CHAPTER VII

HEATING OF ELECTRICAL MACHINES—EQUIVALENT LOAD TESTS

Very often it is found impossible to run actual load tests, especially on large machines, on account of limited facilities. Equivalent load tests have consequently been devised in which the heating of the machine at a certain load may be very closely ascertained without actually loading it. One of five different methods may be employed in making such a test; *viz.*, "open circuit," "short circuit" and "low voltage test," "circulating open delta" or "phase control."

Direct current machines can be satisfactorily tested by short circuiting the armature upon itself, or through the series field, so connected that it will not build up as a series generator. The shunt field is separately excited from an external source, until the required current flows through the armature, or armature and series field. This method is excellent for baking and settling the commutator. Amperes armature and field, and volts field should be read throughout the run.

In the case of alternators, the machine is run open circuited, with a field current that gives a predetermined percentage over normal voltage. The run should be continued until the rise in temperatures above the room temperature is constant, after which the machine is shut down and the final temperatures taken. The armature is then short circuited, the machine started again, and sufficient excitation applied to give a current in the armature of a certain percentage over normal. This run shonld also be continued until the rise in temperatures above that of the room is constant, after which the final temperatures are taken. The resistance of the field should be carefully measured before and after the open circuited run, that of the armature before and after the short circuited run, and the temperatures of the windings cold should also be recorded. During both runs volts and amperes field and speed should be recorded. During the open circuit run, volts armature are recorded, and during the short circuit run amperes armature.

On some of the large induction motors, only about one-fourth of the normal voltage is impressed. The machine is then loaded until the desired current flows in the stator, the run being continued as described above.

Another method of making an equivalent load test, used especially with turbo and other large three-phase alternators, is known as the circulating open delta run. The phases of the machine are connected in delta, one side of which is left open. The fields are excited to give the load desired, this excitation being determined from the saturation and synchronous impedance curves. Due to harmonics which may exist in the legs of the delta, an alternating cross current may flow in the winding. This is measured by an alternating current ammeter (with current transformer, if necessary) inserted in the opening of the delta. The difference between the square of this current and the square of the current with which it is desired to load the machine is found, and a direct current of a value equal to the square root of this difference is circulated through the winding. The run is then continued, a careful record of volts armature, direct and alternating amperes armature, volts and amperes field being made. It will be noted that the alternating cross current in one side of the right angled triangle and the direct current in the other are combined vectorially to obtain the load current desired. This method cannot be used successfully with all designs. Considerable discretion must be used in selecting machines which may be tested by this method.

Another method of loading an alternating current generator is to give it normal excitation and run an unloaded synchronous motor from its armature circuit. The field of the motor is varied to give a leading or lagging current in the armature circuit. This is known as the zero power-factor method. The rise in temperature on the fields during open circuit run, and on the armature during the short circuit run, is practically the same as will obtain during operation under load. The rises in temperature obtained from a circulating open delta run are also so considered.

With induction motors, it has been found that the temperatures on low voltage runs when combined with temperatures at no load and normal voltage, give very nearly the same results as an actual load test.

Except in the case of commutating pole machines, it is often necessary to shift the brushes to get good commutation while under load. The point at which the best commutation is obtained is known as the running point. Its position should be plainly marked on both the rocker arm and the frame by means of a chisel.

Compounding consists in placing a shunt across the series field terminals, in order to obtain the proper voltage at no load and full load. The contacts of the shunt should be perfect. In making a no-load field setting on the machine, the voltage should be raised about 15 per cent above normal no-load voltage, and then reduced to normal. With the rheostat left in this position, the load is thrown on, and if the compounding is high, the resistance of the german silver shunt should be reduced, a new no-load reading taken, and the operation repeated. This should be continued until the machine compounds according to specifications.

To take final temperatures after a heat run requires the greatest care. Arrangements should be made so that no delay results in placing the thermometers on the proper parts. Temperature readings should be made every few minutes until all temperatures begin to drop, when the thermometers may be removed. When final temperatures are being taken the hot resistance of the machine should be measured. After all the necessary tests are made, the wiring should be removed and the high potential tests applied while the machine is still warm.

In calculating the rise of temperature by resistance the following formula is used:

Let Rt_2 = hot resistance of copper measured at the temperature t_2

Rt_1 = cold resistance of copper measured at temperature t_1

R_0 = resistance of copper at 0 deg. C.

$$t_2=\left(234+t_1\right)\frac{Rt_2}{Rt_1}-234$$

When using this formula it is assumed that 0.00428 is the temperature coefficient of copper at 0 deg. C. The rise obtained from this formula should be corrected by one-half of one per cent for each degree C. that the final room temperature differs from 25 deg. C. This correction is added if the temperature is below 25 deg. C. and subtracted if above. The temperature of the winding itself must therefore be very carefully observed, as well as that of the room, when the hot and cold resistances are taken.

It is often neecssary to make a heat run on an alternating current machine at a specified power-factor. To do this, in the case of a generator, the machine is loaded on water boxes connected in parallel with a synchronous motor. The motor merely floats on the line, its field being adjusted to give the desired power-factor. Instead of loading the generator on water boxes, the motor is often belt or direct connected to a direct current generator which feeds back onto the shop circuit.

Synchronous motors are run under load at a certain power-factor by being driven from an alternating current source of power and loaded on a direct current generator. When power-factor runs are made, generators should always be run with lagging and synchronous motors with leading current, unless otherwise specified.

In addition to an ammeter and voltmeter, wattmeters should always be inserted in the armature circuit of the machine tested, in order to check up the power-factor of the circuit.

Equivalent load heat runs are frequently made at a given power-factor. In the case of an open circuit run, the excitation given the machine is a certain percentage over that which will give the desired voltage at the desired power-factor and load. This excitation is determined from saturation and synchronous impedance curves. Short circuit runs are made with a certain perecntage of excitation over that required to give the desired kilovolt-ampere reading.

Circulating open delta runs are made as previously described, an allowance being made for the proper excitation and armature current at the power-factor desired.

CHAPTER VIII

REGULATION TESTS FOR SPEED AND VOLTAGE. INPUT-OUTPUT TESTS

Regulation Test—Speed—Voltage

Shunt regulation should be taken on shunt generators. A reading should first be taken at no-load normal voltage; then, without changing the rheostat, $\frac{1}{4}$ full load should be thrown on and a reading taken of amperes armature, volts armature, amperes field and volts field. Holding $\frac{1}{4}$ full load, the voltage should be brought up to normal and the same readings taken. The load should then be increased to $\frac{1}{2}$ full load, the rheostat remaining in the same position as before, and similar readings taken. This test is repeated for $\frac{3}{4}$ and full load. With full load on the machine the voltage should be brought up to normal. Without altering the position of the field rheostat, the load is then taken off the machine and the rise in voltage observed. A curve should be plotted with amperes armature as abscissæ and volts as ordinates.

If the voltage should drop to zero when $\frac{1}{4}$ load is put on the machine, the load should be applied in smaller increments. Speed should be kept constant throughout the test.

Speed regulation is important in the operation of motors, particularly in the case of direct current machines. The speed on all motors should be adjusted while the machine is hot, by shifting the brushes, but should never be corrected at the sacrifice of commutation. It should always be adjusted for full load unless instructions specifically state otherwise.

If special tests are required for a motor, a hot speed curve should be included. Starting with no load and increasing to full load, the speed should be carefully read at several intermediate points, the voltage being held constant at all loads. A curve is then plotted with speed as ordinates and amperes as abscissæ. No load and full load points of the cold speed curve should also be taken. Fig. 17 shows the general shape of the curve. Some motors with considerable armature reaction give a speed curve which rises as the load increases.

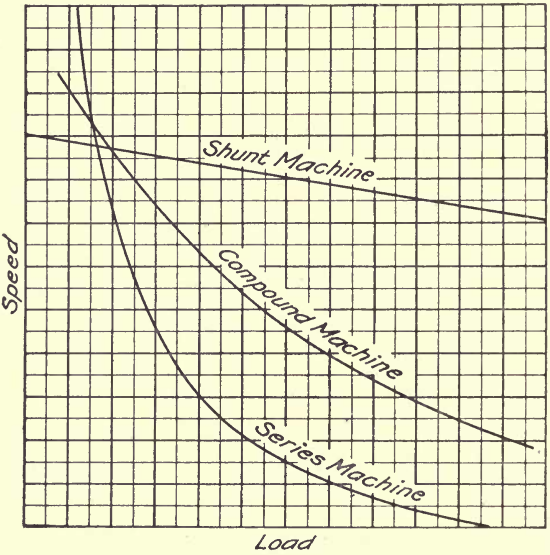


Fig. 17 Speed Curves D-C Motors

When speeding up motors with increasing load, the brushes must never be shifted far enough to produce sufficient armature reaction to weaken the field. Careless shifting of brushes under load has sometimes caused runaways; hence care should be exercised when attempting this operation.

A test of the voltage regulation of alternating current generators is sometimes made, but more frequently the regulation is calculated from the saturation and sychronous impedance curves. The method of making this calculation is more fully treated under the subject of alternating current generators. In making this test the machine is subjected to normal load at normal voltage. Holding the same field excitation, the load is suddenly thrown off and the armature voltage observed. The difference between this and normal voltage, divided by normal voltage, is the per cent voltage regulation.

When a compound wound generator is compounded hot, a compounding curve should be taken after the german silver shunt is properly adjusted. Starting with no-load voltage, readings of volts armature, amperes armature, volts field and amperes field should be taken at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and full load. The load should then be reduced to zero by the same increments, and the same readings taken. A curve should be plotted with amperes line as abscissæ and volts as ordinates. The variation of this curve from a straight line will not usually exceed 5 per cent.

Input-Output Tests

It is sometimes required to measure the efficiency of a machine or set by the input-output method. The measurement of the power input to the motor and output from the generator is then required. The efficiency

$$\text{of the set} = \frac{\text{Total output of generator}}{\text{Total input to motor}}$$

The efficiency of the generator =

$$\frac{\text{Total output of generator}}{(\text{Input to motor}) - (\text{motor losses})}$$

The efficiency of the motor =

$$\frac{(\text{Output of generator}) + (\text{generator losses})}{\text{Input to motor}}$$

In the case of induction motors, input-output test is sometimes taken by the string brake method, which will be discussed more fully under the heading of induction motors.

The input-output method of measuring efficiency is subject to considerable inaccuracy. It is not recommended and should not be used except under special conditions. It is much more preferable to ascertain the losses directly when reliable results are desired. By adding all the losses to the output at any load, the input for the load may be obtained, which, divided into the output, gives the per cent efficiency.

The resulting errors from the input-output method are likely to be large, since any inaccuracy in meters or readings influences the results directly. In loss measurement tests, the same per cent error in meters or meter readings influences the results of the efficiency calculations indirectly. Consequently the latter method is superior for accurate determinations.

CHAPTER IX

PHASE CHARACTERISTIC—SYNCHRONOUS AND STATIC IMPEDANCE—WAVE FORM, POTENTIAL CURVE

Phase Characteristic

In taking phase characteristic curves to determine the field current for minimum input at a given load on either synchronous motors or rotary converters, the machine must be operated as a motor from some source of alternating current, of correct frequency and nearly constant voltage. A reading of amperes input on all phases should be taken with zero field on the motor, when this is possible. Starting with a weak field, volts and amperes armature and volts and amperes field should be read, and the field increased by small steps until the point of minimum input armature current is found. Increasing the field current beyond this point increases the amperes armature. On a no-load phase characteristic curve, the watts input at the lowest point should check very closely with the sum of the core loss, friction and windage losses, since the power-factor is unity on synchronous motors at this point. With a weak field the current is lagging and with a strong field it is leading. In taking a no-load phase characteristic the current should rise to a value of at least 50 per cent of full load current.

A load phase characterictic should be taken, in a manner similar to that employed in obtaining the no-load characteristic. The input is held constant and the amperes load recorded in addition to the readings specified above. It is impossible to obtain a zero field point on the full load characteristic, since the current would be so large as to dangerously heat the machine and the torque not sufficient to carry full load.

All readings should be corrected for instrument factors and shunt ratios, and a curve plotted between amperes field as abscissæ and amperes armature as ordinates. See Table VI and Fig. 18.

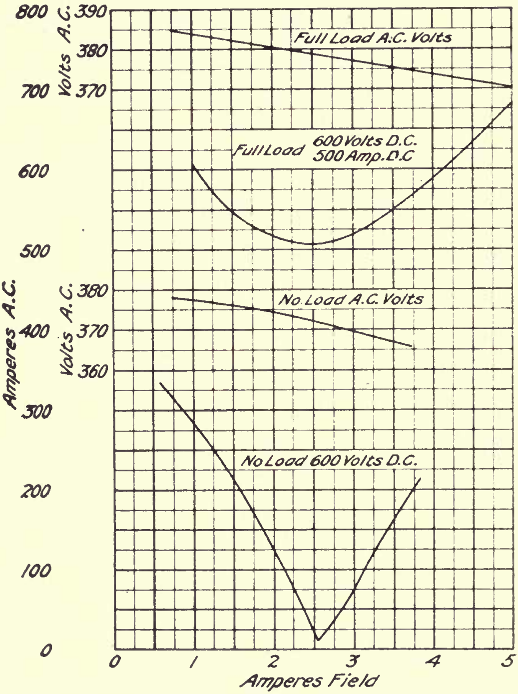


Fig. 18. No Load and Full Load Phase Characteristics on a 300 Kw. 600 Volt 750 R.P.M., 25 Cycle, 3-Phase, Rotary Converter

Synchronous and Static Impedance

Synchronous impedance should be taken on alternating current machines to determine the field current necessary to produce a given armature current when the machine is running short circuited. Since the regulation of the machine is calculated from the impedance and saturation

TABLE VI

Phase Characteristic on a 300 Kw., 600 Volt, 750 R.P.M., 25 Cycle, 3-Phase Rotary Converter

NO LOAD					FULL LOAD 500 AMPS. D-C.				
Volts D-C.	Volts A-C.	Amps. A-C.	Amps. Field	Volts Field	Volts D-C.	Volts A-C.	Amps. A-C.	Amps. Field	Volts Field
600	378	315	0.75	91	600	384	601	1.05	125
600	377	255	1.25	150	600	383 5	570	1.25	150
600	376	210	1.50	180	600	381	543	1.50	180
600	375	156	1.75	210	600	380	520	2.00	240
600	374	120	2.00	240	600	379	512	2.25	270
600	373	85	2.20	265	600	378	507	2.50	300
600	373	65	2.30	275	600	378	505	2.65	320
600	372	41	2.40	290	600	378	510	2.75	330
600	371	23	2.50	300	600	376	525	3.00	360
600	370	14	2.55	305	600	375	547	3.50	420
600	370	17	2.60	315	600	374	585	4.00	485
600	369	21	2.65	320	600	373	627	4.50	540
600	369	35	2.75	332	600	370	685	5.00	600
600	369	75	3.00	360					
600	368	116	3.25	395					
600	367	170	3.50	420					
600	366	205	3.75	450					

curves, care should be taken that consistent results are obtained.

The armature should first be short circuited; then, with the machine running at normal speed and a weak field current, the current in each phase should be read. The field current should be increased gradually until 200 per cent normal armature current is reached, readings being taken simultaneously of amperes armature and field, and volts field.

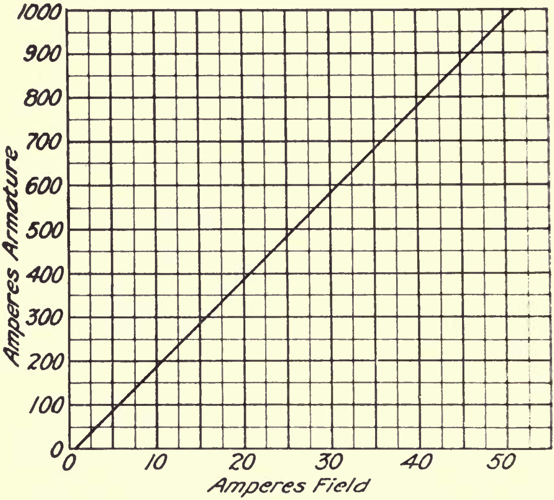


Fig. 19. Synchronous Impedance Curve on a 500 Kw., 600 Volt, 360 R.P.M. 60 Cycle, 3-Phase, A-C. Generator

Although the speed in this test should be held normal, a small variation therefrom will not affect the curve, because in the formula, current $= \frac{\text{e.m.f.}}{\text{impedance}} = \frac{E}{\sqrt{R^2+L^2W^2}}$ the term R^2 is small compared with L^2W^2, and as E and W vary proportionally to the speed, the current remains practically constant.

On some of the standard machines, a stationary impedance is taken in addition to the synchronous impedance. First block the armature or field, in the case of a revolving field machine, then connect the armature leads to an alternator giving the same frequency as that of the machine being tested. Starting with about 50 per cent normal current, the current in the armature of the machine tested is increased by steps to about 150 per cent normal, readings of volts and amperes armature being recorded.

This method should be followed in taking stationary impedance on induction motors, except that it is only necessary to take one reading at normal current. A special stationary impedance test is sometimes taken on induction motors; this is treated under the heading of induction motors.

In the calculation of synchronous impedance all readings should be corrected for the constants of instruments and ratios, and a curve plotted on the same sheet as the saturation curve, amperes or ampere turns field being plotted as abscissæ and amperes armature as ordinates. See Table VII and Fig. 19.

TABLE VII

Synchronous Impedance on a 500 Kw., 600 Volt, 20-Pole, 60 Cycle, 3-Phase Generator

Amps. Arm.	Volts Field	Amps. Field	Speed R.P.M.
224	15.0	11.9	360
260	17.8	13.7	360
300	20.6	15.8	360
352	23.8	18.3	360
398	26.9	20.7	360
474	31.5	24.5	360
480 480 480	32.2	24.8	360
518	34.8	26.7	360
557	37.5	28.2	360
704	47.0	36.1	360
793	52.8	40.6	360
895	59.5	45.7	360
1000	66.5	51.1	360

Wave Form, Potential Curve Between Brushes

In determining the wave form of a direct current machine the following method should be used; The machine should be run at normal speed and voltage and a pair of voltmeter leads, separated a distance equal to the width of one commutator bar, placed on the commutator under the center of one pole and moved from bar to bar to the center of the next pole of like polarity, the voltage at each step being read. In this way the voltage between bars is obtained for a complete cycle of 360 electrical degrees.

The readings should be corrected for meter constants and plotted as ordinates against the number of bars as abscissae, and a sketch showing the position of the poles should be made on the same sheet with the curve obtained.

Wave form on alternators is obtained by the use of the oscillograph.

CHAPTER X

DIRECT CURRENT GENERATORS—PRELIMINARY TESTS AND EFFICIENCIES

Preliminary Tests

Preliminary tests on direct current generators consist in drop on spools, polarity, hot and cold resistance measurements, air gap, potential curve, rheostat data, brush shift, running light and equalizing ring tests. With the exception of potential curve, rheostat data and equalizing ring, the tests have all been previously described.

On multiple wound armatures of self-contained machines not equipped with equalizing rings, a potential curve may be taken. All the brushes except those on two adjacent studs are raised from the commutator, the voltage is raised to normal and the field current noted. This field current and the speed must be held constant for all other points on the curve. The brushes on stud No. 3 should now be lowered, those on No. 1 raised and the voltage read between studs No. 2 and No. 3. This procedure should be continued until voltage readings have been taken between every pair of studs. The test should be made with the field current rising. The maximum voltage variation permissible is 4 per cent of the average value. This test, although similar in nature, should not be confused with the bar potential curve taken to determine the wave form of a direct current machine.

Equalizers consist of rings or cross connections tapping into equi-potential points on the winding of multiple wound armatures between each pair of poles. These rings prevent inequalities in voltage between brushes of similar potential, due to inaccurate centering of the armature. The rings allow alternating currents to flow from the stronger toward the weaker pole pieces, which slightly demagnetize the former and magnetize the latter, thus equalizing the voltage at the brushes. Not only do the rings prevent an interchange of heavy cross currents between brushes, but they also compensate for inequalities in magnetic pull at the pole pieces, tending to bend the shaft or overheat the bearings. The tester should examine these rings to see that the taps are equally spaced and all connections tight.

If a machine has been correctly connected, and there are no open circuits or reversed spools in the field, the machine should build up when the field switch is closed and all resistance cut out of the field. If it does not, the resistance of the field should be checked with that of a similar machine of the same size and voltage as a 500 volt machine may sometimes be assembled with a 250 volt field.

When difficulty is had in building up the voltage of a machine, it will usually be found that the current does not flow through the field in the right direction to build up the residual magnetism. If, with the field switch open, the residual flux gives a few volts on the armature and upon closing the switch the voltage drops to nearly zero, the field terminals are connected to the wrong brushes. To remedy, either reverse the field or shift the brushes over one pole.

In locating the no-load electrical neutral on commutating pole machines, the fibre brush method may be used. A fiber brush, provided with two contacts and terminals separated from one another by a distance equal to the thickness of one bar, is placed in a brush-holder on one stud. The brush is then shifted until zero voltage is read between the two terminals. The position of the rocker arm is marked at this point. The fiber brush is then placed on the next stud and the brushes shifted again until zero is obtained, this position of the rocker arm being also marked. This operation is repeated for each of the studs, the rocker arm being finally set on the mean of the positions previously marked. This setting locates the electrical neutral at no load, which should have the same postition at full load.

The shunt in the commutating pole field is then adjusted to give the best commutation at full load, the amount of current shunted through the commutating pole field being measured. The amount of this shunted current should always be recorded.

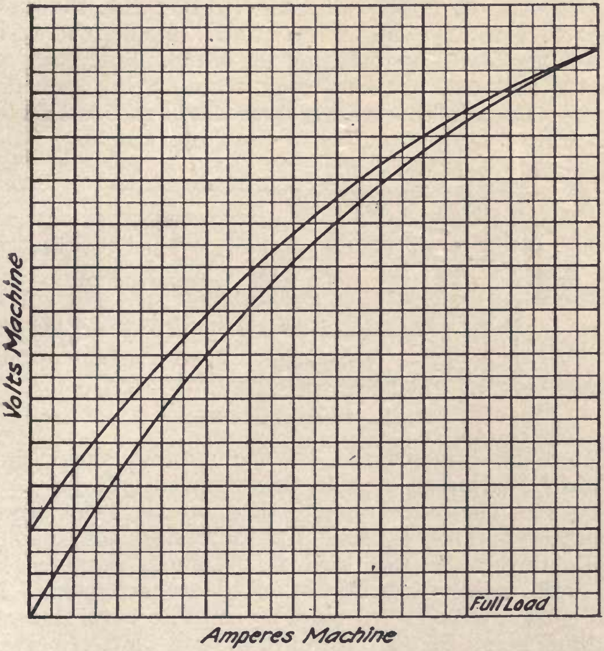


Fig. 20. Series Characteristic

The open circuit tests, already described, are sometimes taken on commutating pole generators.

The building up of a series generator is a more complicated operation. The load increases with the voltage and, therefore, great care should be taken in obtaining the correct external resistance to prevent the load from increasing rapidly. As it is practically impossible to decrease the external resistance enough (i.e., put the blade of the water box in far enough) to allow the generator to pick up, the usual method is to put the water box blades in and short circuit one of the boxes with a fuse wire and then close the circuit breaker and switches. If the machine then starts to pick up, and the voltage decreases as soon as the fuse wire burns away, there is too much resistance in the water boxes- They should therefore be salted (to decrease the resistance) and the operation repeated. Should the resistance in the boxes be too small the load will increase very rapidly and the breakers may have to be opened to prevent the machine arcing over between brushes.

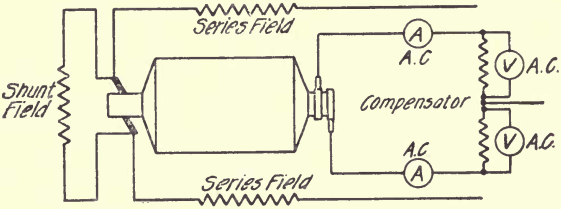


Fig. 21. Three-Wire Generator

After the brushes are set the german silver shunt should be adjusted to give the required voltage.

A series characteristic is taken on all series wound generators. This is done by increasing the load by small steps until full load is obtained, amperes line and volts machine being recorded at each step. The load is then reduced by small steps to no load, the same readings being taken. A curve is then plotted between amperes as abscissae and volts machine as ordinates. (Fig. 20.)

In the case of series machines which form part of booster sets, the guarantee sometimes does not allow this curve to deviate by more than a certain percentage from a straight line. The curve should be taken in all cases with the german silver shunt in place, if the latter is necessary.

Some direct current generators are provided with collector rings for three-wire operation. If there are two series fields, one should be connected in each side of the line. All other tests are made as on any direct current generator. If unbalanced readings are required the compensator should be wired according to diagram. (Fig. 21.)

A reading should be taken at no load, normal voltage. With no change in the field, and holding constant speed, $\frac{1}{4}$ load should be thrown on one side of the line, and the voltage read from the neutral to each side of the line; volts and amperes field should also be read. One-quarter load is then put on the other side of the line, giving a balanced load, readings being taken as before. The load is then increased to $\frac{1}{2}$ load on one side, this procedure being continued until 125 per cent balanced load is obtained, readings being taken at each step. Instructions sometimes call for 50 per cent unbalancing, in which case the load is increased 50 per cent at each step instead of 25 per cent.

Standard Efficiency Test

The method of calculating efficiency by the method of losses is as follows:

Consider a compound commutating pole generator.

Let V_L = Volts line.

C_L = Amperes line $= C_8 + C_9 = C_{10} + C_{11}$

C_6 = Amperes, shunt field

C_4 = Amperes, armature $= C_L - C_6$

C_8 = Amperes, series field $= C_L \frac{R_9}{(R_8 + R_9)}$

C_9 = Amperes, german silver shunt $= C_L - C_8$

C_{10} = Amperes, commutating pole field $= C_L \frac{R_{11}}{(R_{11} + R_{10})}$

C_{11} = Amperes, commutating pole german silver shunt $= C_L - C_{10}$

R_5 = Brush contact resistance

R_6 = Hot resistance of shunt field

R_4 = Hot resistance of armature

R_8 = Hot resistance of series field

R_9 = Hot resistance of series field german silver shunt

R_{10} = Hot resistance of commutating pole field

R_{11} = Hot resistance of commutating pole field german silver shunt

Then total CR drop $= C_4R_4 + C_4R_5 + C_8R_8 + C_{10}R_{10}$

W_1 = Core loss watts, taken from the core loss curve corresponding to $V_L + CR$ for each load

W_2 = Watts brush friction from core loss test.

If the value taken from test appears inconsistent, calculate W_2 by the formula:

$$W_2 = \frac{F \times N \times B \times L \times \mu \times 746}{33000} \text{ where}$$

F = Circumference of commutator in feet
N = R.p.m.
B = Number of brushes
L = Lb. pressure per brush
μ = Coefficient of brush friction for the particular type of brush used.

In the case of engine-driven machines or those which are furnished without base, shaft or bearings, the bearing friction is omitted from the total losses, and is charged against the prime mover.

In nearly every case it is preferable to use the calculated brush friction instead of that obtained from test. During a short test, the commutator and brush contact surfaces cannot get into such good condition as that which obtains after a long period of commercial operation. Consequently, the brush friction test does not represent the conditions that will exist after the machine has been in operation for some time. The coefficient of friction determines the value of brush friction, which in turn is determined by the condition of the commutator and brush contact surface. This coefficient varies considerably at first and only reaches a constant value after a considerable period of operation. The coefficient used in the above formula for the calculation of brush friction was obtained by means of exhaustive tests on carbon brushes of certain types with various pressures and commutators. These tests extended over a long period to obtain constant and satisfactory conditions for both brush and commutator surface. The resulting values of brush friction can, therefore.

be relied on to give accurate and final results for that type of brush.

W_3 = Bearing friction from core loss test
Wb = Watts output = $C_L \times V_L$

The brush contact resistance, R_5, is that taken from a curve made for the type of brush employed, and corresponds to the brush current density per square inch at any given load.

Brush current density per square inch =

$$\frac{C_4}{\frac{1}{2}\text{ total brush area}}$$

One-half the total brush area $= \dfrac{l \times w \times s \times t}{2}$

where l = Length of brush parallel to the shaft
w = Width of brush
s = Number of studs
t = Number of brushes per stud

For reasons similar to those just given, extensive tests have been made to determine the contact resistance of different types of brushes, from which curves have been plotted with brush current densities as abscissæ and either brush contact resistance per square inch or CR drop in brush contact as ordinates. In order to measure the contact resistance directly the commutator would have to be short circuited and the voltage drop measured from the commutator to the surface of each brush. This would be a long operation entailing considerable expense. The results also could not be reliable owing to the newness of commutator and brushes. It is therefore preferable to use the brush contact resistance obtained from the curves mentioned.

If W_3 = bearing friction from core loss test, then total loss in watts $= \Sigma W = W_1 + W_2 + W_3 + C_4^2R_4 + C^2_4R_5 + C_6^2R_6 + (C_6V_L - C_6^2R\ ) + C^2_8R_8 + C_9^2R_9 + C_{10}^2R_{10} + C_{11}^2R_{11}$

The quantity $C_6V_L - C_6^2R_6 = C^2R$ loss in the shunt field rheostats.

The watts input W_a will then be

$W_a = W_b + \Sigma W$, where W_b = watts output $= C_LV_L$

The efficiency $E = \dfrac{W_b}{W_a}$

In case a core loss test is not made, the running light is substituted in the formula for the quantity $(W_1+W_2+W_3)$. If the segregation of the losses in the series and commutating pole fields and their respective german silver shunts is not required, the resistances R_8 and R_9

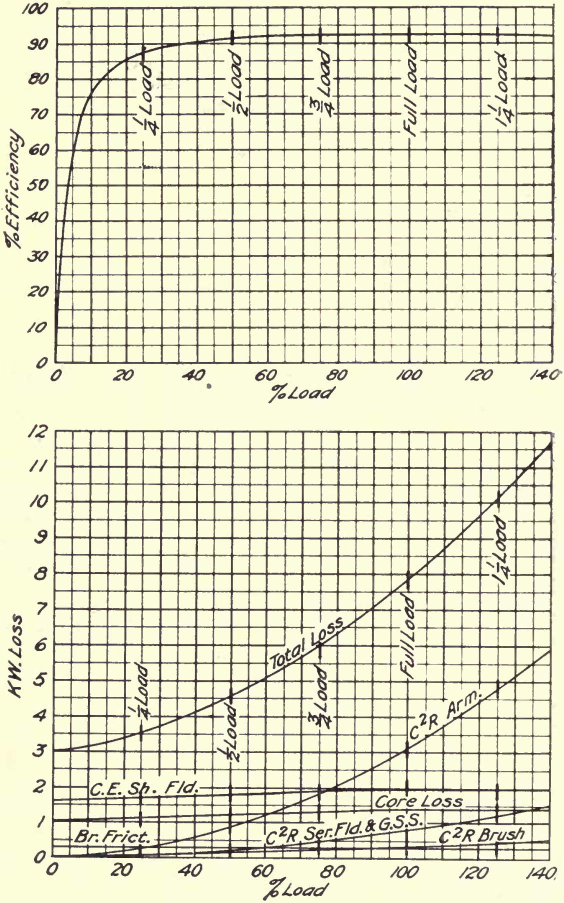


Fig. 22. Efficiency and Losses on a 100 Kw., 6-Pole, 275 R.P.M., 525/575 Volts, Compound Wound D-C. Generator

TABLE VIII

Efficiency and Losses of a 100 Kw., 525/575 Volt, Comp. Wound, 6-Pole, 275 R.P.M., D-C. Generator

% Load	0	25	50	75	100	125	150
Volts Line	525	537.5	550	562.5	575	575	
Amps. Line	0	43.5	87.0	130.5	174	217.5	
Amps. Shunt Field	3.10	3.18	3.25	3.32	3.40	3.4	
Amps. Armature	3.1	46.7	90.3	133.8	177.4	220.9	
Amps. Series Field	0	29.2	58.4	87.6	116.8	416	
Amps. Series G.S.S.	0	14.3	28.6	42.9	57.2	71.5	
CR Drop	0.417	0 628	12.15	18.0	23.9	29.7	
E+CR	525.4	543.8	562.2	580.5	598.9	604.7	
Core Loss	1042	1124	1205	1295	1395	1425	
Brush Friction	314	314	314	314	314	314	
Bearing Friction	—	—	—	—	—	—	
C^2R Armature	—	213	797	1750	3080	4770	
C^2R Brushes	—	36	135	222	331	430	
C^2R Shunt Field	1630	1710	1790	1870	1950	1950	
C^2R Rheostat							
C^2R Series Pield	0	33	131	296	523	820	
C^2R G.S.S.	0	16	64	144	257	403	
Total Losses	2986	3.446	4436	5891	7850	10112	
Kw. Output	0	23.4	47.8	73.4	100	125	
Kw. Input	2.99	26.85	52.24	79.29	107.85	135.1	
% Efficiency	—	87.2	91.5	92.6	92.7	92.6	
Brush Density	—	8.3	16.05	23.8	31.6	19.3	
Brush Contact Res.	—	0.01665	0.0144	0.01244	0.01055	0.0091	

Resistance of Armature 25° C. 0.0893 Ohms, Warm 0.098 Ohms at 51° C.
Resistance of Shunt Field 25° C. 97.4 Ohms, Warm 105.3 Ohms at 47° C.
Resistance of Series Field 25° C. 0.0358 Ohms, Warm 0.0386 Ohms at 46° C.
Resistance of Series G.S.S., 0.079 Ohms.
Dimesnions of Brushes $1\frac{1}{4}'' \times \frac{3}{8}''$. No. of Studs 6. No. per Stud 4. Coeff. of Friction = 0.2.
Brush Contract Area, One Side 5.625 Sq. In. Brush Pressure 1¼ Lb. per Brush.

TABLE IX

Efficiency and Losses ot a 70 H.P , 500 Volt, 6-Pole, 850 R.P.M., D-C. Motor

% Load	25	50	75	100	125
Volts Line	500	500	500	500	500
Amperes Line	29	58	87	116	145
Amperes Field	2.43	2.43	2.43	2.43	2.43
Amperes Arm.	26.5	55.5	84.5	113.5	142.5
CR	3	6	9	12	15
E−CR	497	494	491	488	485
Speed					
Core Loss	2500	2475	2450	2400	2150
Brush Friction	460	460	460	460	460
Bearing Friction	530	530	530	530	530
C!R Armature	63	275	638	1510	1820
C!R Brush	8	36	85	153	240
CE Field	1215	1215	1215	1215	1215
Total Losses	4775	4990	5380	5908	6615
Kw. Input	14.5	29	43.5	58	72.5
Kw. Output	9.7	24	38.1	52.1	65.9
H.P. Output	12.8	32.1	51	70	88.5
% Efficiency	67.0	82.8	87.6	89.6	90.8
Brush Density	5.15	10.3	15.5	20.6	25.8
Brush Contact Resis.	0.0178	0.016	0.0146	0.0132	0.0119
Brush Contact Resis.	0.0178	0.016	0.0146	0.0132	0.0119

Resistance of Armature 25° C. 0.0816 Ohms, Warm 0.0895 Ohms at 50° C.
Resistance of Field 25° C. 169 Ohms, Warm 191.5 Ohms at 60° C.
Dimensions of Brushes 1¼″×½″. No. of Studs 6. No. per Stud 3. 1½ lb. per Brush.
Brush Contact Area, One Side 5.62 Sq. In.

may be combined to equal R_{SF}, likewise R_{10} and R_{11} to equal R_{CF}.

The total losses will then be

$$\Sigma W = \text{Running light} + C_4^2R_4 + C_4^2R_5 + C_6V_L + C_L^2R_{SF} + C_L^2R_{CF}.$$

To calculate resistances hot when calculating efficiencies, the temperature should be obtained from the formula:

$$T = (K \times \text{rise by thermometer}) + 25^\circ \text{ C}.$$

K is the ratio between the rise in temperature by thermometer and that determined by resistance measurement. Resistance measurements of temperature have been determined by actual tests on a large number of different armatures and fields. For all armatures, or field spools of revolving field machines, $K = 1.25$. For stationary ventilated field spools $K = 1.7$. See Tables VIII and IX, and Fig. 22 for form used in calculating and plotting efficiency.

CHAPTER XI

DIRECT CURRENT GENERATORS—COMMUTATING POLES AND THE LOCATION OF THE ELECTRICAL NEUTRAL

Commutating Poles

The commutating pole produces the necessary flux for neutralizing the effect of armature reaction, and prevents that shifting of the electrical neutral point between no load and full load which occurs in direct current machines not equipped with commutating poles; and, in addition, aids the current reversals in the armature coils at commutation. To obtain the reversal without sparking, with normal load current flowing, a definite number of ampere turns is required. In many cases, fractional turns are necessary in the commutating field winding; but as only whole turn or half turns are possible for mechanical reasons, a shunt is connected across the terminals of the commutating field winding and adjusted in test to shunt the current in excess of that required. As the electrical neutral does not shift, the brushes are set on the no-load electrical neutral, the adjustments made, and the rocker arm chisel-marked for that setting. Because of this position of the brushes, the machine is sensitive to conditions that under-excite the commutating poles, or make them inactive. Such conditions may cause the neutral to shift, resulting in bad sparking at the brushes or even a flash over, particularly in the case of machines of 500 volts or over.

Consider, for instance, a 300 kw., 500 volt generator, with a heavy german silver shunt across the terminals of the commutating field winding. If the machine is short circuited, the inductance of the commutating field coils forces the instantaneous heavy overload current through the non-inductive german silver shunt and leaves the commutating field without sufficient excitation to neutralize armature reaction. The electrical neutral immediately shifts and bad commutation results. To eliminate this trouble, an inductive shunt is used across the terminals of the commutating field winding, and must always be in circuit when the machine in test is under load. If a short circuit occurs, the inductance of this shunt, being greater than that of the commutating field winding, forces the heavy line current through the field winding and tends to keep the compensation normal for all conditions of load.

Inductive Shunt

An inductive shunt is used on all machines of 500 volts or more, of a normal current rating of 400 amperes or greater. As a test is necessary to determine exactly how much current must be shunted from the commutating field, the inductive shunt is designed with an inductance greater than that of the commutating field winding and with low resistance and ample carrying capacity. Any additional resistance necessary is obtained by connecting german silver in series with the inductive shunt, the length and resistance of which is varied till an adjustment is obtained that gives practically perfect commutation throughout the whole load range for which the machine was designed.

Location of Electrical Neutral

After a commutating pole machine has been brought to normal voltage at no-load, the no-load electrical neutral must be located. To do this, a fibre brush of the same size as the carbon brushes on the generator in test must be produced. This brush should have two holes drilled through it, each of which will take a No. 12 bare wire; the spacing between the holes being equal to the distance between adjacent commutator bars. The wires should be small enough to move freely through the holes, otherwise they may stick and make poor contact on the commutator, or become wedged and bear on the commutator so hard as to score it badly. One carbon brush should be removed from its holder and the fibre brush inserted in its place, with the two wires in the brush connected to a low reading, or millivoltmeter. With normal volts no-load on the generator, the brushes should be shifted till the instrument needle has passed through the zero point, and then back again until the instrument again indicates zero, to make sure that the actual zero has been found. Pencil mark the rocker arm for this shift and then move the fibre brush to each of the other studs successively, shifting the brushes, if necessary, till zero reading is obtained, and pencil-mark the rocker arm for each stud. If a different shift is required to locate the neutral of the different studs, shift the brushes to a position which is the mean of all the different positions. With the brushes set in the mean position and the inductive shunt properly connected, put on normal load and note the commutation. If commutation is not practically sparkless at normal load and rated overload, take off the load and field excitation, and connect a german silver shunt across the commutating field terminals. If the machine requires an inductive shunt, the german silver and inductive shunts are connected in series. With the total shunt resistance great enough to shunt not more than 10 per cent of normal load current, full load is appiled and commutation noted. The length of the german silver is changed and the commutation is tested until an adjustment has been obtained which gives the best commutation throughout the range of load required. An ammeter is then connected in and the number of amperes flowing through the shunt circuit read and recorded. In case satisfactory commutation cannot be secured, the wiring, spool assembly, pole and brush spacing, air gap, polarity, spacing of equalizing rings, etc., should be checked. If these are all found to be correct, the fibre brush should be used again and the full load neutral of each stud tested. If an appreciable voltage is obtained between adjacent bars, the brushes should be carefully shifted until zero voltage is obtained, and the shunt across the commutating field readjusted. With the best shunt adjustment possible, the fibre brush should be used on each stud, and readings made of the current shunted and the shift of the brushes from the no-load neutral.

If the full-load electrical neutral of one or more studs is found to differ appreciably from that of the others, the commutating pole spacing, brush spacing, and air gaps of those poles and studs which affect the neutral in question should be carefully checked.

When a final adjustment has been obtained on any commutating pole machine of 200 kw. or greater, the fibre brush should be used on each stud and the results with full load recorded.

In general, shunting current from the commutating field will shift the load neutral of all studs away from the no-load neutral by the same distance. Shunting less current will shift all neutrals toward the no-load neutral. Where possible, all adjustments should be made with the brushes on the no-load neutral, and the brushes should be left permanently in that position. The rocker arm of all commutating pole machines should be plainly chisel marked, when the final adjustment has been made. When satisfactory commutation has been obtained, a heavy load should be thrown on and off suddenly and a record made of the resultant commutation and general behavior of the machine. If the machine has an inductive shunt, and flashing or violent sparking is produced by throwing a heavy load on and off quickly, readjusting the air gap of the inductive shunt should be tried.

With a given winding on the core, the inductance of the shunt may be varied by changing the gap, and the relative inductance of the shunt and commutating field winding is thus adjusted. If the current in the shunt circuit quickly falls to zero when a heavy load is thrown off by tripping the breaker, and the brushes show sparking, there is too little inductance in the inductive shunt and its air gap should be decreased. The air gap should be adjusted to give the minimum sparking when the machine is operating with a highly fluctuating load.

Baking Commutator

To bake the commutator on a commuting pole machine, the brushes should never be shifted under load to produce sparking and heating. They should always be shifted at no-load to insure against setting them beyond the safe limit of no-load commutation, thus preventing flash-over should the load be suddenly removed. When baking a commutator, it should also be remembered that the armature must not be short circuited through the commutating pole winding, as in this case the majority of machines will build up as series generators and the armature current cannot then be controlled.

CHAPTER XII

DIRECT CURRENT STATIONARY MOTORS

The connections and wiring of all motors should be carefully examined, with particular reference to the field. At starting, the speed of the machine must be carefully followed with a tachameter, and the circuit breaker immediately opened if the speed rises above the prescribed limit.

With the starting rheostat or water box in the off position, the terminals of the rheostat or box must be attached across the open main switch, with the circuit breaker closed; the lower terminal being attached first. The field switch should then be closed and the pole pieces tested with a piece of iron for excitation. The resistance across the main switch should then be gradually cut out and, if the speed is all right, the main switch closed.

If the motor runs above normal speed the wiring should be carefully examined to see that the field is connected across the circuit. Sometimes by mistake the field is connected across the main switch; in which case as soon as the starting resistance is cut out the field current falls rapidly and the motor speeds up excessively. To test for wrong connection, read volts field during starting and, if the field is wrongly connected, the volts field will drop as the starting rheostat is cut out.

If a potential curve cannot be taken on a motor with a multiple wound armature by running it as a generator, a "motor potential curve" may be taken by the following method: The machine is run as a motor with the field self-excited, the field current is held constant, and a constant voltage is applied to the armature, using only two adjacent sets of brushes on the commutator. A careful reading of the speed is then taken. The brushes on the next pair of studs should be placed on the commutator, and the speed again taken with the same voltage and field current as before; this procedure being repeated for all pairs of adjacent brushes. For a direct current generator, the speed should vary directly with the voltage if a potential curve is taken as described. This method should never be employed unless it is impossible to drive the machine as a generator, as it is very difficult to read the tachometer sufficiently accurately.

With no load, normal voltage, and full field, a speed reading is taken, the brushes being shifted so that when full load is on, the speed is not less than 5 per cent below nor more than 2 per cent above normal speed. At the end of the speed run the machine is loaded, the brushes shifted if necessary, and the commutation noted.

On compound wound motors, a shunt is adjusted across the series field to give a speed within a few per cent of the correct speed at rated road. Speed curves and running light should be taken with the series field disconnected.

Running light should be taken at hot full load speed.

Commutating Pole Motors

The electrical neutral on commutating pole motors is determined by shifting the brushes until the same speed is obtained in both directions with the same value of field current. This position of the rocker arm is marked. In double speed motors of this type, the neutral should be obtained at the high speed.

Machines sometimes hunt with full commutating pole field, thus preventnig the location of the neutral from being obtained. In this case, the field current should be slightly shunted, even if commutation is affected. Good commutation is rarely obtained in the unstable condition.

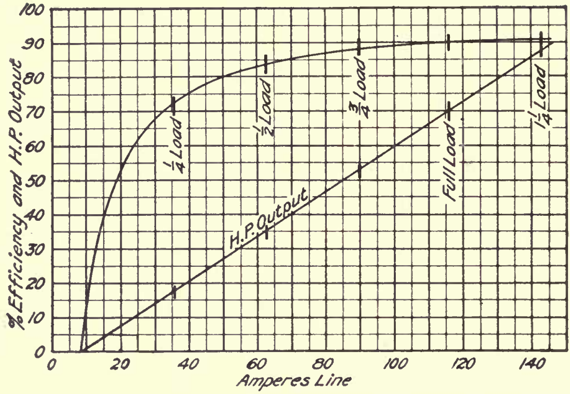
In testing motors sent out as single units, of which the direction of rotation is not known, the electrical neutral should be located by shifting the brushes at no-load, till a position is found that will give the same speed in both directions of rotation. The fibre brush method should not be used. To perform this test quickly, reversing switches are used in the series and shunt field circuits. Care must be taken, when shifting the brushes, to avoid a dangerous rise of speed.

When the proper no-load shift has been found for full commutating field, normal load is applied and the commutation and speed noted. If the speed has increased under load or the commutation is not sparkless, a german silver shunt is used across the commutating field and adjusted for commutation, the speed for each change in the shunt being noted to ascertain whether the speed is decreasing under load. When the final shunt adjustment is taken, a speed curve reading is taken and the speed and commutation in both directions of rotation, at no-load, full load and whatever overload is required are recorded. At the conclusion of all tests required, while the machine is hot, a hot speed curve covering the same range of load as used in the cold curve is taken. In the case of two-speed machines, this curve should be taken at both speeds. Additional no-load and full-load readings should be taken at full field. If a falling or constant speed is obtained, and commutation is satisfactory, no shunt is necessary; otherwise, a shunt must be placed across the commutating field and adjusted to give these speeds.

Commutating pole variable speed motors must have the shunt in the commutating pole field adjusted for the highest rated speed. Speed curves and running light tests should be made at both speed limits.

Shunt wound variable speed motors have the brushes set for commutation at the speed limits. Speed curves and running light tests should be made at both of these speeds.

Some compound wound variable speed motors are not designed to run light; consequently, before starting, the smallest load the motor is designed to carry should be ascertained. Commutation should be adjusted at the various speeds, series full field readings being taken and the speed carefully recorded. Speed curves should be taken at the different speeds; also running light with the series field disconnected.



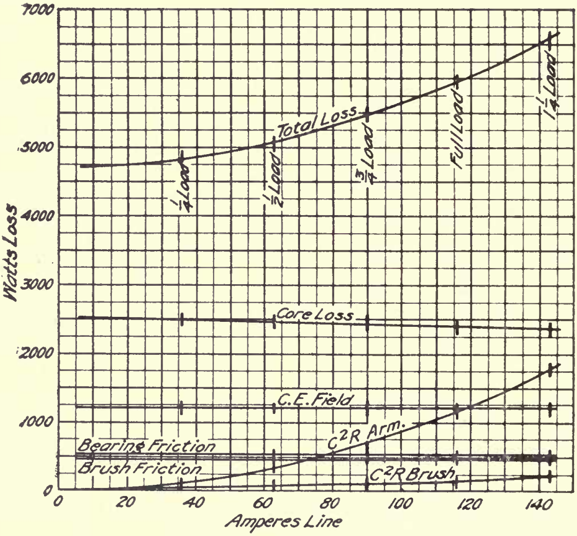


Fig. 23. Efficiency and Losses on a 70 H.P., 6-Pole, 850 R.P.M., 500 Volt D-C. Motor

(Plotted to values of Table IX, page 88)

Standard Efficiency Tests are made by the method of losses.

Employing the same nomenclature as that used in calculating the standard efficiency of direct current generators, a motor efficiency is calculated as follows:

$C_4 = C_L - C_6$

Watts input $W_A = C_L V_L$

W_1 = Core loss taken from the core loss curve corresponding to V_L—CR

Then $$\Sigma W = W_1 + W_2 + W_3 + C^2_4R_4 + C^2_4R_5 + C^2_6R_6 + (C_6V_L - C^2_6R_6) + C^2_8R_8 + C^2_9R_9 + C^2_{10}R_{10} + C^2_{11}R_{11}$$

as before.

Watts output $W_b = W_a - \Sigma W$ and $E = \dfrac{W_b}{W_a}$

Since motors are always rated according to horsepower output $H.P. = \dfrac{W_b}{746}$

If, as in the case of direct current generators, only a running light is taken and it is desired to combine the resistances of the series and commutating pole fields with their respective shunts and to combine the losses in the shunt field and rheostats, then

$$\Sigma W = \text{Running light} + C^2_4R_4 + C^2_4R_5 + C_6V_L + C^2_LR_{SF} + C^2_LR_{CF}$$

In the case of shunt motors

$$\Sigma W = \text{Running light} + C^2_4R_4 + C^2_4R_5 + C_6V_L$$

The remarks made under the subject of direct current generators in reference to the calculation of brush friction, brush contact resistance and hot resistances, as well as to all other efficiency calculations, apply in the case of motors.

It will be seen from Fig. 23 that motor efficiencies are plotted with amperes line as abscissæ and per cent efficiency and horse power output as ordinates. The horse power curve should be produced to intersect the axis of X at running light *amperes line*.

For Normal Load Heat Run the machine is run under load until it has reached constant temperatures, and these are then recorded, All series field shunt adjustments must be made to give the required regulation at the specified load.

For OVERLOAD HEAT RUN the machine is brought to normal load temperatures and the required overload is then applied for the specified time and the temperatures recorded.

CHAPTER XIII

DIRECT CURRENT RAILWAY MOTORS

Direct Current Series and Railway Motors

The principal type of series motor is the railway motor. Other types, however, are built for use with hoists, air compressors, pumps, etc. As all these motors are designed for intermittent service, the test, unless otherwise specified, is a one hour run at full load, with the brushes set on the neutral point. The load must *never* be taken off a series motor unless the armature circuit is first opened, otherwise the motor will run away. For the same reason a series motor should always be started under load. All running light tests must therefore be made with the field separately excited.

As the tests on railway motors are very complete and the general method applies to tests on any series motor, those on railway motors will be discussed more or less in detail. Hot and cold resistances must be taken on all railway motors and high potential applied both while the motor is cold and hot.

GENERAL TESTS consist of sufficient preliminary tests to warrant engineering approval or disapproval for production. It is impossible to definitely define the heading, since the tests may include only a few minor tests, or they may include complete and special tests. For instance, it may be necessary to make slight changes in either the construction or design of a standard motor in order that it may meet special requirements. After these changes have been made, tests are conducted to make sure that the motor will meet such conditions satisfactorily. These tests are included under general tests, and if after completion they are found to be satisfactory, engineering approval is given for the production of the machine in question.

COMPLETE TESTS consist of special tests, thermal characteristics, commutation and input-output. With the exception of commutation, the other tests under this heading will be considered separately.

Commutating tests on series railway motors should be made by holding normal voltage and operating the machine at loads varying from 33⅓ per cent to 200 per cent normal load.

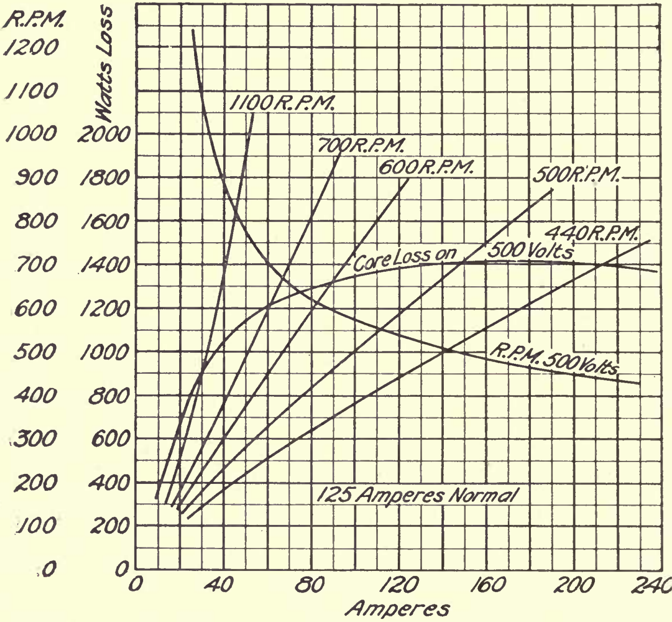


Fig. 24. Core Loss and Speed Curve of a 50 H.P., 500 Volt Railway Motor

On series commutating pole motors, interruption tests are taken. These tests consist in opening and closing the motor circuit while the machine is running at various loads and speeds. The machine should stand such tests without arcing over at line voltage as high as 125 per cent normal. The loads are varied from 33⅓ per cent to 200 per cent normal. Mill motors are tested for commutation by suddenly reversing the direction of rotation under various loads.

Development tests consist of general tests and special tests, and are made when an entirely new type of machine is being developed.

SPECIAL TESTS consist of speed curves, core loss, and saturation tests.

In taking a speed curve two similar motors are placed on a testing stand and the pinion of each is meshed in the same gear mounted on a shaft. One motor drives the other as a separately excited generator and is run loaded until the motor is heated to about 50 deg. C. rise. The speed curve is then taken on the motor rotating in first one direction and then the other, the voltage being held constant. The resistances of armature and field should be measured both before and after taking the curve.

Core loss should be taken by the belted method, as on any other machine, except that the test should be made at about five speeds. (Fig. 24.) The lowest speed should correspond to about 175 per cent full load amperes (taken from speed curves) and the highest at about 200 per cent full load speed. During this test the machine is separately excited.

A saturation curve may be taken on a series motor just as on any other machine by separately exciting the field. Saturation curves at different speeds may be obtained from data taken during the core loss test.

The speed curves, core losses and saturation are calculated as previously explained. The speed curves and core losses should be plotted on the same sheet against amperes line as abscissae and revolutions per minute and watts as ordinates. From these two sets of curves another curve can be developed, which will give the core loss of the motor at any speed or current.

The thermal characteristic should be obtained by making a series of heat runs at varying current values for a sufficient time to get a temperature rise of 75 deg. C. All runs should be made at the same constant voltage, the current value for each run varying from 50 to 150 per cent normal. If a sufficient number of heat runs are taken on a sufficient number of motors of the same class, type and form, the horse-power rating for 75 deg. C. rise may be obtained for any length of run from one-half hour to continuous running. Before starting a heat run, cold resistances and temperatures should be taken. After the motor has run continuously for the specified time, with all covers off and all openings unrestricted and with amperes and volts held constant, it is shut down, hot resistances measured and all temperatures taken. The results of the thermal heat run

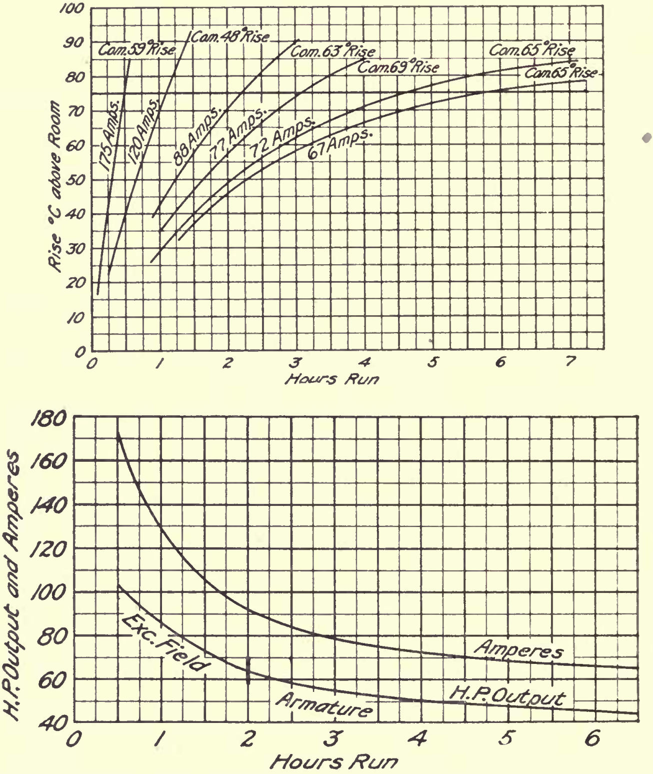


Fig. 25. Thermal Characteristics of a 75 H.P., 600/1200 Volt Railway Motor

should be plotted, one curve for armature and one for field, against times in hours as abscissae and degrees centigrade rise as ordinates. Lines should be drawn through zero and the plotted points corresponding to the different loads; the intersections of these lines with the line of 75 deg. C. rise give the respective values of time that the motor takes to attain 75 degrees rise with that load. From these curves another curve should be plotted with time as abscissae and amperes load as ordinates. This is an ampere-time curve for 75 deg. C. rise. On the same sheet on which the ampere-time curve is plotted, a curve should be drawn with time as abscissae and horse power as ordinates, the horse power being calculated from the stadnard 75 deg. C. characteristics. (Fig. 25.)

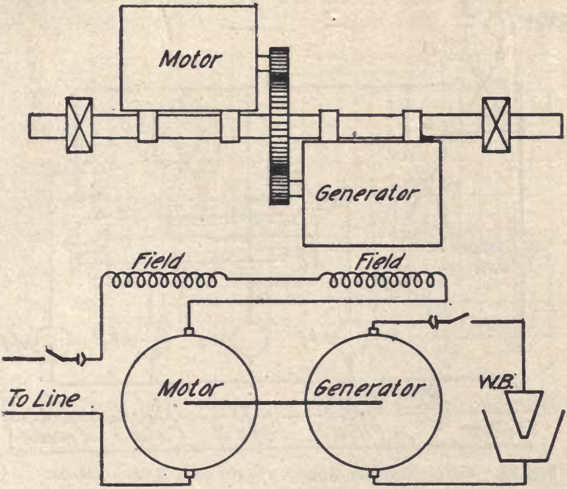


Fig. 26. Connections for Load Running Test on Railway Motors

In taking a load running test, as in the speed curve test, two motors are geared together on the same shaft (Fig. 26), one running as a motor at the rated voltage and full load current and driving the other as a separately excited generator. The separately excited field of the generator is in series with the motor field, thus giving normal full load excitation. The armature of the generator is connected to a water box, the resistance of which is varied until full load on the motor is obtained. The run is made for one hour, after which temperatures are taken.

Resistances are measured and high potential applied both before and after the test and before starting. The speed should be checked in both directions of rotation.

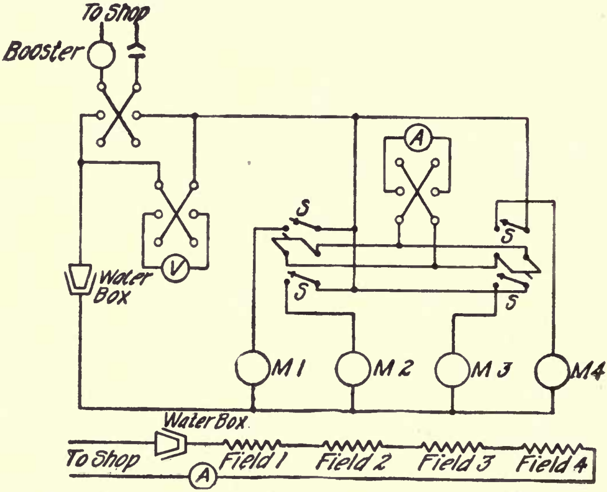


Fig. 27. Connections for Running Light on a Railway Motor

One out of every fifty of all types of motors should receive the one hour load run. All 600 volt commutating pole motors, with the exception of those receiving the one hour load run, should be run under load for ten minutes in each direction of location. Other motors the characteristics of which are well established should receive "commercial tests."

Commercial tests consist in running a motor light for a short period. It is the practice to run four motors in parallel, the fields being connected in series and separately excited by a current equal to the full load current of the motor. (Fig. 27.)

With normal voltage held constant across the armatures, the motors are run light for ten minutes in each direction of rotation, readings of speed, and armature and field currents being recorded.

With rated voltage across the motors, the fields should be weakened until about twice normal speed is attained. Under these conditions the machine should be run in each direction for five minutes, the same readings as listed above being taken.

Resistance measurements and high potential tests must be made before and after this test.

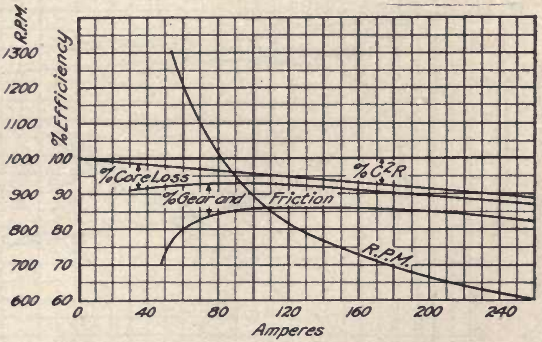


Fig. 28. Input-Output Curves for a 100 H. P., 600 Volt Railway Motor

Care must be taken that the resistance and speed at 25 deg. C. come within the prescribed limits already mentioned.

On all series motors, *with the exception of railway motors*, standard efficiency tests are made by the method of losses and the calculation of the efficiency is identical with that for any other motor. In this case, of course, amperes armature equal amperes line.

In making an input-output test the motors are geared and connected as for the load heat run and are usually run under full load for one hour up to ordinary working temperatures to get the bearings in good running condition. Before the load is put on, careful measurements of the armature and field resistance of the motor and of the armature of the generator are taken by the drop in potential method. Three different measurements should be made of each, with as many different values of current near normal load current.

Holding normal voltage constant, 12 or 15 different loads ranging from as low as possible to 150 per cent load should be put on, the direction of rotation being such that the motor tends to lift from its bearnigs. Readings at each load should be taken of the amperes, volts armature and speed of the motor, and amperes and volts armature of the generator. The direction of rotation should then be changed and several check points taken in speed and amperes, after which the machine should be shut down and hot resistance measurements made.

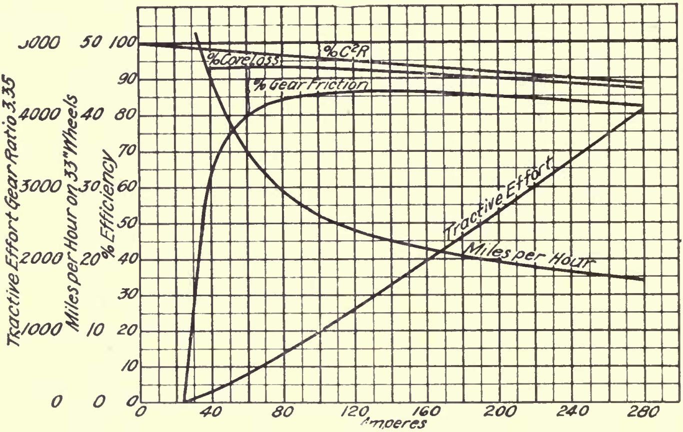


Fig. 29
Speed, Tractive Effort, Efficiency on a 100 H.P., 600 Volt Railway Motor

Table XI and Fig. 28 show the method of working and plotting the data obtained from the input-output test. Unless otherwise specified, the tractive effort and miles per hour are calculated for 33 in. wheels. The formulæ used are:

$$\text{Miles per hour} = \frac{\text{R.p.m.} \times \text{diam. of wheels in inches} \times \pi}{\text{Gear ratio} \times 1056}$$

$$\text{Tractive effort} = \frac{\text{Amps.} \times \text{nvolts} \times \text{efficiency} \times 252}{\text{Miles per hour} \times 500}$$

The gear ratio is that between the gear and pinion.

TABLE X

Speed, Tractive Effort and Efficiency of a 100 H.P. 600 Volt Railway Motor

INPUT		C^2R %	Core Loss %	Gear + Friction %	Efficiency %	Miles per Hour on 33″ Wheels Gear Ratio 3.35	Tractive Effort
Volts	Amps.						
600	40	1.7	5.3	30.0	63.0	45.0	170
600	60	2.5	4.1	14.0	79.4	35.4	407
600	80	3.3	3.4	9.0	84.3	29.6	687
600	100	4.2	3.0	7.5	85.3	26.2	984
600	120	5.0	2.6	6.5	85.9	23.8	1310
600	140	5.9	2.3	5.7	86.1	22.5	1615
600	160	6.7	2.1	5.0	86.2	21.3	1960
600	200	8.4	1.8	5.0	84.8	19.5	2630
600	240	10.0	1.5	5.0	83.5	18.1	3350
600	280	11.7	1.3	5.0	82.0	17.2	4040

Resistances at	75°C
Armature	.107
Exciting Field	.076
Commutating Field	.050
Brush Contact	.017
Total	.250

TABLE XI

Input-Output of a 100 H.P., 600 Volt Railway Motor

Motor	Volts	600	600	600	600	600
	Amps.	60.5	94.0	134	178	249
	R.P.M.	1216	935	790	700	610
	Watts Input	36300	56400	80400	106800	149200
	C^2R Arm. + Brushes + Exc. Fld. + Com. Field	935	2260	4590	8100	15800
	(A) = Watts − (C R)	35365	54140	75810	98700	133400
	(A) − (Core Loss × Fric.) = Output	29382	48180	69410	90755	123150
	Efficiency	80.9	85.4	86.4	85.0	82.5
Generator	Volts	602	592	580	551	522
	Amps.	385	70	105.5	142.5	203
	Watts	23150	41400	61150	79400	106000
	C^2R Arm. + Brush + Com. Field	248	820	1860	3410	6900
	(B) Watts + C^2R	23398	42220	63010	82810	112900
	(A − B) ÷ 2 = Core Loss × Friction (1 Mach.)	5983	5960	6400	7945	10250

Resistances		Motor	Generator
	Armature	.1082	.1015
	Exciting Field	.0792	—
	Comm. Field	.0522	.0492
	Brush Contact	.0170	.0170
	Total	.2566	.1677

From these characteristics new ones should be plotted, as shown in Fig. 29, the C^2R being corrected for 75 deg. C. rise, and the gear loss assumed as 5 per cent at full load. If the gear loss derived from test has to be changed at full load, it should be changed in the same ratio throughout the curve. (See Table X.)

Cooling off tests are made by running the motor under full load, with covers off, for one hour, shutting down and reading temperatures as the machine cools down. For the first hour after the machine is shut down, the temperatures of the following parts are read every fifteen minutes: armature, commutator, field, frame, air in the motor, and room. After the first hour temperatures should be taken every half hour until the temperature of the hottest part is not more than 25 deg. C. above the surrounding atmosphere.

The results of the cooling off test should be plotted to time as abscissæ and degree C. rise as ordinates. The curves for armature, field, commutator, frame, and air in the motor, should all be plotted on one curve sheet.

CHAPTER XIV

ROTARY CONVERTERS

Preliminary Tests

The cold resistance of the armature of a rotary converter is measured between the collector rings, as follows:

For a three-phase machine, between rings 1–2, 1–3, 2–3.

For a two-phase machine, between rings 1–3, 2–4.

For a six-phase machine, between rings 1–4, 2–5, 3–6.

The resistance of the various phases should be the same and it is immaterial whether the rings are numbered from the inside or from the outside for this measurement.

Running light on a rotary is taken with the machine running from the direct current end. With the brushes set on the neutral point, the direct current voltage is held constant and the shunt field varied until the rated speed of the machine is obtained. The input to both field and armature is then read. Since there is very little armature reaction in a rotary converter, the brushes are set on the neutral point before the machine is started. It often happens, however, that better commutation can be secured by shifting the brushes away from the neutral point very slightly. In case of unsatisfactory commutation, the brushes should be shifted in each direction, since some machines require a forward and some a backward shift from the mechanical neutral.

The determination of the ratio of the alternating current to the direct current voltage is one of the important tests on a rotary, and care should be taken to secure accurate results. The converter may be driven from either the alternating or the direct current end and, in order to check the accuracy of the instruments, two alternating current voltmeters, two potential transformers, and two direct current voltmeters should always be used. During the test the direct current voltage is held constant and the alternating current voltage read between rings 1 and 3 on a two-phase, and 1 and 4 on a six-phase machine.

The ratio is taken at no load and at full load, and should be as follows when the machine is running from the alternating current end:

RATIO A-C. TO D-C. VOLTAGE

	No Load	Full Load
Single-phase	71.5	73
Two-phase (measured on diameter) .	71.5	73
Three-phase	61	62.5
Six-phase (measured on diameter .	71.5	73
Six-phase (measured on adjusting ring)	35.8	36.5
Six-phase (measured on alternate rings)	61	62.5

The amount of pole face arc will change the ratio.

An easy and approximately correct method of telling whether a rotary is running with the proper shunt field excitation is to note the ratio of the alternating current to the direct current, which should be as follows:

Three-phase alternating current and direct current practically the same.

Two-phase alternating current equal to three-quarters of the direct current.

Six-phase alternating current equal to one-half the direct current.

Equalizer Taps

As soon as a rotary is assembled and before any running tests have been started, the spacing of the equalizer taps and the taps to the collector rings must be carefully checked. Occasionally a wrong connection is made and, if it is not corrected before the running tests are started, one or more equalizer leads may become badly overheated or be burned off.

Constant Ratio

The standard shunt wound rotary converter has a very nearly constant ratio of alternating to direct current voltage, so that any fluctuation in the voltage of the alternating current supply will show directly on the direct current voltage delivered. Such machines are unsatisfactory when such variation in load occurs. When the direct current volts have to be varied on a standard machine, the impressed alternating current volts must be altered. This is generally done by using transformers provided with dial switches, by means of which the transformer ratio is changed.

If a series field winding is added to the standard machine, a practically constant voltage can be obtained with sudden changes in load by introducing reactance into the circuit, or in some cases by using the inductance and resistance inherent in the feeder circuit. This is possible, for the reason that an alternating current passing over an inductive circuit will decrease in potential if lagging, and increase in potential if leading.

A rotary converter running as a synchronous motor requires a certain definite field excitation to effect the minimum input current to the armature. Varying the excitation either way changes the input current, so that by using sufficient reactance in the alternating current circuit from which the converter receives its power, the alternating current voltage at the converter terminals may be increased or decreased by increasing or decreasing the field current. By adjusting the shunt excitation of the compound wound machine to give a no load lagging current of about 25 per cent full load current, and the series field to give a slightly leading current at full load, the impressed voltage at no load will be automatically lowered and that at full load increased. Hence, a practically constant direct current voltage will be delivered at all loads.

Variable Ratio Machines

The split pole rotary differs from the ordinary rotary in that the poles consist of two separate and independent parts, each provided with its own field coil. The auxiliary pole may be placed on either the leading or the trailing side of the main field, depending upon the conditions under which the machine is to operate. If it is to operate as a straight rotary, the auxiliary pole is to be placed on the trailing side; while if the machine is to float on the line to take fluctuations of load through a storage battery, and hence run inverted part of the time, the auxiliary pole should be on the leading side. The reason for this is as follows: The auxiliary pole influences commutation when on the leading side, as well as regulates the direct current voltage, and will be of correct polarity for commutation if the machine inverts at a direct current voltage corresponding to no excitation of the auxiliary poles.

In wiring a split pole rotary for test, the transformers used must be exactly alike. The best results are obtained by using transformers with two secondaries excited by one primary. Care should be taken to see that the cables from the transformers to the rings do not differ in length or cross section, and that all switches in these circuits have their contact surfaces well cleaned with sandpaper. These precautions are necessary to prevent and unbalancing of the current in the alternating current circuits outside of the armature.

The testing instructions should specify the manner in which the transformers are to be connected, both primary and secondary; the alternating current volts to be held across corresponding rings; and the range through which the direct current volts are to be varied by means of the auxiliary field. The following no load readings should he taken:

Current per phase. (Must be balanced.)

No load phase characteristic.

Ratio of voltage.

Volts between adjacent collector rings with main field only.

A set of readings of alternating current amperes while varying the direct current volts by means of the auxiliary field through the total voltage range, the main field being held at minimum input value, the alternating current volts constant, and the brushes shifted to give the best commutation over the whole range.

A set of readings while varying the direct current volts through the total range by means of the auxiliary field, the main field being adjusted to give minimum input for each change in direct current voltage.

A full load ratio and the current per phase for minimum input, using main field only.

Phase Characteristics

Three full load phase characteristics should be taken as follows:

1st. Holding the alternating current volts constant and using the main field only.

2nd. At the lowest limit of the direct current volts: holding the alternating current and direct current volts constant and adjusting the direct current line current to that value which gives the rated output for the mid voltage with zero auxiliary field.

3rd. At the highest limit of the direct current volts: holding the alternating current and direct current volts constant and adjusting the direct current line current to that value necessary to give the rated output for the mid voltage with zero auxiliary field.

Core Loss

Three core loss tests are required to cover the various conditions of operation. These are made as follows:

1st. Core loss while varying the direct current volts by means of the main field only, with auxiliary field not excited.

2nd. Core loss while holding the excitation of the main field constant at that value which gives mid direct current voltage, and varying the auxiliary field to change the direct current voltage.

3rd. Core loss while holding the alternating current volts constant and varying the main field each time the auxiliary field is changed to change the direct current volts throughout the range. This gives unity power-factor.

All other tests are made as on standard rotaries.

Inverted Rotaries

The speed of a rotary when running from the alternating current side is determined by the line frequency. The same machine running as an inverted rotary and delivering alternating current operates as a direct current motor. Its speed depends upon the field excitation and load, and it will deliver a variable frequency, particularly if compound wound. When run inverted, a compound wound machine should have its series field almost, if not entirely, short circuited when part of its load is inductive, since a lagging current will weaken the field and increase the speed, sometimes causing a runaway. For this reason care must always be taken when running a rotary inverted to see that sufficient shunt field excitation has been obtained to prevent excessive speed, particularly when another machine is operating as a rotary from the inverted machine.

Starting Tests from the Alternating Current End

The rotary should be wired to an alternating current generator of sufficient capacity to start it without overloading. If transformers are needed in order to get the correct voltage, they should be placed between the dynamometer board and the generator.

A rotary, when starting from the alternating current end, is similar in action to a transformer. The armature corresponds to the primary, and the field, which has a large number of turns, to the secondary. Hence the induced volts on the field may be very high, often 3000 or 4000 volts, In all cases, therefore, the field connection must be broken in two or more places to keep this voltage within safe limits. A potential transformer and voltmeter should be connected across one or two spools in series for reading the induced volts field, and a record made as to the number of poles included in the reading.

Starting tests should be made from several different positions of the armature with respect to the field. A scale, corresponding in length to the distance between collector ring taps, should be laid off on the armature and divided into five equal parts. A point of reference is then marked on the field, opposite to which the marked positions of the armature are placed for the successive starts.

Having brought point No. 1 opposite the reference point, the alternating current switches should be closed and the field on the alternator increased until about one-half normal full load current is sent through the rotary, reading volts and amperes in the various phases. As it is impracticable to read all phases at once during the start, the ammeter should be cut into that phase which shows the highest currest and the voltmeter across the phase which indicates the highest voltage, in order to get the maximum readings at the instant of starting. The field of the generator should be increased until the armature begins to revolve, when volts and amperes input and induced volts on the field should be read. The voltage across the collector rings should then be held constant until the rotary reaches synchronism, the time required to reach this point from the start being noted.

There are several methods of determining whether the rotary is in synchronism; one, by the fact that the induced volts field will fall to zero; another, that the voltmeter across the armature will read a definite voltage, which will vary from a negative to a positive reading if the rotary is below synchronism. Readings of volts and amperes should be taken on all phases after the rotary has reached synchronism. The machine should then be shut down, the armature brought to position No. 2, and the test repeated. In this manner all five points should be tested. After these tests have been made, the time required to bring the rotary to synchronism should be taken by throwing one-half voltage across the collector rings.

Starting Tests from Direct Current End

When starting from the direct current end, the rotary must be wired to a direct current generator of ample capacity. The rotary should be separately excited with a field current corresponding in value to that for no load to minimum input (unless full field is specified), and the voltage across the armature brought up gradually by increasing the field on the driving generator, until the armature begins to revolve. The voltage should then be steadily increased at that rate which will bring the rotary to normal speed in approximately one minute. This rate can be found by trial, and when once found, the test should be repaeted once or twice to make certain that the results are correct.

Phase Characteristics

NO LOAD. If the phase characteristic tests follow a heat run in which an IRT regulator has been used, it must be disconnected. The most satisfactory combination is to run two converters for this test, the one under test running as a rotary and driven by the other running inverted with a direct current loss supply. The speed and the direct current voltage are held constant by varying, respectively, the field of the inverted machine and the voltage of the loss supply. It must ke remembered that a lagging current will increase the speed of the inverted rotary, and therefore the inverted machine should be watched constantly so long as the current lags.

With the field excitation of the rotary reduced to the lowest limit permitted by the inverted machine, the alternating current amperes and volts line and the direct current amperes and volts field should be read. As stated above, the speed and the direct current volts are held constant throughout the test. The field current of the rotary is increased by small increments and readings taken as above. The alternating current amperesin put will decrease rapidly until the minimum input point is reached, when they will increase again. The field excitation should then be increased until the input current has a value of at least half the full load current of the machine.

FULL LOAD. The full load characteristic is taken in exactly the same way as for no load. The direct current volts are held constant to normal rating and the amperes output constant at full load value. The field excitation is varied through nearly as possible the same range as for no load characteristic. The readings taken are, for the alternating current side, volts and amperes; and for the direct current side, volts armature (held constant), amperes output (held constant), volts field, and amperes field. The speed is held constant.

Compounding Test with Reactance

When a rotary is required to deliver automatically a constant direct current voltage under a load subject to sudden changes, a compound wound machine is used with a definite reactance inserted between the rotary and the line. Such reactances must be tested with the machines for which they are designed. A constant voltage is possible, since an alternating current passing through a reactance will increase the potential if leading, and decrease it if lagging. By adjusting the shunt field so that about 20 per cent lagging current flows at no load, the strength of the series field can be adjusted to give a slightly leading current at full load and thus maintain a constant direct current voltage. A compound converter operating with reactance in circuit must be compounded like a direct current generator. Unless otherwise specified, the voltage of the alternator driving the rotary should be held constant and the shunt field adjusted to give the correct no load voltage; then, without touching the field rheostats, full load should be applied and the direct current volts read. If the machine over-compounds, the series field is too strong and gives too large a leading current, in which case a shunt must be adjusted across the terminals of the series winding to shunt a portion of the current. In this compounding test all readings are taken and all adjustments made without touching the field rheostat after the no load adjustment is effected, as in the case of a direct current generator.

Pulsation Bridges

Since the torque of a rotary only needs to be great enough to overcome the mechanical losses, the machine is very sensitive to changes in line conditions; i.e., excessive line drop or speed changes of the driving unit. In many cases the line drop alone will start a rotary pulsating and once started the pulsating generally increases rapidly until the rotary falls out of step or flashes over, To prevent pulsation, copper or brass bridges, which act as short circuited secondaries and prevent sudden changes of the input armature current, are placed between the poles. Rotaries of new design are tested for pulsation by inserting a definite resistance in each phase between the machine itself and the driving alternator. The drop through this resistance corresponds to the line drop which will probably occur in practice Usually 15 per cent drop is assumed.

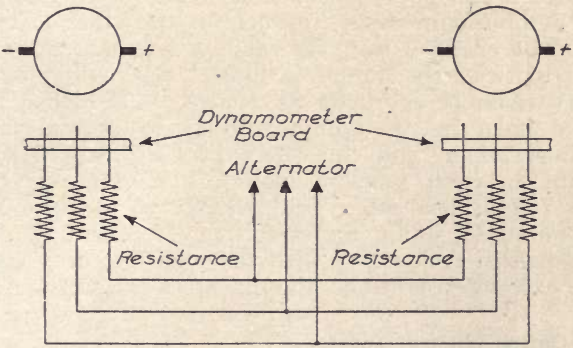


Fig. 30. Connections for Pulsation Test on Rotary Converter

If two rotaries are tested together each machine should have 15 per cent drop between it and the driving alternator, or 30 per cent between the two rotaries, as shown in Fig. 30.

With the two machines running in synchronism, self-excited, and with fields adjusted to give minimum input, observe the direct current voltmeters on the two machines. Any slight pulsation will be shown by these instruments at once. The direct current volts should be held constant on one machine throughout the test. Now, with the field current on one machine held at minimum input value, the field current on the other machine should he reduced to about one-half minimum input value. If no pulsation is noted, a full set of readings should be taken on both machines, reducing the field current of the other machine to one-half minimum input value and watching for pulsation on both machines, which now take a heavy lagging current. A full set of readings under these conditions should be taken. The field of the first machine is again adjusted to the minimum input value, readings are taken, and pulsations watched for. With this field held at minimum input, the field of the other machine should be changed from its value of one-half minimum input to twice the minimum input value, readings and observations being made as before. The other field should then be brought up to twice normal value, readings taken, and the effect of the heavy leading current in each machine noted. Leaving one field over-excited, the other field should be weakened to give minimum input, and a full set of readings taken. If no pulsation develops with the high line drop under these extreme conditions, the machines are satisfactory.

Input-Output Efficiency Test

Input-output tests on small machines (300 kw. or less) are made with the machine running as a rotary, dead loaded on a water-rheostat. Larger machines are tested in pairs, one machine pumping back on the other with an electrical loss supply. The machines are wired in a manner exactly similar to that used in a pump back heat run (circulating power heat test), special attention being given to the wiring to see that no unbalancing occurs on either the alternating current or the direct current circuits. With the machine running as a rotary, wattmeters are connected in the alternating current end, between the rotary and transformers, and preparations made for reading direct current armature and field amperes and volts. If current transformers are used with the wattmeters, duplicate transformers must be used in the other phases of the machine to prevent unbalancing caused by the resistance and inductance of the transformers. With the machine running in synchronism at rated speed and zero load, and all meters connected, the alternating current volts impressed on the rotary should be held constant and careful readings taken of all instruments. The currents and volts in each phase should be read as a check on the wiring and balancing of all phases. All instruments should also be carefully checked for stray fields and any instruments affected by these must be protected by iron shields, or their location changed. With full load, the test for stray field should be repeated, since any instrument affected will give misleading and erroneous results. With the no load minimum input field current held constant, the alternating current input, as shown by the wattmeters, should be carefully read as a check on the no load losses.

As efficiency is usually guaranteed at ¼, ½, ¾, 1 and 1¼ full load, careful readings must be taken at these loads. Each time the load is changed, the rotary field excitation must be changed to the minimum input value for that load, which is shown when the sum of the wattmeter readings is exactly equal to the kv-a. input. To obtain this condition for each load, several trials and considerable time is usually required, so that an efficiency test made in this way is more expensive than one made by the separate loss method. The likelihood of error is also greater. This method, therefore, is not satisfactory for rotary efficiencies at other than full load.

The method employed to calculate the efficiency of a standard rotary converter is similar to that used for direct current generators, except for the additional C^2R and friction losses of the alternating current brushes. Because of the neutralizing action of the motor and generator currents it should be noted that only a certain percentage of the C^2R loss in the armature should be used for calculating the efficiency of the rotary converter. This percentage varies for different machines as follows:

Single-phase	147%
Two-phase	39%
Three-phase	59%
Six-phase	27%

The calculation of the alternating current brush contact resistance requires a measurement of the alternating current flowing in the armature, which varies in different types of machines. The following are the constants by which the direct current should be multiplied to obtain the alternating current.

For Single-phase	1.00
Two-phase	.72
Three-phase	.943
Six-phase	.472

As with the direct current brush resistance a curve of the alternating current contact resistance must be referred to and no direct measurement of resistance attempted. In every case the contact resistance per ring should be calculated, the total loss being obtained by multiplying by the number of rings.

Brush contact area per ring = width of brush in inches × arc of contact in inches × the number of brushes.

$$\text{The brush density per ring} = \frac{\text{alternating current}}{\text{brush contact area per ring}}$$

The resistance obtained from the curve corresponding to this value, divided by the brush area per ring, is the contact resistance per ring.

The alternating current brush friction should be calculated in the same manner as that for direct current measurements, the coefficient of friction being taken from a curve. (See Fig. 31.)

Table XII and Figs. 31-a and 31-b show the form used in calculating and plotting rotary converter efficiencies.

Normal Load Heat Runs

When loading a rotary converter on a water rheostat, see that all cables from the transformers to dynamometer boards and to the alternating current rings of

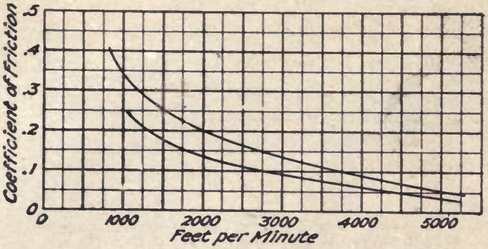


Fig. 31. Coefficient of Friction of A-C. Brushes

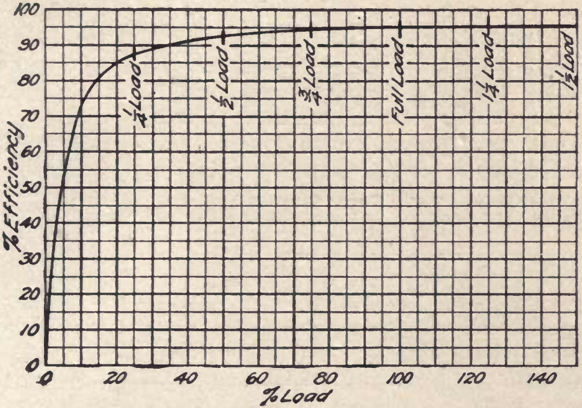


Fig. 31-a

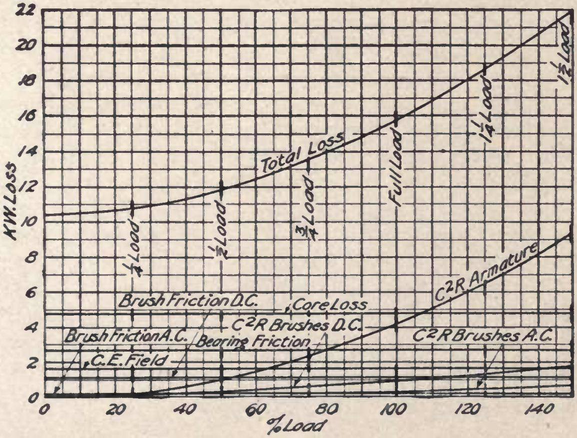


Fig 31-b. Efficiency and Losses on a 300 Kw., 600 Volt, 750 R.P.M., 25 Cycle, 3-Phase Rotary Converter

TABLE XII

Efficiency and Losses of a 300 Kw., 600 Volt, 4-Pole, 25 Cycle, 3-Phase Rotary Converter

% Load	0	25	50	75	100	125	150
Volts Line	600	600	600	600	600	600	600
Amps. Line	0	125	250	375	500	625	750
Amps. Shunt Field	2.65	2.65	2.65	2.65	2.65	2.65	2.65
Amps. Arm. D-C.	2.65	127.6	252.6	377.6	502.6	627.6	752.6
Amps. Arm. A-C.	—	122.5	242.5	362	482	602	722
Core Loss	4760	4760	4760	4760	4760	4760	4760
Brush Friction D-C.	1134	1134	1134	1134	1134	1134	1134
Bearing Friction	2654	2654	2564	2654	2654	2654	2654
C^2R Armature (.585×D-C. C^2R)	0	267	1046	2340	4140	6450	9300
C^2R Brushes D-C.	0	105	340	641	960	1280	1720
C^2R Shunt Field	900	900	900	900	900	900	900
C^2R Rheostat	690	690	690	690	690	690	690
C^2R A-C. Brushes	—	17	73	161	286	446	575
C^2R A-C. Brush Fric.	211	211	211	211	211	211	211
Total Losses	10349	10738	11808	13491	15735	18525	21944
Kw. Output	—	75	150	225	300	375	450
Kw. Input	10.3	85.7	161.8	238.5	315.7	393.5	471.9
% Efficiency	0	87.4	92.7	94.3	95.0	95.3	95.4
Brush Density A-C.	—	10.45	19.9	29.8	39.6	49.5	59.3
Brush Density D-C.	—	8.5	16.9	25.2	33.6	41.9	48.2
Brush Contact Resis. A-C.	—	0.00123	0.00123	0.00123	0.00123	0.00123	0.00110
Brush Contact Resis. D-C.	—	0.0062	0.00534	0.00451	0.0038	0.00323	0.00304

Resistance of Armature D-C. End 25 deg. C. 0.0243 Ohms, Warm 0.0280 Ohms at 65 deg. C.
Resistance of Shunt Field 25 deg. C 111.3 Ohms, Warm 128. Ohms at 85 deg. C.
Dimensions of Brushes { 1⅝×1⅞ are (A-C.) No. of Studs 4 D-C./12 A-C. No. per Stud 8 D-C./1 A-C.
{ ¾×1¼ (D-C.)
Brush Contact Area, One Side { 15 A″D-C.
{ 12.2 (A-C.) Sq. In. Brush Pressure 2 Lb. per Brush.
Coeff. of Friction = 0.2 D-C. Coeff. of Friction = 0.12 A-C.

the machine are of the same length and capacity, and that all contracts are cleaned and brightened before connection. Equal resistance per phase will thus be obtained and unbalancing in the alternating current circuits external to the armature prevented. In wiring the direct current circuit, the series field and its shunt are disconnected.

When wiring rotaries, as in the case of all other high current direct current machines, both sides of the circuit should be laid close together. No iron, such as a bearing pedestal or a section of the frame, must lie within the loop of the circuit, since it will become magnetized and materially affect the operation of the machine and instruments. Divide the shunt field into at least four sections by a "break up switch," which must always be open while starting from the alternating current end; since, due to transformer action and the relative number of turns of the field and armature, a high voltage is induced in the field at starting.

Always wire the positive ring of the rotary through a breaker to the blade of the water box, and the negative ring to the box itself. Connect enough boxes in multiple to limit the current per box to about 400 amperes maximum. Make provision for reading alternating current amperes and volts armature, direct current amperes and volts armature, amperes and volts field, and the speed of the alternator.

To start the machine, close the alternating current line switches, and the field switch of the driving alternator, increasing the excitation of the alternator and keeping close watch on the current in the alternating current lines. If this current reaches 150 per cent normal before the rotary starts, check over the wiring. If the machine starts rotating in the wrong direction, reverse two of the leads on the primary side of the transformers. After starting, as soon as the alternating current drops to the minimum value (showing that the machine is in synchronism), and the alternating current volts become normal, close the field "break up switch." If, after closing the shunt field switch, the brushes begin to spark, the residual magnetism left the in the poles by the induced voltage at starting is of the wrong polarity.

Two methods can be used to correct this; first, reverse the field with respect to the armature; or second, reverse the residual polarity by opening the alternator field circuit, and then closing this circuit and bringing the rotary back to synchronism, repeating the operation if necessary until the field builds up in the right direction. This second method is the more satisfactory since no change of wiring is required.

Before proceeding further, read the current in each phase to make sure that there is no unbalancing, These currents should not vary over 1 per cent from the average; any greater variation due to wiring must be remedied at once. After balance is established, both no load and full load phase characteristics are taken.

These operations complete the preliminary tests and the full load heat run may now be made, care being taken to set the brushes for the best commutation. For the load run, hold full load direct current amperes and volts constant with minimum input field current The load should be kept on at least one hour after all temperatures are constant. At the end of the run, temperatures must be taken on all parts of the machine and the resistance measured on the armature (alternating current end) and field. If the rotary is a six-phase machine, the armature resistance is measured between rings 1–4, 2–5, 3–6, counting outwards from the armature.

If an overload run is required, take a few points on the overload phase characteristic to determine the field current required for minimum input; then hold this current and the direct current volts and amperes constant, as on the normal load run.

After the heat runs, the test should be finished by taking a phase rotation, hot drop on spools, direct current running light at normal voltage, and direct current starting tests.

D-C. Circulating Current

Fig. 32 shows the connections for two three-phase converters wired for a pump back heat run without a potential regulator to control the load. The core losses and C^2R losses are supplied from the direct current end.

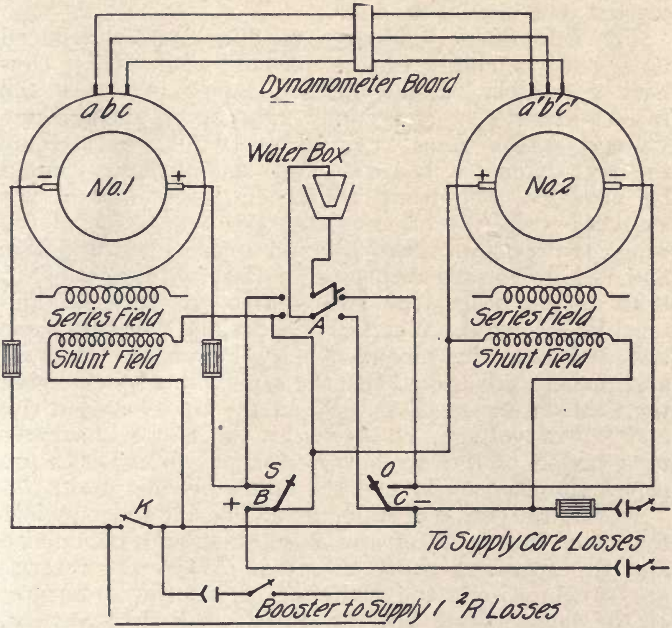


Fig. 32. Connections for Pumping Back Rotary Converters Without the Use of a Regulator

The diagram shows, also, the standard starting panel, which should always be used when two converters are tested together.

To start the rotaries, for instance No. 1, close the shunt field switch and the switch *K*, the latter short circuiting the armature of the loss supply. Note that the shunt fields are wired across the core loss supply, which in turn is wired to busses *B* and *C* of the starting panel, and that the series fields are left open. Throw switch *A* to the left and slowly reduce the resistance of the water rheostat until it is practically short circuited, when the switch *S* may be closed. The blade of the water rheostat is now drawn out of the water and the switch *A* thrown to the right. Machine No. 2 is then started in a similar manner.

The field strength of each machine is then reduced until both machines run at normal speed. Next connect a number of incandescent lamps in series, the rated voltage of which is equal to the sum of the machine voltage across rings; i.e., across switches located on the dynamometer board. Two sets of lamps should be provided, one being connected across one of th switches while the other is stepped across each of t other switches in turn. Should one set show a rise and fall in voltage displaced in time with relation to that of the other, the two phases are reversed and must be corrected. When all phases show a simultaneous rise and fall, the machines may be phased together and their speeds brought to the same value by changing the field on one of them. When the time between rise and fall of voltage, as shown by the lamps, decreases to a period of five seconds or longer, all switches are closed simultaneously and the lamps become dark.

During the period of starting and phasing the machines together, the fields of the booster should be opened and the armature short circuited. When the rotaries are synchronized, the switches across the armatures of the boosters are opened and a weak field applied, the line meter on machine No. 1 being watched. The reading of this meter should reverse from that given on motor load, if machine No. 1 is taking load as a rotary. By reversing the booster field either machine can be made to run as a rotary.

After balancing the current in each phase, full load phase characteristics may be taken by holding the speed constant by means of the field of the inverted machine, and the load constant by means of the booster, the shunt field of the rotary being varied throughout its range and the current input read. Full load voltage ratio should next be taken, after which the heat runs may be made.

A line shunt must be used in each side of the direct current circuit, otherwise one line will have more resistance than the other and the currents flowing through them will have unequal values, the unbalanced current returning through the alternating current ends of the machines. The currents in these lines can be balanced by decreasing the resistance in the low reading line. The direct currents should be balanced before attempting to balance the alternating current.

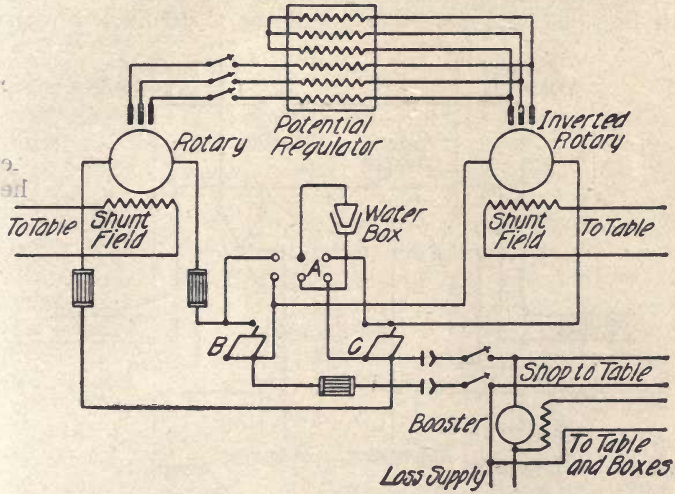


Fig. 33. Connections for Pumping Back Rotary Converters with Regulator

In running a pump back test there will be a slight difference in the direct current voltages of the two machines, equal to the *CR* drop of the set. The field of the inverted machine will be less than that required for minimum input and will carry the additional current necessary for supplying the core losses.

This method of supplying the C^2R losses from a booster requires such a large low voltage booster that it is not often used, except for small rotaries.

With a Booster in the A-C. Side

A second method of pumping back rotaries on full load heat runs is to use an induction voltage regulator in the alternating current side of the machines as shown in Figs. 33 and 34. The regulator is connected with its secondaries in series with the alternating current lines and its primaries across the alternating current terminals of the inverted machine. It is always preferable to connect the regulator between the inverted rotary and the dynamometer board. The regulator takes the place of the booster used in the previous method, and is very satisfactory for supplying the C^2R losses.

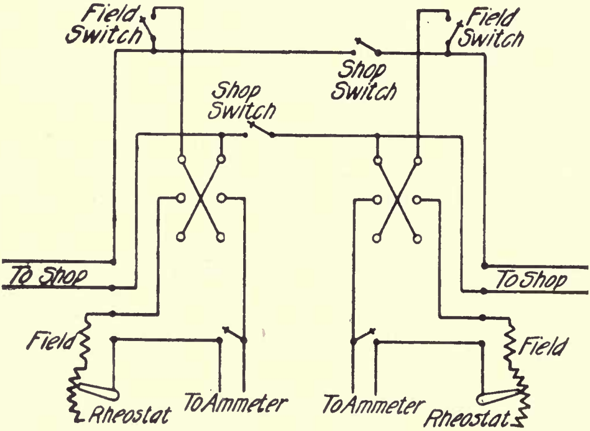


Fig. 34. Table Connections for Rotary Converter Pump Back

Starting the machines, checking the phase rotation, phasing in, and other operations already described, are repeated with this method. Always see that the regulator is set at the no boost point before phasing in, otherwise load will be thrown on when the switches are closed.

Load is increased by turning the core of the regulator in the direction of boost, the ammeter of machine No. 1 being watched at the same time. If the reading reverses from motor load, then No. 1 is running as a rotary; if, however, No. 1 does not reverse, the regulator should be turned in the opposite direction. This shows that the regulator is wrongly connected in reference to its markings; there is no necessity, however, to change connections.

Using A-C. Loss Supply

If, instead of supplying the losses from a direct current source of power, an alternator is connected across the alternating current lines, between the inverted rotary and the regulator as in the preceding method, the losses can be supplied at the alternating current end. When the alternator is large enough to start the rotaries, the wiring on the direct current end is greatly simplified. The starting panel is omitted and the shunt fields are connected according to the print of connections for the machine. Load is obtained by means of the regulator as before and the test carried out as already described.

If the alternator is too small to start the machines, the latter may be started singly from the direct current side as before, and the two phased together. The alternator is then synchronized with the pair. If only one machine can be started by the alternator, bring it up to speed, open all its circuits, and let it run by its own momentum while the second machine is quickly started. The excitation is then removed from the alternator field and the switches on the first machine are closed. Excite the alternator field and bring both machines up to speed together. After the machines are once started, they can be brought up to speed without an excessive current from the alternator.

CHAPTER XV

ALTERNATING CURRENT GENERATORS

Complete tests consist of special tests and temperature tests.

Special tests include saturation and synchronous impedance, and from these the regulation of the machine is calculated as follows:

Let V = normal voltage line, C = amperes line, R = hot resistance between lines.

For three-phase machines $C = \frac{\text{Kw.}}{\text{Voltage } \sqrt{3}}$

For two-phase machines $C = \frac{\text{Kw.}}{2 \text{ Voltage}}$

For three-phase machines, voltage drop in armature, $C_1R_1 = \frac{\sqrt{3}CR}{2}$

For two-phase machines, $C_1R_1 = CR$.

Let a_1 = amperes field on saturation curve corresponding to $V + C_1R_1$ and a_2 = amperes field on the synchronous impedance curve corresponding to C.

The amperes field required to produce normal rated voltage with full load on the generator will be

$$a_3 = \sqrt{a^2_1 + a^2_2}.$$

Let the voltage on the saturation curve corresponding to $a_3 = V_1$.

Then the per cent regulation $= \frac{V_1 - V}{V}$

If it is desired to calculate the regulation of the machine at any power-factor, then C becomes $\frac{C}{\%\text{P-F.}}$ and $a_3 = \sqrt{a^2_1 + a^2_2 + 2a_1a_2 \sin \theta}$ when θ is the angle of which the per cent power-factor is the cosine.

Input-output efficiency test is made by the input-output method.

Standard efficiency test is made by the method of losses.

The calculation of a standard efficiency test is made as follows:

Let V_L = volts line
W_b = output = $\sqrt{3} V_L \; C_L$ for three-phase and $2 \; V_L \; C_L$ for two-phase
C_L = amperes line R_1 = hot res. of armature between lines
C_1 = amperes field
R_2 = hot res. of field
W_1 = open circuit core loss corresponding to $V_L + CR$ on the core loss curve
W_2 = short circuit core loss corresponding to C_L on the short circuit loss curve
W_3 = friction and windage obtained from core loss test

C_1 is calculated for each load, as in the test for regulation.

CR = the drop in the armature $= \frac{\sqrt{3}}{2} C_L \; R_1$ for three-phase machines and $C_L \; R_1$ for two-phase.

$\Sigma W = W_1 + \frac{1}{3} W_2 + W_3 + \frac{3}{2} C_L \; R_1 + C_1^2 \; R_2$ for three-phase machines
$= W_1 + \frac{1}{3} W_2 + W_3 + 2 \; C_L^2 R_1 + C_1^2 R_2$ for two-phase machines
Watts input = $W_a = W_b + \Sigma W$

$$\text{Efficiency} = \frac{W_b}{W_a}$$

W_3 need not be considered if the machine is furnished without base, shaft or bearings.

The above method of calculation is used when the machine is to operate at unity power-factor.

If it is desired to calculate the efficiency at any power-factor, the following calculations must be made:

$$C_L = \frac{\text{Kw.}}{V_L \times \sqrt{3} \times \% \text{ P-F.}} \text{ and}$$

$W_b = \sqrt{3} \times V_L \times C_L \times \%$ P-F. for three-phase machines

$$C_L = \frac{\text{Kw.}}{V_L \times 2 \times \% \text{ P-F.}} \text{ and}$$

$W_b = 2V_L \times C_L \times \%$ P-F. for two-phase machines.

C_1 should be calcultaed for various power-factors as given under regulations.

The change in the line current will affect C_1, W_1, W_2, and the C^2R of the armature. See Fig. 35 and Table XIII.

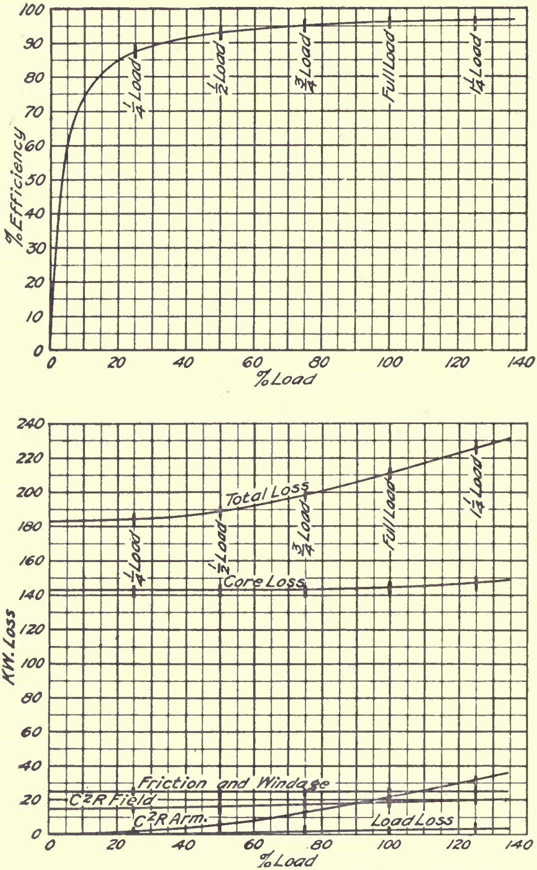


Fig. 35. Efficiency and Losses on a 5000 Kw., 11000 Volt, 3-Phase A-C. Generator

TABLE XIII

Efficiency aud Losses of a 5000 Kw., 11,000 Volt, 28-Pole, 60 Cycle, 3-Phase Generator

% Load	0	25	50	75	100	125
Volts Line	11000	11000	11000	11000	11000	11000
Amps. Line	0	65.5	131	196.5	262	317
Amps, Fld.	220	224	228	235	245	257
CR	—	12	24	36	48	50
(V+CR)	11000	11012	11024	11036	11048	11050
Core Loss	143000	143000	143100	143006	144100	147000
⅓ Short Cir. Core Loss	—	—	200	580	1300	2500
C R Arm.	0	1330	5320	12000	21300	31100
C²R Fld..	14500	15000	15600	16600	18000	19800
Friction	25000	25000	25000	25000	25000	25000
Total Losses	182500	184330	189220	197700	209700	225400
Kw. Output	0	1250	2500	3750	5000	6250
Kw. Input	182.5	1434	2689	3948	5210	6475
% Efficiency	0	87.3	93.0	95.0	96.0	96.5

Res. Arms. (Line) 0.1927 Ohms 25 deg. C. 0.207 Ohms Hot.
Res. Fld. 0.2795 Ohms 25 deg. C. 0.3005 Ohms Hot.

Non-inductive normal load heat runs consist in running the machine under normal load at unity power-factor until constant temperatures are reached. These final temperatures are then recorded and readings taken of regulation with unity power-factor.

Non-inductive overload heat runs consist in bringing the machine to normal load temperatures, applying the overload at unity power-factor for the specified times and recording the overload temperatures. Readings for regulation at unity power-factor should be taken.

Normal load and overload power-factor heat runs are made in the same way as normal and overload non-inductive runs, except that the machine is operated at a specified power-factor. Wattmeters should be used with the voltmeter and ammeters to determine the power-factor.

CHAPTER XVI

SYNCHRONOUS MOTORS

The preliminary tests taken on sychronous motors consist of drop on spools, air gap, resistance measurement, balancing of phase voltages, phase rotation and running free minimum output.

Complete tests consist of special tests and normal and overload heat runs.

Special tests consist of starting tests, open and short circuited core loss, saturation, synchronous impedance, no load and full load phase characteristics, and wave form. The method of taking phase characteristics has previously been described.

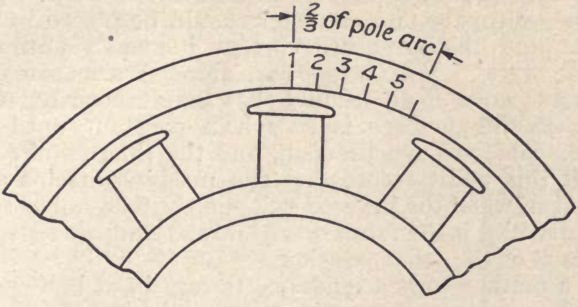


Fig. 36

Starting tests should be made both with and without a compensator, if the motor is of a new type and rating and is to be started with a compensator when installed. If the motor does not form part of a motor-generator set, it should be belted to a generator so that it will have some load at starting.

The motor should first be tested for starting without the compensator. The center line of one pole is placed in line with the center line of the frame and 180 electrical degrees marked off in a clockwise direction from this line on the head end of the motor. The total length of this scale should be two-thirds of the distance between the center lines of adjacent poles for three-phase machines, one-half for two-phase machines, and one-third for six-phase machines. The scale should be divided into four equal parts, each division line being numbered. On each one of these scale divisions, the center line of the marked pole should be placed and the motor started. Thus five tests are made to insure that the motor will not stick in any position. (See Fig. 36.)

With the pole A moved to position No. 1 and the machine at rest, sufficient current should be sent through the armature to give a reasonable reading of amperes and volts on the various phases, and induced volts on the field. The induced volts field should be read by a potential transformer and alternating current voltmeter. These readings are taken to determine which phase gives maximum readings of current and voltage.

The voltmeter and ammeter should be placed in this phase and the armature current increased until the motor starts. Volts armature, amperes armature and induced volts field should be simultaneously read. The starting voltage is now held constant until the motor comes to synchronism, and the time required to reach this point recorded. The machine attains synchronism when the induced volts on the field fall to zero. The machine is then shut down and the tests are repeated for each of the other positions.

If a motor shows a tendancy to remain at half speed, the alternating current voltage should be increased until the motor breaks from half speed and comes up to synchronism, the voltage required to accomplish this being held until full speed is reached and then recorded.

If the test is required to be made with a compensator, the motor should be set with its field in the position where greatest starting current is taken and allowed to rest in that position for at least six hours until the oil is well pressed out of the bearings. This is done in order to obtain the worst starting conditions likely to occur in normal operation. Connections are then made to the lowest tap of the compensator, and with normal voltage held on the line the starting switch of the compensator is closed. If the motor fails to start, the voltage must at once be switched off and connections made with the next higher taps on the compensator, and so on until the motor starts. Readings should be taken on each of the taps of the compensator in the starting position, with the machine at rest, to determine the voltage ratio of the taps of the compensator. All these tests should be made with the field circuit of the motor open, and enough time allowed between trials to permit the compensator to cool, since it is designed for intermittent service only. See Table XIV.

Input-output efficiency test is made by the input-output method.

Standard efficiency tests are made by the method of losses. In calculating efficiency, the same nomenclature is used as that employed for alternating current generators. C_1 is either taken from the phase characteristics or is calculated in the same manner as for alternating current generators.

Watts input $W_a = V_L C_L + C_1^2 R_2$.

Watts output $= W_b = W_a - \Sigma W$.

Efficiency $= \frac{W_b}{W_a}$

W = open circuit core loss corresponding to $V_L - CR$ on the core loss curve.

Horse power output $= \frac{W_b}{746}$

See Table XV and Fig. 37.

The non-inductive load heat run is made as follows: Run the machine under load at unity power-factor until it has reached constant temperature and record temperatures. Take readings of regulation at normal and no load and full load phase characteristics.

The non-inductive overload heat run consists in bringing the machine to normal load temperature, applying the overload for the specified time, recording temperatures and taking readings of regulation at unity power-factor.

Normal load power-factor heat run is similar to the normal load non-inductive run, except that the machine is operated at a specified power-factor. Wattmeters should be used as described for alternating current generators.

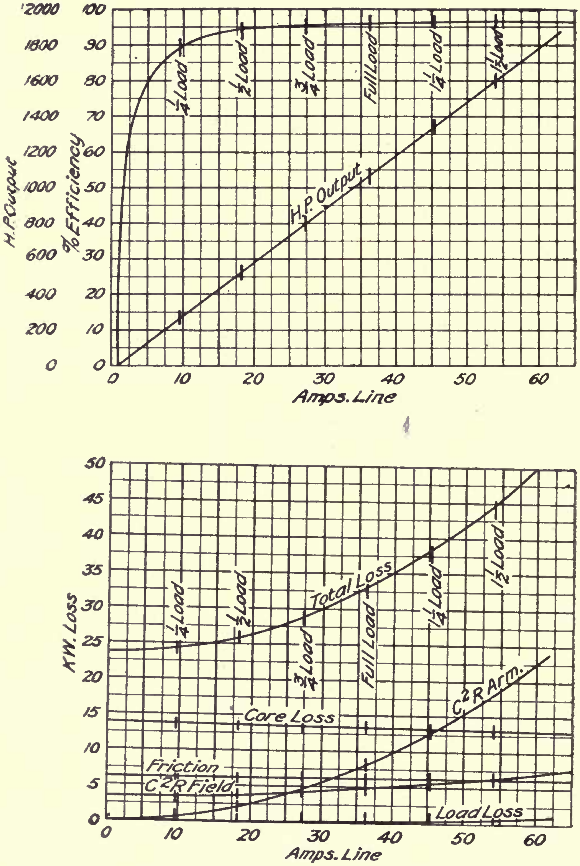


Fig. 37. **Efficiency and Losses on a 1070 H.P., 13200 Volt, 3-Phase Synchronous Motor**

Overload power-factor heat run is similar to the overload non-inductive run, except that the power-factor is less than unity.

TABLE XIV

Starting Test on a 425 Kw., 11,000 Volt, 8-Pole, 25 Cycle, 3-Phase Syn. Motor

	VOLTS LINE			AMP. LINE			Ind. Volts per Spool	Pos at Start	Time to Syn.
	1–2	2–3	1–3	1	2	3			
Rest	1340	1430	1480	15	17.5	15.2	52	1	
Start			2650		35		90.7		
Syn.	2650	2650	2650	9.2	9	89.			66 Sec.
Rest	1255	1340	1340	15	16	13.6	47	2	
Start		2560			30		88.3		
Syn.	2560	2560	2560	9.5	9.3	9.2			70 Sec.
Rest	1155	1300	1320	15	14	12.7	45	3	
Start			2380	29.5			84.7		
Syn.	2380	2380	2380	10	10.2	10			70 Sec.
Rest	1248	1260	1165	15	12.8	13.8	44	4	
Start		2590		33			80.8		
Syn.	2590	2590	2590	9	9.3	9.5			68 Sec.
Rest	1400	1308	1302	15	13.9	16.2	49	5	
Start	2620					32	87		
Syn.	2620	2620	2620	8.9	9.1	9.3			64 Sec.

Is there any tendency to stick at half speed? No.

TABLE XV

Efficiency and Losses of a 1070 H.P., 13,200 Volt, 6-Pole, 25 Cycle, 3-Phase Syn. Motor

% Load . .	0	25	50	75	100	125	150
Volts Line . .	13200	13200	13200	13200	13200	13200	13200
Amps. Line . .	—	9.5	19.0	28.5	38.0	47.5	57
Amps. Fld. . .	50.1	50.6	51.0	55.1	59.7	63.8	68.9
CR . . .	—	34.5	69.0	103	168	172	205
(V – CR) . .	13200	13165	13131	13097	13032	13028	12995
Core Loss . .	13900	13800	13700	13600	13500	13400	13300
⅓ Short Cir. Core Loss . .	—	47	107	190	310	473	760
C^2R Arm. . .	—	565	2265	5100	9040	14100	20400
C^2R Fld. . .	3550	3630	3680	4300	5050	5770	6710
Friction . .	6272	6272	6272	6272	6272	6272	6272
Total Losses .	23722	24314	26024	29424	34172	40015	27442
Kw. Input . .	23.72	220.63	436.68	654.3	870.05	1089.8	1306.7
Kw. Output . .	0	196.32	410.66	624.8	835.9	1049.8	1259.3
H.P. Output .	0	263.2	550	837	1121	1408	1689
% Efficiency .	0	89.0	94.4	95.5	96.1	96.3	96.4

Res. Arm. (Line) 3.86 Ohms 25 deg. C. 4.18 Ohms Hot. 47. Res. Fld. 1.34 Ohms 25 deg. C. 1.42 Ohms Hot 40

CHAPTER XVII

INDUCTION MOTORS

The preliminary tests made on induction motors include the measuring of the air gap, bearing and end play, slip and resistance, as well as the tests for starting, running light, excitation and static impedance.

Special measuring scales are used for taking induction motor air gap.

Bearing play is taken by measuring the gap at the top, bottom and on each side. With the rotor in the same relative position to the stator, that is, without turning the rotor, the motor is turned over in all four positions of the quadrant and the same measurements of air gap taken. Any defects in the bearings which will affect the air gap of the machine are thus disclosed.

A starting test on form K* motors is made by switching the machine onto the line at a low voltage and then increasing the voltage until the motor starts, the current and voltage at this point being recorded. The starting current should not exceed 200 per cent normal current. This test is occasionally made with a compensator.

With all the internal resistance in the rotor circuit, full line voltage should be impressed on form L motors and the starting current recorded. This current should not exceed normal current.

Form M motors are started at full line voltage with all the external resistance in the rotor circuit, and the starting current is recorded, which should not exceed normal value. Sometimes the collector rings on form M motors are short circuited and the starting test made at reduced voltage, as in the case of form K motors.

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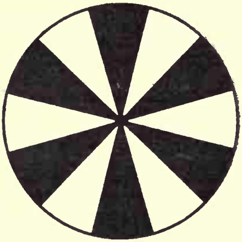
* K, M and L are trade symbols, denoting the three types of induction motors. K is the squirrel cage machine; M the slip-ring type; while L has a wound rotor with an internal resistance which may be cut out in steps.

Slip is usually measured at full load and running light by means of the slip indicator. During this test, constant speed must be held on the driving alternator, and constant voltage on the motor.

To take slip by the lamp method, an arc lamp is connected in the circuit from which the motor is running. On the end of the motor shaft a disk is placed which has as many white and black sectors as there are poles in the motor. As the lamp is running from an alternating current source, the current wave passes through zero twice in each complete cycle. At the zero instant, the light given out by the lamp is a minimum.



Slip Disk for 6-Pole Motor

Consider a six-pole 60 cycle motor running at 1200 r.p.m., that is to say, at 20 revolutions per second; then $20 \times 6 = 120$ black sectors passing a stationary point on the circumference of the disk in one second. As the frequency is 60, the number of maximum illuminations will be 120. At each maximum illumination, therefore, the black strips will always occupy the same positions. However, the slip which always occurs in an induction motor will cause the black strip to lag by a small angle behind the position occupied at the previous illumination. These successive differences in position appear as a sector rotating backwards, which can be followed by the eye. The slip, that is, the difference between the actual speed and the synchronous speed of the motor per minute, can thus be counted.

The resistance of the stator should be measured cold and hot.

Running light is taken by applying normal voltage to the stator and reading the amperes input to the motor. Static impedance is taken by blocking the rotor and applying such a voltage to the stator as will give about full load current, reading the current in each leg, together with the voltage between each of the legs. If the motor is of the form L type, impedance is taken with the resistance all in and then all out, always holding the same voltage across the stator. This practice has been found to give the best results. End play should be tested both with and without voltage on the stator, and on all motors particular care should be taken to see that the rotor is in perfect balance.

When cutting out the internal resistance, the starting switch of form L motors should be watched closely for sparking or any other defects. The brushes must make good contact on the resistances in all positions and the switch must not work too easily, otherwise the resistance may be cut out too rapidly.

On form M motors, the brushes must fit the collector rings perfectly, as a successful test on this type of motor depends considerably on a good fit. The voltage ratio should be taken on form M motors by impressing normal voltage on the stator and measuring the voltage between the rings of the rotor on open circuit. Volts and amperes stator, and volts between rotor rings should be read and recorded.

Two speeds on a motor can be obtained by changing the connections on the stator by means of a switch and connection board, these changes altering the number of effective poles. These machines are usually run at the lower speed during test. The rotor must have the correct number and ratio of slots in the stator and rotor, otherwise dead points may occur at certain starting positions, or again the motor may operate at subsynchronous speeds.

Excitation

The tests for excitation and impedance are important, and the following precautions must be observed in all cases. The calculation of the characteristic curves of induction motors depends entirely on test results, and great care must therefore be taken to obtain accurate measurements.

The motor should be located so that all the conditions affecting its operation during test remain unchanged throughout the run. A solid foundation is necessary to prevent vibration at full speed, and the table must not be near any source of stray field. The driving alternator should be at least ¾ the kw. capacity of the motor.

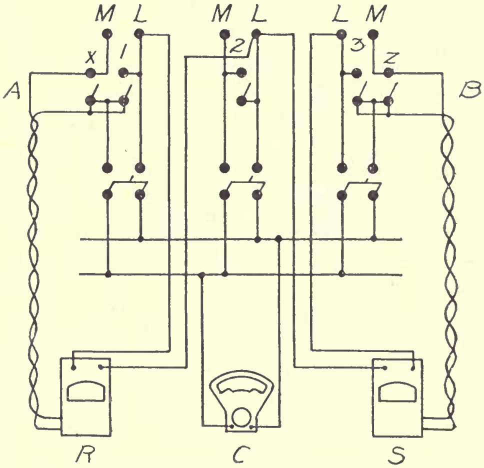


Fig. 38. Wattmeter Connections for Excitation

The transformers and other apparatus must be connected so that the alternator will work under normal conditions, since satisfactory wattmeter readings cannot be obtained if the alternator is run too low on the saturation curve. Transformers, when used, must be well balanced and not forced beyond their voltage range, otherwise unsatisfactory results may be obtained.

The table must be adapted for wattmeters by providing a special wattmeter switch connected on two of the three phases as shown in Fig. 38. A and B are the terminals for the current leads to the wattmeters, X and Z being the short circuiting switches. Calling the phases

1–2–3, then phase 1 is on the current coil of wattmeter R, connected at A, and the pressure coil is connected across 1 and 2. Likewise with the other meter S, the current coil of which is on phase 3 at B, with its pressure coil between 2 and 3. If the voltage is too high for direct use on wattmeters, multipliers (non-inductive coils of known resistance) or potential transformers must be connected between the meter and the volt lines at the table.

On motors of less than 40 h.p. the lines to the primaries of the potential transformers must be attached to the generator side of the lines coming to the top of the dynamometer board. If placed on the motor side of top of the board, or on the motor terminal block, the excitation current of the potential transformer passes through the wattmeters. Although this current is small, with a small motor it may be an appreciable percentage of the excitation current. Hence an error is caused and an abrupt break made in the excitation curves every time the ratio of the potential transformer is changed. On large motors the excitation current of the potential transformer is so small in comparison with the motor current that the incidental errors are negligible. The above does not apply to multipliers because they are non-inductive.

On large motors the volt leads should always be attached to the terminal block in order to eliminate the line drop in switches and leads from the table to the motor. The current leads to the wattmeters should be twisted together throughout their length and come direct from the terminal to the meter without loops or sharp turns. All connections must be kept tight and clean.

The air gap should be taken before the test is started. On voltages above 500 volts all instruments must have any static charge thereon discharged and a small fuse connected between the current terminal and the nearest volt terminals of the wattmeter. Do not ground the secondaries of the transformer.

As soon as the machine is wired and ready to start, the switches on the dynamometer board should be closed.

(Always see that the wattmeter switches are closed whenever a change in the field current is made.) The exciter field switch is then closed and the voltage brought up slowly until the motor starts and reaches normal speed. The machine should then be inspected to see that it is operating normally and the amperes and volts in the different phases read and any unbalancing corrected or its cause discovered.

The end play of the motor should be tested next, since the rotor must always run centrally in the frame. A slight pressure against one side will change the friction watts and give an incorrect value to the core loss. Small motors should be run about one hour and a half and large ones two hours and a half or more, to obtain constant friction before starting tests. If the wattmeter needle goes off the scale in a negative direction when connected in circuit, the current leads on the current terminals should be interchanged. On a two-phase circuit, with a machine underload, both wattmeters should read positive.

For running light readings on a three-phase machine the sign of the meter must be determined, since one reads negative on the upper part of the curve. With both meters reading positive, one of the phases containing the current coil of the wattmeter should be opened and the other meter observed. If the needle drops off the scale below zero the meter reads negatively. If the needle drops to some value above zero the reading is positive. This process must be repeated for determining the readings of the other wattmeter.

The alternator speed must be held constant during the test and about 130 per cent normal volts used for the first reading; volts, amperes, watts and speed of generator and motor being read and recorded. The volts should then be decreased in steps so as to obtain about 20–25 points on the curve, down to 10 or 15 per cent of normal volts. Here the conditions are no longer stable. The meter with the negative sign will read less than the other, and its readings will fall off more rapidly, becoming less and less until zero is reached and its sign changes. When it becomes positive, the current leads must be interchanged.

After the volts have been reduced from the starting point of the curve to normal, three single-phase wattmeter readings, one above, one below and one at normal voltage, should be taken on the two legs to check the results. Check readings should also be taken with a different voltmeter and ammeter.

The single-phase excitation amperes are theoretically 1.73 times the three-phase and twice the two-phase values; that is, the kv-a. has equal values for the motor whether single-phase or polyphase. Practically, the single-phase amperes are from 1.6 to 1.7 times the three-phase, instead of 1.73 times. The ratio, twice, holds for quarter-phase. The watts excitation is the same for polyphase or single-phase, so far as core loss is concerned. The increase in watts single-phase over the watts polyphase is equal to the polyphase C^2R. For instance, if the three-phase excitation requires 1000 watts and the C^2R three-phase is 100 watts, the single-phase excitation will be 1100 watts.

Before shutting down, a curve should be plotted with volts as abscissæ and the algebraic sum of the watts as ordinates.

Wattmeter work may be somewhat uncertain, and accurate results can only be obtained under good conditions. An endless belt on the driving alternator is necessary, a laced belt making the wattmeter needle swing with a steady beat corresponding to the striking of lacing on the generator pulley. Any belts running near the table must have their static charges drawn off by a grounded wire and the cases of all transformers should be connected together and grounded. Wattmeters must be carefully handled on high voltages, since all three phases of the alternator are connected on the table and contact between two of the instruments short circuits one of the phases.

The two important points on an excitation curve are the watts at normal voltage and friction watts. These points determine the percentage core loss for the motor. Several readings, only a few volts apart, should be taken on each side of normal voltage and the volts and amperes in the different phases at two or three other points in the curve should be carefully read and recorded as a check on the balance of the motor. As the lowest point of the curve, or friction reading is approached, many readings should be taken. This portion is the most difficult part of the curve to locate, especially in the case of large motors, as in many instances "hunting" begins at a low voltage. A reading taken when the motor is accelerating is greater than the steady reading.

Hunting usually makes the meter needle swing with a slow beat, the range of the beat varying with the size of the motor and degree of hunting. Bad cases of hunting are not numerous and reliable readings can generally be secured between beats. To test successfully, the speed of the driving generator must be kept constant and no reading taken until the speed is properly adjusted. The tachometer used must be carefully checked.

The excitation tests on all forms of induction motors are the same.

The form M motor is provided with collector rings for the external resistance. These must be short circuited at the brush-holder terminal and the brushes carefully sandpapered until they fit the rings accurately.

Calculation of Excitation Test on Induction Motors

All readings must be corrected for the instrument constants and ratios used. Special care should be taken to use the proper signs for the wattmeter readings. Table XVI shows the form used in calculating an excitation test, and Fig. 39 the method of plotting it. The friction and windage watts are obtained from the excitation curve by producing the watt curve to zero volts.

Impedance

In the motor having a symmetrical bar winding in the rotor the impedance is the same for any position of the stator relative to the rotor.

On motors which have wound rotors, a position curve is first taken. Two-thirds of the distance between two consecutive poles on a three-phase motor and one-half that distance on a quarter-phase motor are marked off

TABLE XVI

Excitation on a 100 H.P., 2080 Volt, 6-Pole, 60 Cycle, 3-Phase Induction Motor

Volts	Amps.	Watts +	Watts —	Total Watts
2510	11.5	18300	12150	6150
2370	10.4	15500	9900	5600
2175	9.5	12900	8000	4900
2105	9.2	12090	7368	4710
2075	8.8	11470	6920	4550
2020	8.6	10870	6370	4500
1830	7.7	9060	5060	4000
0610	6.76	6950	3450	3500
1440	6.03	5740	2670	3070
2160	15.4	5150	—	—
2070	14.6	4750	—	—
2000	14.2	4550	—	—
2070	14.6	—	4950	—
2200	15.85	—	5040	—
2235	15.9	—	5540	—
1366	5.78	5440	2310	3130
1185	5.08	4390	1540	2850
988	4.3	3185	685	2500
816	3.75	2550	178	2372
585	3.35	1670	+380	2050
485	3.25	1370	530	1900
292	3.9	1200	644	1844
244	4.85	1210	673	1883
176	5.8	974	500	1474

on the bearing bracket, this space being divided into about eight parts. A pointer should be attached to the motor shaft or pulley so that its outer end will pass over the division marks; it is then set on mark 1 and the rotor blocked so that it cannot move from that position. The switches are next closed and the impressed voltage increased gradually until about normal current is obtained. Volts and amperes should be read and recorded on all three phases to make sure that no unbalancing occurs. Holding the same volts as for position 1, the pointer is moved to mark 2, and the amperes read; this procedure being repeated oneach of the succeeding marks and a curve plotted, giving amperes and pointer position. The motor is then blocked in the position which gives an average value of the current. Form K induction motors are blocked in any position.

The current is then increased until 150 per cent normal current is obtained, and the amperes, volts and watts are read. The sign of the wattmeter must be determined in the same way as at the beginning of the excitation test. About six or eight readings should be taken between zero and 150 per cent normal current, but the current should not be held on the motor longer than necessary to secure a reading. After each reading the exciter field should be opened, until ready for the next reading, otherwise the motor will get too hot. As soon

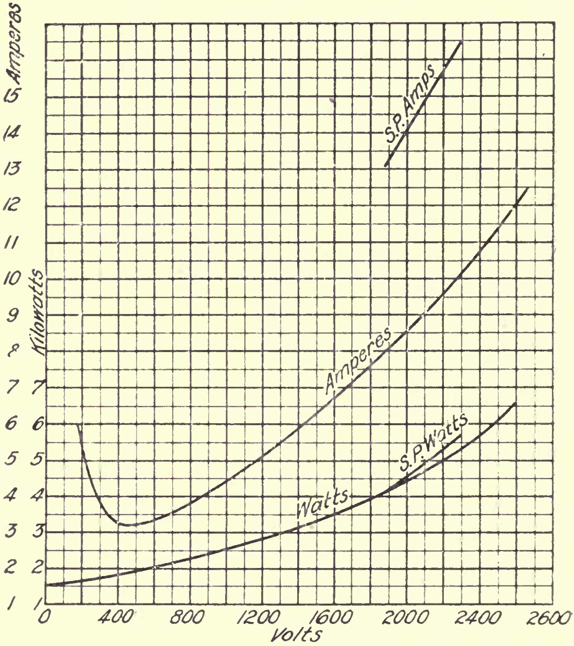


Fig. 39. Excitation Curve on a 100 H.P., 2080 Volt, 1200 R.P.M., 60 Cycle, 3 Phase Induction Motor

as the readings are taken, curves should be plotted with volts as abscissæ, and amperes and the algebraic sum of the watts as ordinates. The ampere curve should be a straight line, through sometimes the top portion curves upward very slightly.

Single-phase check readings should be taken, one above, one below and one at normal amperes, on the two phases containing wattmeters.

The single-phase impedance current should be 86.5 per cent of the three-phase (line) values. The single-phase impedance watts should be approximately half of the three-phase watts. In a quarter-phase motor single-phase impedance is the impedance of one of the two phases.

TABLE XVII

Impedance on a 100 H.P., 2080 Volt, 6-Pole, 60 Cycle, 3-Phase Induction Motor

Volts	Amps.	Watts +	Watts —	Total Watts
146	11.9	1230	445	785
188	15	1870	660	1210
220	18	2825	1080	1745
263	21.5	4060	1485	2575
301	24	5260	1930	3330
355	28.5	7255	2845	4410
384	30.7	8360	3190	5170
410	33	9450	3710	5740
455	36	11680	4450	7230
297	20.6	—	1460	
272	19.1	—	1190	
322	22.2	—	1680	
273	19	1255	—	
297	20.5	1500	—	
322	22.2	1720	—	

On form M motors, when taking impedance, the collector rings should be short circuited either by metal brushes or by metal strips, as the contact resistance varies with carbon brushes. The ratios between the primary and secondary voltage should be taken with the secondary open circuited.

Calculation of Impedance Test on Induction Motors

Table XVII shows the form used in calculating an impedance test, and Fig. 40 the method of plotting it.

Torque

Two methods are used for measuring torque on induction motors, one employing a spring balance and the other a special torque indicator.

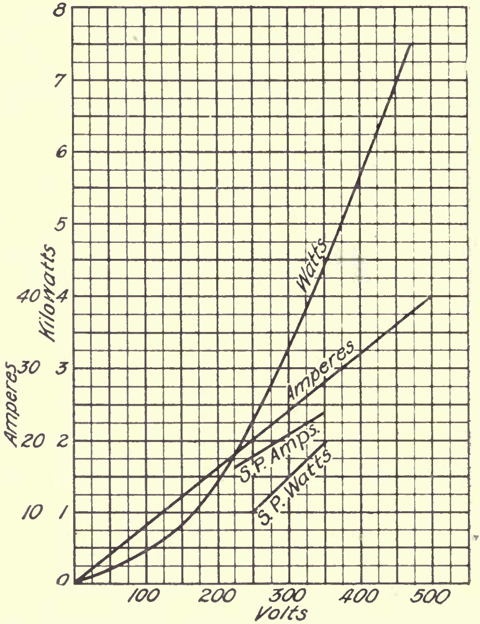


Fig. 40. Impedance Curve on a 100 H.P., 2080 Volt, 1200 R.P.M., 60 Cycle, 3-Phase Induction Motor

In the first method a wooden brake lever is clamped around the pulley as shown in Fig. 41. The size and length of lever depends on the size of the motor, the length being chosen to give a maximum reading at one-half or two-thirds the capacity of the spring balance used, Let the point of attachment to the lever be at X; then the length of the lever arm $= XY$. On the frame of the motor a mark should be made at M, and a pointer, P, attached to the lever as shown. The lever arm is then raised until the distance $XT=YS$, and the pointer set so that it is on mark M. If the weight of the lever alone is not sufficient to overcome the friction of the bearings and turn the rotor round till the end of the lever touches the floor, attach a weight at W. Now if the spring balance H is pulled upwards until the pointer P is on mark M, XY will be parallel to TS, and the pull X will make an angle of 90 deg. with the center of the shaft—the position in which all readings must be taken.

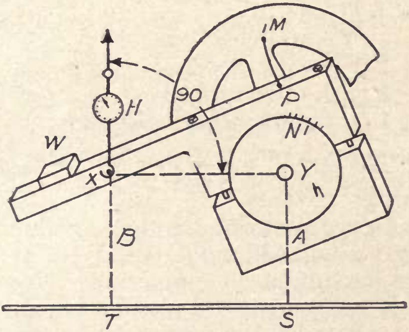


Fig. 41. Measurement of Torque by Means of Spring Balance

Open all switches on the dynamometer board to eliminate the residual magnetism of the alternator, raise the lever arm by pulling vertically on the spring balance till the pointer passes the mark M, and at the instant of passing take a reading of the spring balance. Call this reading $W+F$. Let the lever be raised until the pointer is some distance beyond M; then lower the spring balance and let gravity pull the lever toward the floor, reading the balance when the pointer passes the mark. Call this reading $W-F$. To get good readings, the lever arm should be moved rather slowly, but steadily, and with as nearly constant speed as possible, a reading of the balance being taken every time the pointer passes the mark. As a check, three or four readings should be taken as described above.

Close the line switches and increase the amperes to twice normal and take readings as before; also read volts and amperes. Call the reading obtained as the pointer passes the mark as the lever goes up, $W+F+T$, and that obtained as the lever comes down, $W-F-T$, T representing torque.

Readings should be recorded as below, assuming that they were taken on a 440 volt motor:

Volts, 150; Amps., 40; $W+F$, 9 lb.; $W-F$, 5 lb.; $W+F+T$, 19 lb.; $W-F+T$, 15 lb.; T, 10 lb.

To find the torque:

$2W=14. \quad . \quad .w= \ 7$ lb.

$2(W+T)=34$ lb.

$T=10$ lb.

Torque at 1 ft. radius $T\times L$

Where $L=$length of lever arm

Torque at 1 ft. radius at normal volts

$$=\left(\frac{(\text{normal volts})^2}{(\text{volts read})}\right)\times T\times L$$

On squirrel cage or wound rotors a value of current should be used which will make $W+F+T$ at least twice $W+F$. The maximum and minimum values of $W+F+T$ and of $W-F-T$ should also be taken.

All wound rotors and most squirrel cage rotors will show a torque variation depending on the rotor position.

As a check on the torque readings, the lever should be loosened on the pulley and the pulley rolled forward until the mark on its rim at N is in line with a second mark on the lever arm, thus changing the relative positions of the rotor and stator. Further readings should be taken and this procedure repeated for four or five different points. The torque should be the same for all points on form K motors.

A special consideration to be observed in making a test for torque is the maintaining of a constant and correct generator speed. The volts read, when amperes are 200 per cent normal on the first point, should be held constant on all other points, since the torque varies as the square of the volts. The torque also increases as the resistance of the rotor winding increases owing to heating. On large machines the rotor winding sometimes becomes quite hot, so that the temperature of the end rings and bars of the winding should be taken and recorded.

Starting Resistance

The form L motor has a starting resistance in the rotor which in the smaller sizes is controlled by means of a rod sliding within the shaft and in the larger machines by a lever and ratchet combination. The resistance of the different starting steps must be measured.

The rod should be pulled out to the full extent by means of the knob handle, thus putting all the resistance in circuit. The rod is then divided into five equal parts and from the impedance test the voltage that will give about 125 per cent normal amperes when the rod is in the running position (resistance all cut out) is found. Apply this voltage, and with the rod in the first position read volts and amperes stator. Similar readings should be taken on each of the five different steps marked on the rod. The same procedure holds good for the larger machines, where the resistance is cut out step by step. These readings, with the resistance in circuit, must be taken as quickly as possible, otherwise the resistance becomes unduly heated and may be injured.

Table XVIII shows the form used in calculating stationary torque on induction motors.

Efficiency

Input-output efficiency and power-factor tests can be made by either the "string brake" or "pumping back" methods. Neither of these methods are particularly accurate nor are they recommended.

In the "brake method" the size of the brake limits the size of the motor tested. In Fig. 42, *L* is a lever or scale beam suspended at the point X From *T* the small platform *A* is suspended, on which calibrated weights are placed. *P* is a flat faced pulley on the shaft of the motor, running in the direction shown by the arrow; *i.e.*, toward the lever *L*. One end of a small rope is attached at *B*, which is wound one or more times

TABLE XVIII

Stationary Torque on a 15 H.P., 220 Volt, 6-Pole, 60 Cycle, 2-Phase Induction Motor

Lever Arm.	Con-troller Pos.	Volts	Amp.	W+F	W—F	W+F+T	W—F+T	W	W+T	T	Norm. T 1 Ft.
2 ft.	1	220	21–41	16.25	14.25	33	33	15.25	33	17.75	35.5
	2	220	36–39	17.25	14.25	50.75	28.75	15.75	49.75	34	68
2.292 ft.	2	220	38–37	17.25	16.25	47.75	47.75	16.75	47.75	31	71
	3	220	57–34	17.25	16.25	54.75	53.75	16.75	54.25	37.5	86
	4	220	96–44	17.25	17.25	67	66	17.25	66.5	49.25	113
	4	220	98–45	17.25	17.25	68	66	17.25	67	49.75	114
	6	209	121–92	16.25	16.25	78	78	16.25	78	61.75	156
	7	187	195–97	17.25	16.25	61.75	59.75	16.75	60.75	44	139
	8	175	173–162	16.25	15.25	51.75	50.75	15.75	51.25	35.5	128.7

Lever Arm. = 2 ft. and 2,292 ft.
Normal running torque at 1 ft. radius = 65.6 lb.

around the pulley. The other end is made fast to a spring balance *G*. A strip bearing a mark is located at *K* so that when the point of the lever *L* comes opposite to the mark, the lever is in a horizontal position at an angle of 90 degrees to the force exerted by the pulley.

Since the stress along a rope is transmitted through its center, adjust the brake until the points *M* and *N* are a distance apart equal to the diameter of the pulley plus the diameter of the rope, one-half the diameter of the rope being added to each side of the pulley. This adjustment must be accurately made and care taken to see that nothing moves to throw the brake out of line or proper adjustment. When ready, slip the rope off the pulley but leave it attached at *B* and *G*, then balance the lever until the pointer on the end comes to rest at the mark *K*. This balancing of *L* must be repeated each time the rope is changed.

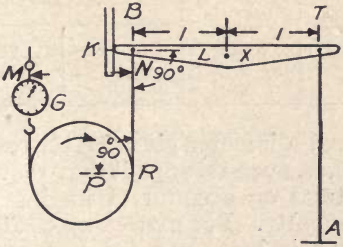


Fig. 42. Diagram of Apparatus Used in Taking Input-Output by the String Brake Method

The motor should be run light for at least one hour before the test proper is commenced, so that friction may become constant. Since speed is one of the important factors in the output of the motor, it should be taken very carefully. The slip should be taken with the slip machine.

Running light readings should now be taken on the motor, the impressed voltage, as well as the frequency, being held constnat. A small weight is next attached to the spring balance to give enough tension on the spring for a reading on the balance of a quarter or half a pound.

This "no load" scale reading must be recorded and subtracted from all subsequent readings taken.

A small weight is now placed on *A* and the spring balance *G* pulled up until the pointer on lever L reaches *K*; when the motor volts and speed of the generator are normal and all meters are steady, the volts, amperes, watts, weights on *A*, spring balance deflection, and speed given by the tachometer should be read. A reading should also be taken with the slip machine. Continue to add weights to *A* and take readings until the breakdown load of the motor is reached. The readings should be recorded in the following manner:

Volts Amps.	+ Watts	— Watts	WEIGHT TENSION		Speed of Slip Motor
			On *A*	On Balance	

A rope of small diameter gives better results than one of large diameter, even through it may require more time to make the tests on account of having to renew the rope more frequently. For motors up to 20 h.p., a ¼ in. oiled hemp rope is best, and for motors from 20 h.p. to 50 h.p., a ½ in. rope can be used. The rope will usually last longer if doubled, and two strands used in parallel. The rope should be wrapped around the pulley one and a half times, care being taken to have no strands twisted or crossing each other; all strands should lie closely and evenly together on the face of the pulley. The tension read on the balance *G* will vary with the temperature of the rope and may differ widely with different loads.

The additional weight added to *A* each time should be such as to allow of from fifteen to twenty readings between no-load and breakdown.

When the breakdown point has been reached and complete readings taken and recorded, the diameter of the pulley should be carefully measured.

Weight on $A-$(tension on balance)$-$ ("no load" reading on balance)$=$actual load in pounds$=P$.

Normal speed − slip = actual speed of motor.

R = radius of pulley in inches + ½ diameter of rope.

S = speed in revolutions per minute.

$$\text{Power-factor} = \frac{\text{watts}}{\text{volts} \times \text{amps.}}$$

$$\text{Then horse-power} = \frac{2\pi R \times P \times S}{12 \times 33{,}000}$$

$$\text{Efficiency} = \frac{\text{horse-power output} \times 746}{\text{watts input}}$$

Considering Fig. 43, let *M* be the motor and *L* the load machine, the latter being a direct current machine of about the same capacity as the motor, belted to the motor and separately excited from a suitable source.

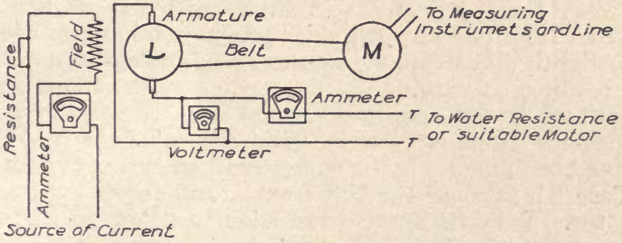


Fig. 43. Connections for Measuring Input-Output by Pumping Back

To make the efficiency test, connect *M* so that the total input can be obtained. The necessary connections are not given, as they vary widely, depending on whether *M* is a one, two or three-phase machine. Separately excite the field of *L* and connect an ammeter and a variable resistance in circuit. Connect the armature of *M* to a water-box or to a motor, the load of which can be varied. An ammeter should be placed in the circuit and a voltmeter across the brush terminals. If the test involves a considerable range of speeds, run *M* over that range and hold the field current of *L* constant, its value being such that the speeds or loads required for *M* can be obtained.

Having made the necessary connections, etc., keep the current of field *L* constant at its predetermined value.

Vary the load on *L* by changing the water resistance or the load on the motor to which it is connected to suit the testing conditions required on *M*. The efficiency of *M* may be required for a series of speeds or of loads. Read the input and speed of *M* and the volts and amperes of *L*.

The "counter torque" must now be obtained to complete the calculations. To obtain this, disconnect *M*, connect *L* to a source of current which can be varied so as to give *L* different speeds, keeping *L* separately excited. If the "pumping back" method for loading *L* has been used, the connection will probably not require any change. Run *L* as a motor driving *M*, keeping the field current of *L* constant at the same value that it had when *L* was used as a generator.

Vary the speed of *L* so that the speed of *M* can be varied slightly from below its previous minimum speed to slightly above its maximum speed. Take a number of readings at varying speeds, reading volts and amperes input of *L* and speeds of *L* and *M*. If the electrical efficiency alone is desired (Case A), sufficient readings have been taken. If the commercial efficiency is desired (Case B), take off the belt from *L* and run it light as a motor. Vary its speed from slightly below to slightly above the speeds used before when running as a motor and take a number of readings at different speeds, reading volts and amperes input and speed; *L* being separately excited with the same value of current that was used in the two previous cases. The necessary readings are now complete for calculating the efficiency.

Case A

Let Wm be the total input of *M*.

Let Wl be the product of volts and amperes read for *L*.

Let Fm be *M's* friction, windage, etc.

Let Fl be *L's* frcition, windage, etc.

Divide the belt friction equally between *L* and *M*, including this in Fm and Fl.

Let R be the hot resistance of *L's* armature, which must be measured.

Let C be the current in *L's* armature.

Then electrical efficiency $= \frac{Wl + C^2R + CT}{Wm}$ where CT is the mechanical losses in L and M and the belt loss.

For Case B

Efficiency $= \frac{Wl + C^2R + C'T'}{Wm}$ where $C'T'$ is the mechanical losses of L, including belt loss.

In running the counter torque curves, the field of L must be held constant throughout and readings must not be taken when accelerating.

CHAPTER XVIII

TESTING ELECTRIC FANS AND BLOWERS

Blowers

This test is made in accordance with Government specifications issued by the Navy Department under the cognizance of the Bureau of Construction and Repair.

Use of Air Tube

When making a fan test the temperature of the air near the fan should be taken by two Fahrenheit thermometers, one hanging free in the air and the other with the bulb wrapped in thin cloth, this cloth being saturated by having its lower end placed in a small receptacle filled with water. The water must be at the maximum temperature which it will naturally attain in the room. The corrected barometer reading must also be recorded on the test sheet.

The method of finding the weight of air from the air tables (mentioned in the specifications) is as follows: On the page containing the dry bulb reading, as given by the test sheet, is noted the corresponding barometer reading. In the column under the dry bulb temperature and opposite the barometer reading, the corresponding weight of air is given. The weight of air found in the table must then be corrected to correspond with the corrected barometer reading found in test; this correstion being found in the second line from the top of the page. Correction must also be made for the difference between the wet and dry bulb temperatures by adding to the weight of air already obtained the number corresponding to the numerical difference between the wet and dry bulb reading, found in the third sub-division under dry bulb temperature. The numerical differences are tabulated in the second sub-division of the column.

Example:

Given barometer reading	30.15 in.
Dry bulb reading	67 deg. F.
Wet bulb reading	59 deg. F.

Under the column showing the dry bulb temperature of 67 deg. and opposite the barometer reading of 30.1, the weight of air is given as 0.07517. The addition for each 0.01 of an inch of barometer is given as 2.6 in the second line from the top of the page. Multiplying this by 5; i.e., by the excess of the corrected barometer reading over that selected in the table, the result is 13, which number must be added to the weight of air previously found. The wet bulb depression is the difference between 67 deg. and 59 deg.; viz., 8 deg. The number opposite 8 is 23, which must also be added, making the total weight of air 0.07553. All pressure readings should be corrected for standard air (see page 172) by multiplying the actual pressure obtained by the ratio of the weight of standard air to the weight of air at the time of test. The readings of horse-power input to the fan should also be multiplied by this ratio.

Pressure and Horse Power Curves by Double Tube Method

A pressure curve may be taken by the double tube method as follows:

The opening at the outer end of the discharge pipe should be closed and pressure and power readings taken. Under this condition the static and impact pressures should be exactly the same, since no air passes through the fan. Readings should then be taken as the opening is increased by equal increments from closed to wide open, the opening being measured each time. The speed of the fan should be held constant throughout the test, and the air readings and electrical input readings taken simultaneously.

It will be noted that in a test which is made with a pipe on the discharge side of the fan, the reading of the impact tube is always greater than the static reading. If the pipe is on the suction side, the opposite will be true; the difference between the two readings being the velocity head. The Pitot tube should point against the stream of air in both cases.

If the readings are taken by means of a U tube, the readings of both sides of the tube should be recorded. It should always be stated whether the readings were taken by the U tube or by a manometer; if by a manometer, the manometer constant should be recorded and should always be used in working up the test.

Calculation of Fan Tests by the Double Tube Method

A fan test of this kind should be worked up in the following form:

Fan rating
Motor rating
Double tube test, taken at r.p.m.

No.	h''	h'	h	"f"	V	Q	$h''+$"f"	$h'+$"f"	Air H.P.	Fan H.P.	Eff.
1 2 3 3 4											

Wet bulb......................deg. F.
Dry bulb......................deg. F.

$$\text{“}f\text{”}=\frac{L\times h'''}{D\times 39}$$

Effective area of pipe...........sq. ft.
Barometer..........................in.
Wt. of air..........................lb.
Effective area of pipe = ...sq. ft.

The first column gives the number of the reading.

The second and third show the impact and static readings taken from the test sheet and corrected for standard air.

The fourth column shows the velocity head or the difference between h' and h''.

The fifth column is friction, which must be calculated from the velocity head by the formula "f" $=\frac{L\times h'''}{D\times 39}$; where "$f$" is the friction loss in inches of water, L the length of pipe between the fan and the Pitot tube, D the diameter of the pipe, if round, or the average of the width and depth, if square or nearly square. L and D must always be of the same denomination. The friction loss should be added to both the static and impact readings before the curves are plotted, but it does not affect the volume.

The sixth column gives the air velocity and may be obtained from the formula

$$V = 1097\sqrt{\frac{h'''}{w}}$$

The volume must be given in the seventh column. It is obtained by multiplying the velocities given in the sixth column by the effective area of the pipe; i.e., 0.91.

The horse power in the air can be calculated from the formulæ:

$$\text{Air horse power} = \frac{P \times Q}{33000} \text{ or } \frac{p \times Q}{3367} \text{ or } \frac{h \times Q}{6346}$$

The horse power input to the fan is the horse power output of the motor.

Unless instructions are issued to the contrary, all fan tests for government work should be plotted with pounds per square foot, horse power input to fan, and efficiency, as ordinates; and volume in cubic feet per minute as abscissæ. Both static and impact pressure should be plotted.

Cone Method of Test

In the cone method of test an adapter is used, where necessary, to change the fan outlet from rectangular to circular, a cone being placed on the circular end. This cone is made up of sections about one foot in length, the sides of which slope about two inches to the foot. Readings are taken by a single Pitot tube, the open end of which is held flush with the opening in the cone and pointed against the stream of air. Pressure is registered as before by a manometer or U tube. The readings are taken, one at the top, one at the bottom, and one at each side of the cone, at a distance from the edge of the pipe of about $\frac{1}{6}$ of the diameter of the opening. A reading is also taken in the center of the cone opening. The average of these five readings represents the impact pressure produced by the fan, and is taken as the velocity head. The velocity may be obtained from the formula given for the double tube test.

The static pressure may be obtained as follows: Divide the volume as figured for each opening by the area of the fan outlet, thus obtaining the outlet velocity V_1. The corresponding velocity head can then be obtained from the formula. The velocity head subtracted from the impact pressure gives the static pressure, which should be plotted as well as the impact pressure.

These tests should be plotted with pressures in inches of water, horse-power input to the fan, and efficiencies, as ordinates; and volumes as abscissæ.

The following form should be used for tabulating the results of calculations:

Fan rating
Motor rating
Cone test taken at r.p.m.

No.	h''	V	Ae	Q	V_1	h''	h'	Air H.P.	Fan H.P.	Eff.
1 2 3										

Wet bulb........................deg. F.
Dry bulb........................deg. F.
Barometer........................in.
Wt. of air........................lb.

After the curves are plotted, the efficiency as given by the calculations should be checked with the efficiency obtained from the curves. This will correct any discrepancy between the efficiencies as obtained from the curve and as calculated.

The Box Method

The fan is arranged to discharge directly in to a box of sufficient capacity to reduce the air velocity to a minimum. Cones similar to those used in the cone test are attached to an opening in the side of the box at right angles to the opening in to which the fan discharges. Readings are taken in the same manner as in the previous test, and a record is also made of the box pressure by a U tube connected to a pipe inserted through a hole in the side of the box. This end of the pipe should be flush with the inside of the box to avoid eddy currents. The pressure shown by this pipe will be somewhat higher than that registered at the end of the cone, and both pressures should be corrected for standard air and plotted on the final curve sheet.

The volume must be calculated as in the cone test, but the pressure obtained in the box is taken as the static pressure produced by the fan, since the velocity head is lost in the box. To obtain the impact pressure, the volume obtained should be divided by the area of the opening of the fan, and the corresponding velocity head figured from the formula. This velocity head should be added to the static pressure shown by the cone readings. For transformer ventilation it is customary to calculate the pressure in ounces, measured at the cone opening.

The following form should be used in tabulating the calculations:

Fan rating
Motor rating
Box test taken at r.p.m.

No.	h'	p	V	Ae	Q	V_1	h'''	h''	Air H.P.	Fan H.P.	Eff
1											
2											
3											
4											

Wet bulb........................deg. F.
Dry bulb........................deg. F.
Barometer..........................in.
Wt. of air..........................lb.

Air horse power should be calculated from the static pressure and the efficiency obtained will be the static efficiency.

Formulae for Blower Tests.

H = Head of air in feet.
h = Head of water in inches shown by manometer.
h' = Static head; h'' = impact head; $h''' = h'' - h'$ = velocity head.

Weight of water = 62.4 lb. per cu. ft. at 62 deg. F.

Weight of column of water 1 ft. sq., 1 in. high, 5.20 lb. at 62 deg. F.

Weight of cu. ft. of air at 30 in. Bar., 70 deg. F., 70 per cent humidity = 0.07465 lb.

This is taken as "Standard Air."

Weight of air under other conditions, neglecting humidity =

$$\frac{0.07465 \times B \times 530}{30(460 + t^\circ)} \text{ for Fahrenheit,}$$

or

$$\frac{0.07465 \times B \times 2941}{30(273 + t^\circ)} \text{ for centigrade.}$$

V = Velocity of air in feet per minute.

v = Velocity of air in feet per second.

Q = Volume in cubic feet per minute.

P = Pressure of air in lb. per sq. ft.

p = Pressure of air in ounces per sq. in.

w = weight of air corrected for standard air.

$$= \frac{h}{1.732} = .577\ h.$$

"f" = Loss of head in inches due to friction in pipes

$$= \frac{\mathrm{L} \times h'''}{D \times 47}$$

L = Length of pipe between the fan and the Pitot tube.

D = Diameter of pipe, if it is round; or = the average of the width and depth, if it is square or nearly square.

P $= 5.20 \times h = 9\ p.$

A = Area of pipe in sq. ft. A_e = Effective area of pipe $= A \times K$.

H $= 5.20 \times \frac{h}{w} = 69.73 \times h$ for standard air.

v $= \sqrt{2gH'''} = 8.02\sqrt{H'''}$

$$= 8.02\sqrt{\frac{5.2 \times h'''}{w}} = 18.28\sqrt{\frac{h'''}{w}}$$

$$V \quad = 481.2\sqrt{H'''} = 1097\sqrt{\frac{h'''}{w}}$$

$$= 4015\sqrt{h'''} \text{ for Std. Air.}$$

$$Vol. \quad = 1097\sqrt{\frac{h'''}{w}} \times KA$$

$$= 3654 \times A\sqrt{h'''} \text{ for } K = 0.91:$$

$$= 3774 \times A\sqrt{h'''} \text{ for } K = 0.94:$$

for Std. Air.

K = 0.94 for the Cone Method.

K = 0.91 for double Pitot tube or Navy method.

For a given opening, pressure varies as the square of the speed of the blower.

Volume varies as the square root of the pressure, hence, directly as the speed.

Air horse power varies as the cube of the speed.

$$\text{Eff.} = \text{Efficiency} = \frac{\text{Air horse power}}{\text{Fan horse power}}$$

CHAPTER XIX

SINGLE-PHASE TRANSFORMERS

The following order of tests on transformers has been found to be most convenient:—Cold resistance; polarity; ratio and checking of taps; impedance; core loss and exciting current; parallel run; insulation tests; double potential for one minute; one and one-half potential for five minutes; and high potential test.

Transformers built for potentials above 50,000 volts should have the double potential test taken after the high potential test.

Since many of the tests on the different types are almost identical, a complete discussion on the air blast type will first be given, and then shorter discussions on the others.

Single-Phase Air Blast Transformers

The transformer should be properly placed over a pit and no opening left through which air can escape and influence the reading of the thermometer on the transformer iron. When the transformer is in place, a careful inspection should be made, making note of any defect, no matter how slight, and if found, it should be repaired immediately.

The order of tests may be varied if found necessary. Usually two or more transformers of the same rating are tested at once. In the following discussion, two or three transformers are considered.

Cold Resistance

If the temperature guarantee of the windings specifies that the increase-in-resistance method be used, considerable care must be taken in measuring resistances. This measurement is usually made as follows:—Place a thermometer on the coils of each transformer and send from 10 to 15 per cent full load current through the transformer coils; this being generally the proper amount for two or four transformers. The ammeter should not read below the center of the scale, nor should the current be sufficient to appreciably heat the windings while taking resistance. For very low voltage secondary windings, use about 40 amperes, as this current usually gives sufficient drop to be read on the voltmeter. The drop lines must not include the resistance of any temporary connections. Adjust the resistance in the box until the reading comes to about the middle of the scale of the voltmeter. Considerable time will be saved by short circuiting the secondary while the primary is being measured, and by short circuiting the primary while the secondary is being measured. In measuring secondary resistances, especially when low, the contacts for the voltmeter leads should be carefully cleaned with sandpaper.

Take three readings on each coil, holding about the same current. It is far better to allow the ammeter to vary slightly, than to try to hold exactly the same reading, as the observer is likely to be prejudiced. In entering readings, always record the constants of the meters, the voltmeter resistance, the resistance of the drop lines, the resistance in the box and the temperatures of the coils. If the transformers have more than one primary and one secondary coil, a clear sketch should be made and the coils so marked as to prevent confusion. In recording results, the value of the unit deflection should be noted and readings pointed off accordingly. Readings should be taken as rapidly as is consistent with accuracy. The method of calculating rise in temperature by increase of resistance is explained under heat runs.

Polarity

The polarity test is taken, since it affords the only means of readily determining the connections required for transformers in banks; for instance, several transformers in parallel. When transformers are connected for measurement of resistance, the polarity test can readily be made with a special voltmeter. Select one transformer as a standard; when several are in test at once, one near the middle of the group should be chosen as it will be safer and more convenient when the transformers are run in parallel. With direct current flowing through one winding of the transformer, connect the special voltmeter across the terminals so as to get a positive deflection; then transfer the drop lines to the corresponding terminals of the other winding and break the current in the first winding. If the polarity is correct, a positive kick will be obtained. When making this test, have sufficient resistance in series with the voltmeter to protect it from damage.

It is not necessary to take polarity on more than one transformer of a group, as the parallel run will show whether or not they all have the same polarity. In taking polarity on special transformers, a clear sketch should be made showing the polarity. For tap polarity, see headings "ratio" and "checking taps."

Ratio

The ratio of a transformer is the ratio of primary voltage to secondary voltage, and should be equal to the ratio of primary turns to secondary turns. The usual method of determining this value is to apply about one hundred volts to the secondary winding and read the primary voltage, stepping it down with a suitable potential transformer. The ratio of the potential transformer should be as nearly that of the transformer in test as possible. The potential transformer must be operated at normal frequency and voltage, otherwise the ratio will be unsatisfactory. In very small transformers, the voltage should be applied to the primary windings.

When the ratio of the potential transformer is very nearly that of the transformer in test, the voltmeters should be interchanged after five readings have been taken. When this is done it is not necessary to correct voltmeter readings from curves, as the meter errors will appear in both columns and be eliminated. In determining any ratio at least five readings should be taken, and the result carefully calculated. If the ratio by test varies more than *one* per cent from the rated ratio of voltage, check the ratio of turns; if the ratios of voltage and turns agree, repeat the ratio with the same meters; and if still out, repeat with an entirely different set of meters and potential transformer. If the ratio is still out, the transformer is wrong. Try the ratio of another transformer. If, however, the ratio should be correct when the second set of meters is used, a third set should be used and the ratio checked again. If the second and third sets of meters give a correct ratio, record both sets of readings.

In taking ratio on transformers with taps or dial switch note whether or not full windings are used. If the transformer has more than one primary or secondary coil, note whether the coils are in series or multiple. The ratio must check within one per cent of the ratio of turns. It is not necessary to take ratio on more than one transformer of a group, as the parallel run will determine whether they all have the same ratio.

Checking Taps

Nearly all transformers are provided with taps in one or both windings, so that a slight change in ratio or a low voltage for starting duty may be obtained. Before checking taps, procure the proper winding specification and sketch. Taps are easily checked by applying a certain voltage per turn to the low tension winding and reading the voltage between the terminals of the winding and the first tap; then between successive taps on the same coil. In some cases it is equally satisfactory to apply full potential to one winding and read the voltage between adjacent taps. This is done on dial switch transformers.

The method can best be explained by an example. Take an AB-25-400-6300/6195/6046/5985/5835/5600-170. The primary winding has six coils connected in series, of 43 turns each, with inside and outside ends. This is called a single section coil. The secondary winding consists of six coils connected in multiple of 7 turns each. Taps are brought out of the primary coils P–1, P–2, etc., at the ending of the 29th, 34th, 38th and 41st turns from the inside end. This gives tap turns of $43-41=2$,

$41-38=3$, $38-37=1$, $37-34=3$, $34-29=5$ turns. Since the secondary winding has four coil terminal blocks, these coils can be connected in series, giving 14 turns. Applying 5 volts per turn $=70$ volts to the secondary (Fig. 44), we read volts across terminals (1–2) $=10$, (2–3) $=15$, (3–4) $=5$, (4–5) $=15$, (5–6) $=25$. The same readings will be obtained on the other end of the primary winding. These readings must be checked with the voltages required by the sketch. The volts per turn at normal potential $=\frac{170}{7}=24.2$ volts. In changing from (1–7) to (2–8), four turns are cut out of the primary winding, and the primary voltage is decreased

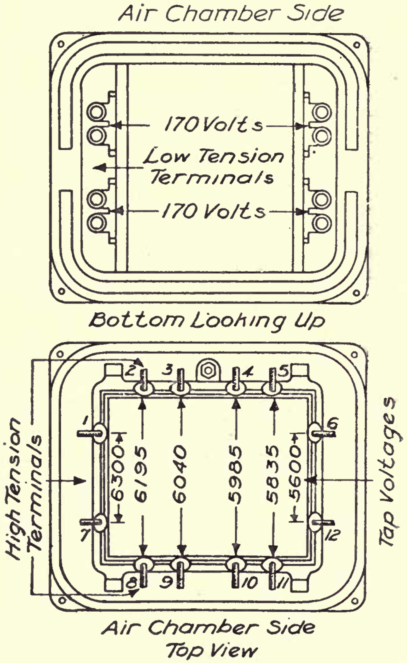


Fig. 44. Taps

by 6300–6195 = 105 volts. Multiplying 24.2 by 4, 96.8 is obtained which is as near 105 as possible, unless a tap be brought out at a half turn, which is seldom done. Changing to (3–9), six turns are cut out and the primary voltage is decreased by 6195 – 6040 = 155 volts. Now 6×24.2 = 149.2, which is near enough to 155. The remainder of the taps should be checked in the same manner.

Great care should be taken in handling the voltmeter connected to the taps, for although the voltmeter reading is low, the circuit to which it is connected may be several thousand volts above ground. If the opposite end of the circuit be grounded, a severe shock may be obtained from the meter.

In checking 50 per cent taps, one meter should be used as a check and another to read the voltage across each half of the winding, the readings being taken first on one side and then on the other, holding the same reading on the check meter. A neat sketch showing the position of the taps should always be made. On transformers with only one tap on each end, it is often necessary to check its location by polarity. (See Fig. 45.) This is done as follows: with direct current flowing through the secondary, take polarity of (1–4), (1–2) and (3–4); if all the deflections are in the same direction, the taps are properly brought out; if some are reversed, the tap and line lead are interchanged.

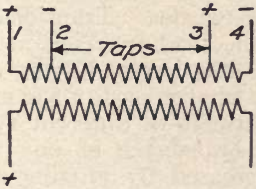


Fig. 45. Taps

Impedance

The expression $C=\frac{E}{R}$ for continuous current circuits is replaced in alternating current circuits by the equivalent expression $C=\frac{E}{\sqrt{R^2+(2\pi fL)^2}}$, where C is the current, E the impressed e.m.f., f the frequency, L the coefficient of self-induction, and R the ohmic resistance. The expression $\sqrt{R^2+(2\pi fL)^2}$ is known as the impedance of the circuit and is defined as the apparent resistance of a circuit containing ohmic resistance and self-induction. The term $2\pi fL$ is called the reactance of the circuit.

The impedance of a transformer is measured by short circuiting one of the windings and impressing an alternating e.m.f. on the other winding, taking simultaneous readings of amperes, volts, watts and frequency. The impedance of transformers should be carefully measured for the following reasons: Transformers operating in multiple divide the load inversely as their impedance voltage; i.e., the transformer having the higher impedance will take the smaller part of the load and *vice versa*. When the transformers of different types are operated in multiple, the impedance of one transformer must sometimes be increased by putting a reactive coil in the secondary circuit and adjusting until the desired impedance is obtained.

Impedance tests show whether a given arrangement of coils is satisfactory or not. In transformers wound with large conductors the impedance watts will differ from the calculated C^2R of a transformer wound with small wire.

The following method should be followed in making an impedance test: Place a thermometer on the coils to obtain the temperatures; make a good short circuit on one winding, using as short a cable as possible and one of ample cross section, so that no appreciable losses will occur. Calculate the full load current by dividing the watts capacity by the maximum voltage of the winding in which the meters are placed. Select suitable meters and make connections as shown in Fig. 46, wiring to the alternator through a suitable transformer. The alternator must be operated at as near normal voltage as possible when the normal impedance reading is taken.

Take ten readings, starting at 50 per cent and raising to 125 per cent full load. Hold the speed constant and take simultaneous readings of amperes, volts and watts. It is essential that the speed be exactly right, since the reactance varies directly with the frequency. This curve should be plotted after the readings are taken (not as they are taken) to see if the curve is smooth; if the curve is not smooth, check it at once. Plot volts as ordinates and watts and amperes as abscissæ. The volt-ampere curve should be a straight line; the volt-watt curve should be a parabola. (Fig. 47.) In taking the readings, results will be more satisfactory if meters are selected so that no change in them is necessary throughout the curve. On the record sheet, note the temperature of transformer coils and constants of all meters used. If a potential transformer is used, record its number and ratio.

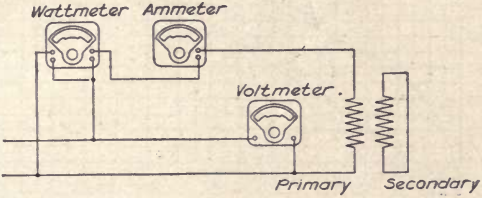


Fig. 46. Connections for Impedance Test

The connections shown in Fig. 46 are used in preference to those in which the losses of the voltmeter and of the potential coil of the wattmeter are included in the reading of the wattmeter. In Fig. 46 the only extra loss is that in the current coils of the ammeter and wattmeter, and this is negligible.

A potential transformer or multiplier should be used with a wattmeter when the voltage exceeds 150 volts. It will be noted that the lower binding posts on Thomson wattmeters must be connected together when neither a potential nor a current transformer is used; and when the voltage of the circuit is above 2000 volts, they should be connected by a small fuse wire. The secondary of the potenial transformer should not be grounded, however, unless a current transformer is used. The adjacent ends of the current and potential coils are connected to these binding posts and, unless they are connected to the same side of the line, there is danger of breaking down the insulation between the coils and burning out the wattmeter. Above 2000 volts the fuse wire is used to avoid electrostatic effects.

Core Loss and Exciting Current

When a transformer is connected to a source of alternating current, a loss of energy takes place in the iron, owing to cyclic reversals of the magnetic flux. This loss of energy is known as the core loss; its value depending on the wave form of the impressed e.m.f., a peaked wave giving a somewhat lower core loss than a flat wave. It is not uncommon to find alternators giving such a peaked wave form that the core loss obtained on transformers excited by them is 5 to 10 per cent less than that obtained on the same transformers when excited from generators giving a true sine wave. On the other hand some generators give a very flat wave form, so that the core loss is greater than that obtained when sine wave is used. The core loss test is similar to the impedance

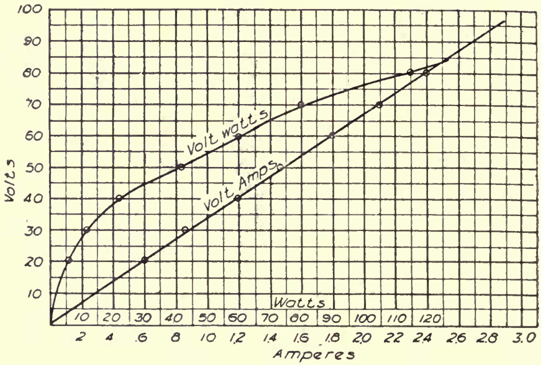


Fig. 47. Impedance Curve

test, except that voltage is applied to one winding, the other being left open circuited. Voltage should always be applied to the low potential winding in order to avoid placing meters in high potential circuits. Core loss should always be taken from a sine wave alternator and transformer connections made so that the alternator is operated at normal excitation when normal potential reading of core loss is taken.

To make this test, estimate the capacity of the meters required, connect the ammeter in circuit and take a preliminary reading of exciting current to show what meter capacity is required. Be sure to place the high tension leads so that no one can come in contact with them and that there is no danger of short circuit. The instruments should be so placed that they have no influence upon one another, and are not affected by any stray field.

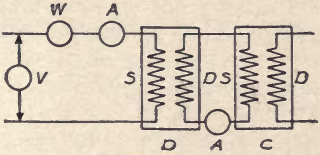


Fig. 48
Connections for Core Loss Test

A core loss curve should be taken, starting at 50 per cent of rated potential and increasing the voltage to 25 per cent above normal. To do this, hold the frequency constant and vary the voltage, taking simultaneous readings of the excitation amperes and watts core loss. Do not plot the curve as each reading is taken, but as soon as all are finished. If the curve is not smooth, repeat the test. The curve will be more satisfactory if meters can be so selected that no change in them is necessary throughout the curve. Record all meter numbers, their constants and date of cailbration, temperature of iron, and numbers and ratios of potential transformers or of multipliers. Wherever possible, use the wattmeter without a potential transformer or multiplier, by connecting the transformer for the lowest potential.

When the normal voltage of both windings is above 5000 volts it is often more satisfactoy to take core loss indirectly; that is, to read input into the secondary of a transformer used to step up to the voltage of the transformer in test. This step-up transformer should have its ratio, resistance and core loss carefully measured.

Connect the primary of the step-up transformer to the secondary of the transformer in test, putting a low reading ammeter in circuit to read the exciting current. Read volts, watts and amperes in the secondary of the step-up transformer as usual. In calculating the actual core loss, subtract the C^2R and core loss of the step-up transformer from the total wattmeter reading. Connections for this test are shown in Fig. 48.

CHAPTER XX

SINGLE-PHASE TRANSFORMERS: PARALLEL RUN, HEAT RUN, OVERLOAD, HIGH TENSION TEST

Parallel Run

The discussion of the parallel test is given here rather than under the heading of "ratio" or "polarity," because the heat run is the next test, and excitation voltage must therefore be provided.

Having previously tested the ratio and polarity on one of the transformers of the group, the parallel run can be made and the polarity of the others checked with the one tested; also the ratio of the remaining transformers. If the transformers differ in ratio by one-tenth of 1 per cent, the fact will be shown in the parallel run, because the test is made at the full potential of the transformer. If a transformer is one turn out, a difference of voltage between the two transformers of from 15 to 40 volts will be shown, depending upon the size of the transformer. This potential gives quite a spark and the exact amount of voltage difference may be determined by connecting a voltmeter between the two transformers.

The connections for the parallel run are shown in Fig. 49, No. 2 being the standard transformer—the one on which polarity and ratio have been taken. Only two transformers must be connected at the same time, for if voltage is on the entire set, there is more danger of some one coming in contact with the primary leads. Connect two of the transformers as shown in Fig. 49, making one side of the primary connections permanent, and arranging the other side so that the circuit may be completed with a small fuse wire of not over 3 amperes capacity. One end of this fuse wire should be carefully fastened to one end of a clean dry stick about two feet long. Close the secondary switches and by touching the frame of one of the transformers with the fuse wire, determine whether voltage is on the transformer; a small spark indicates that the transformer is excited. Now excite the alternator, gradually bringing it up to normal potential. As soon as field is applied to the alternator, the man handling the fuse wire should begin tapping its loose end on the primary terminal of the other transformer; if no spark is seen the transformers will operate in parallel. If a small spark appears, connect a voltmeter in series and read the difference of voltage with normal potential on the transformers. If this voltage

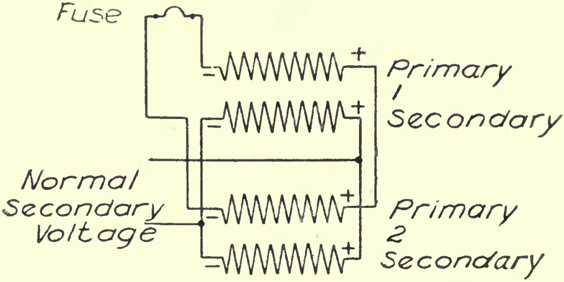


Fig. 49
Connections for Parallel Run

is more than one-fourth of 1 per cent of the rated voltage of the transformer, the wrong coil should be located and corrected. Instead of reading the voltage, the exchange current may be read by connecting an ammeter in the circuit instead of the voltmeter. This current should not exceed 5 per cent of the normal current. Continue the parallel tests as above, until all the transformers have been run in parallel with the one selected as standard.

If the transformer has two circuits that may be operated either in series of parallel, the parallel test should be made by connecting together the corresponding ends of these coils on one side, completing the circuit by means of fuse wire and applying full potential to the other winding of the transformer. It is just as essential that the coils of a transformer operate satisfactorily in multiple as that two transformers so operate.

Normal Load Heat Run

The heat test may be conducted in several ways, all of which are designed to approximate as nearly as possible the operating conditions of the transformers. A run with actual load might be made by using water rheostats; but as this would be very expensive, some form of motor-generator method should be used. Fig. 50 shows the connections for testing two transformers by the motor-generator method. The secondaries of both transformers are connected in multiple and then connected to an alternator which supplies the core loss and exciting current. The primaries are connected in series, opposing each other; if the transformers have the same ratio, the voltage from *A* to *B* will be zero.

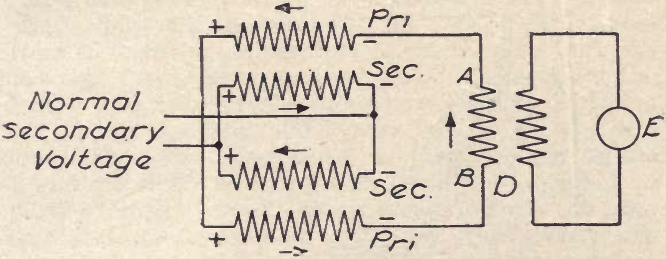


Fig. 50
Connections for Heat Run

The secondary of an auxiliary transformer *D* is connected in series with the primaries of the transformers in test. Alternator *E* connected to the primary of transformer *D* supplies the copper losses. The same method may be used for any even number of transformers, but it is not advisable to run more than six at one time. Fig. 51 shows connections for the heat run on three transformers, the primaries and secondaries of which are connected in delta. Across one corner of the delta, impedance voltage is impressed for the three transformers connected in series. The current circulates within the delta and is entirely independent of the secondary voltage.

The two methods outlined above require only sufficient power to supply the losses.

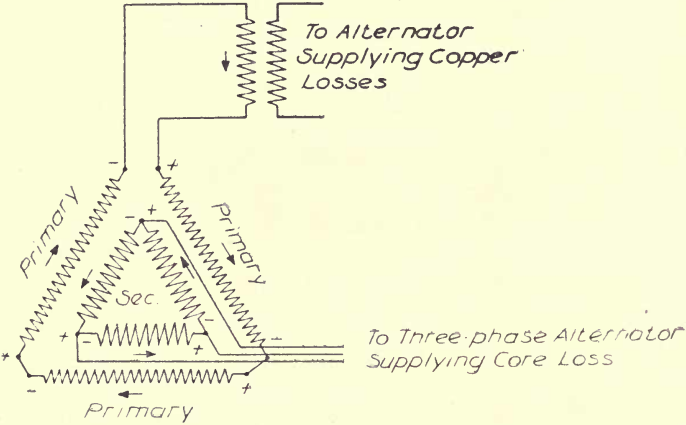


Fig. 51
Connections for Heat Run

In arranging for the heat run, see that the alternators and transformers are of sufficient capacity to carry the load; the current necessary to supply the iron losses being equal to the sum of the exciting currents of the transformers. If the transformers have several secondary coils, connect them in series so that when the heat run is completed on time will be lost in making connections for measuring hot resistance. The alternator supplying the core loss should operate at normal excitation; the voltage required to supply the load current being equal to the impedance voltages of the transformers. If there is more than one primary, arrange to run them in series if possible. If the transformer is to have a 50 per cent overload test, add 5 per cent to the voltage already obtained.

Shop transformers should always be interposed between the primaries of the transformers in test and the alternators to prevent the breaking down of the armature and to avoid high potentials on the switchboards. "Step" the voltage either down or up, or down and up again, depending upon circumstances; but always have transformers between the alternator and the primaries of the transformers in test. There should be some resistance left in the field of the alternator so that as the alternator fields and the winding of the transformers heat up, the load can be kept normal.

Place spirit thermometers in the top of each transformer to read the temperature of the air escaping form the coils. Two thermometers should be used for the primary and two for the secondary windings, placing them about one inch above and just over the ducts between the coils. Also, place two thermometers on the top and one near the bottom, and two thermometers to read the temperature of the air escaping from the iron. The transformers can now be loaded. With the alternator running at proper speed, the total exciting current of the transformers should be read and the secondary voltage can be checked.

Air blast transformers may run at full load for 50 minutes without air, in order to heat them up and thus shorten the heat run. Some transformers can not be operated for more than 20 minutes without air and they must be carefully watched to see that they do not get too hot. After the air blast is put on, it is usually necessary to keep the iron damper closed for some time to allow the core to heat up, as the copper heats much faster than the iron. The amount and pressure of air required depends on the guarantees as to temperature and to some extent on the voltage of the transformers. The large amount of insulation on the coils of high voltage transformers tends to retard radiation.

If the trasnformers are guaranteed for a maximum temperature rise of 40 deg. C. at normal load, and 55 deg. C. rise after 25 per cent. overload for two hours, the air should be adjusted to give about 35 deg. rise on the copper and 40 deg. rise on the iron. If the iron seems too hot, increase the air pressure, partially closing the top damper; if the copper is too hot, increase the pressure and partially close the lower damper.

If the transformers are guaranteed for a maximum rise of 35 deg. C. at normal load and 55 deg. rise after 50 per cent overload for two hours, the air should be adjusted to give about 30 deg. rise on the copper and 35 deg. rise on the iron. These adjustments should be carefully made during the first hours of the heat run.

When properly adjusted the transformers should run about four hours at a practically constant temperature. Place the thermometers for measuring the room temperature near the intake of the blower so as to get the temperature of air delivered to the transformers. Read all thermometers and take the resistance on one winding of each transformer every hour. Iron temperatures may be read while the transformers are under load, since the frames are grounded. If the primary leads are brought out at the top of the machine, the voltage should be cut off when taking other readings; if, however, the transformers are bottom connected, the temperatures may be read while the machines are under load. If it can be avoided, do not change the position of thermometers when taking readings.

When ready to measure resistances, shut down the blower, take off the load and measure the resistances as rapidly as possible, so as not to allow the transformers to cool off. One minute per transformer should be ample time for these readings. The rise by resistance is calculated as follows:

t = Cold temperature of coil.
T = Hot temperature of coil.
R_t = Cold resistance of coil.
R_T = Hot resistance of coil.

$$T = (234+t)\frac{R_T}{R_t} - 234.$$

$T-t$ = Rise in degrees C.

During the heat run a careful inspection should be made for loose laminations. If any transformers are found that rattle or buzz, due to loose iron, they should be plainly tagged and a chalk mark made on the core as near as possible to the point at which buzzing was heard. The heat run and other tests should now be finished, except the double and high potential tests, which must always be taken after all repairs are made. If a motor-generator method can not be used, the copper and iron heat runs may be taken separately.

To make a short circuit heat run, short circuit the secondary windings and apply normal current to the primary. When this test is finished and the hot resistances taken, open-circuit the primary, arranging the primary leads so that there is no danger of any one being injured, and apply normal voltage at proper frequency to the secondary until the iron temperatures are constant. Finish up the tests as if the heat run were taken by the motor-generator method. The same amount of air will be required and the heating will be practically the same as though both iron and copper were loaded at the same time.

At the end of the heat run measure all resistances carefully and read the thermometers. The same care should be used as when taking cold resistances, and if any set of readings indicates a doubtful increase of resistance, the readings should be checked, using a different set of meters. If the work is properly conducted, ten minutes is ample time to take a complete set of resistance readings on four transformers. A careful inspection of all soldered joints should be made to see that there is no undue heating.

When no overload is specified, the transformers may be run for 20 minutes at 50 per cent overload current to test soldered joints. This test follows that of hot resistance.

Overload Heat Run

This test is ordinarily limited to two hours and is taken as a continuation of the normal load heat run.

Transformers are sometimes designed to run continuously at overloads, or may be guaranteed to operate at a certain kilowatt output at some power-factor less than unity. Overload heat runs should be very carefully watched, particularly those of short duration. Special attention should be given to the length of the run, as the temperatures often rise very rapidly. At the finish of the heat run, record all temperatures and measure all resistances. The same air pressure should be used for the overload as for the normal load.

Insulation Test—Double Potential Test

In this test, as well as in the core loss and impedance test, the alternator supplying the voltage should be operated at as near normal voltage as possible, so as to avoid distortion of the wave form. Double potential is applied to test the insulation between turns and between sections of the coils. Since it is impossible to obtain double voltage on a transformer at normal frequency, due to high density in the iron, the frequency must be increased. Apply twice the normal voltage for one minute, followed by one and one-half times normal voltage for five minutes. The last test is taken in order to discover any short circuits that might develop during the double potential test, and yet not become apparent in the short time that the double potential is applied. The primary bushings should be cleaned before the test and the transformer guarded to prevent accidents from the high voltage circuits. Any buzzing or leakage of current should be noted.

In applying and taking off the high potential, vary the alternator field gradually; that is, do not open the field switch with a jerk, for if this is done trouble may occur. As soon as this test is taken, make the proper comments on the test sheet.

In case a transformer breaks down, the defective coil should be located and plainly marked. Then, in unassembling the machine, the coil can be easily found and the cause of the defect ascertained, thus preventing a repetition of the breakdown.

Air Readings

A method at present used is to read the velocity of the air through a standard orifice by means of an air meter. Knowing the velocity and the area of the orifice, the cubic feet per minute can be easily calculated. A large box with an opening in the bottom should be held against the transformer, using a small piece of felt as packing and being careful to allow no air to escape. The size of the orifice should be noted, and the time that the air meter is allowed to run. Always record the reading in cubic feet per minute. The air readings are to be taken with the dampers in the same position that they occupied during the heat run, and at the same air pressure.

High Potential Test

The application of a high potential to the insulation of a transformer is the *only* method for determining whether the dielectric strength is sufficient for continuous operation. Mechanical examination amounts to little and measurement of insulation resistance is equally valueless, since insulation may show high resistance when measured by a voltmeter with low voltage, but offer comparatively little resistance to the passage of a high tension current.

The insulation test which should be applied to the windings of a transformer depends upon the voltage for which the transformer is designed. In testing between the primary and the core or the secondary, the secondary should be grounded for the following reasons: In testing between one winding and the core, a potential strain is induced between the core and the other winding which may be much greater than the strain to which the insulation is subjected under normal operation, and therefore greater than it is designed to withstand. In testing between the primary and the core, the induced potential between the secondary and core may be several thousand volts, and the secondary may thus be broken down by an insulation test applied to the primary under conditions which would not exist in normal operation. During the test, all primary leads as well as all secondary leads, must be connected together. If only one terminal of the transformer winding is connected to the high potential transformer, the potential strain may vary throughout the winding, and at some point may even be greater than at the terminal of which the voltage is applied. Under such conditions, the reading of the electrostatic voltmeter or the arcing across the spark gap affords no indication of the insulation strain. Indications which are best learned by experience reveal the character of the insulation under test.

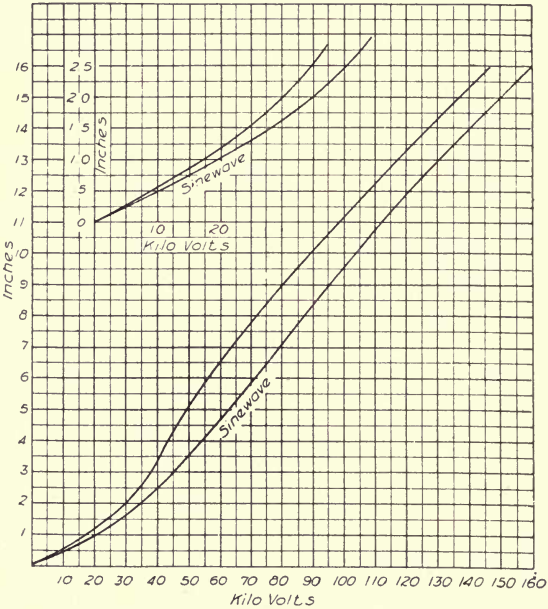


Fig. 52
Curve of Arcing Distances

The charging current of a transformer varies with its size and design. The current may be measured by means of an ammeter, placed in the low potential circuit of the testing transformer. It will increase as the voltage applied to the insulation is increased. Inability to obtain the desired potential across the insulation may be due to large electrostatic capacity, or to the inability of the high potential transformer to supply a large capacity current at the voltage desired. A breakdown in the insulation will result in a drop in voltage indicated by the electrostatic voltmeter. An excessive charging current will flow and the insulation will burn if the discharge is continued for any length of time.

For any test above 10,000 volts always use a spark gap, setting it according to the sine wave curve of arcing distances (Fig. 52). Connect both ends of the primary winding to one terminal of the high potential transformer and ground both ends of the secondary to the core and frame, connecting the other terminal of the high potential transformer to the frame. Set the spark gap for the voltage to be applied and connect in the proper electrostatic voltmeter. Be sure that everything is clear, then apply the voltage, bringing it up gradually until the gap arcs over. Then decrease the voltage until the arcing ceases and again bring it up just to the arcing point, holding this voltage for one minute before gradually taking it off. A note of the charging current should be made on the record sheet.

When a transformer breaks down, the defective coil should be located by making it "smoke up." In doing this, burn only enough to show the coil. If much damage is done by smoking it may be impossible to discover the cause of the breakdown.

CHAPTER XXI

THREE-PHASE TRANSFORMERS

Special Tests

The order of tests on three-phase air blast transformers is the same as for the single-phase type. The mechanical construction of the coils is identical with that of the single-phase type; but as the air paths through the iron are longer, the air pressure required is slightly higher.

Cold Resistances

The general instructions given for measuring the resistance of the single-phase type apply to three-phase transformers, but since primary circuits are opened for the heat run, the resistance of each set of coils should be measured. If secondary coils are permanently connected in delta, the resistance between each set of leads should be measured. If the secondary coils are arranged for diametrical connection, measure the resistance of each set of coils. Note on the record sheet how these readings are taken, so as to avoid confusion in measuring and recording hot resistances.

Polarity

The determination of polarity on three-phase transformers requires much care. The diagrams allow a comparison to be made of the various standard connections. Figs. 53, 54 and 55 are three-phase connections for three single-phase transformers, and Figs. 56, 57, 58 and 59 are connections for three-phase transformers.

In determining the polarity of three-phase air blast transformers, see that the primary and secondary coils are connected as shown. (Figs. 56 and 57.) Supply direct current to primary lines No. 1 and No. 2 to give the proper deflection on the voltmeter, then transfer the voltmeter lines to the secondary, connecting the line that was on No. 1 primary to No. 1 secondary, and the line that was on No. 2 primary to No. 2 secondary. Now break the primary current and if the polarity for this phase is correct, a positive kick will be obtained.

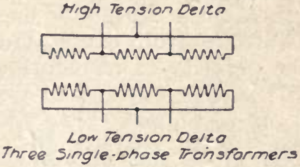


Fig. 53

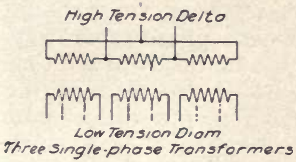


Fig. 54

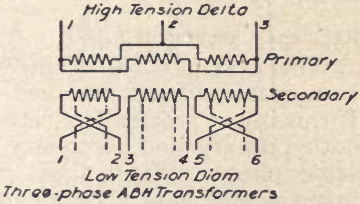


Fig. 57

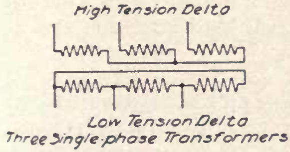


Fig. 55

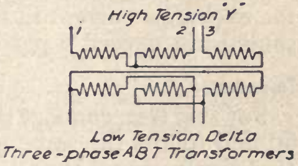


Fig. 58

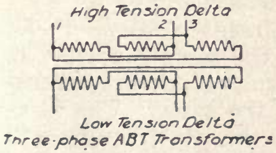


Fig. 56

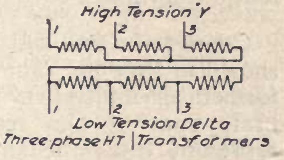


Fig. 59

Wiring Diagrams for Polarity with Three-phase connections

Repeat this process for the two other phases and if they all agree with the first one, the polarity is correct. A sketch should be drawn on the record sheet, showing how the polarity test was made.

The polarity test on three-phase transformers also determines whether there will be a change of rotation of phase in transforming from one potential to the other. To determine the polarity of transformers connected as shown in Fig. 57, supply current to primaries 1–2 and take deflection on secondary 1–2; this should show reversed polarity. With current on 1–3 primary the deflection on 3–4 secondary should be positive. With current on 2–3 primary, the deflection on 5–6 secondary should be reversed.

Ratio and Checking of Taps

Whenever possible, a three-phase transformer should have ratio and taps checked on each phase separately. If this is not practicable, care must be taken to see that both primary and secondary voltages are read on the same phase. When these measurements can not be taken single-phase, three-phase voltage must be applied. If the ratio appears to be wrong, connect both windings in delta, apply full voltage to the secondary, and read the exchange current in the primary delta. This current should not exceed 6 per cent of full load current.

Impedance

For this test, connect the transformer according to Fig. 60 and follow the same general instructions as given for the single-phase type. Calculate the current corresponding to the primary voltage of the transformer as follows: $\text{primary current} = \dfrac{\text{capacity in watts}}{\text{line voltage} \times \sqrt{3}}$

Connect in two wattmeters of the same capacity, as shown in Fig. 60. The ratio of the two potential transformers or multipliers should be the same. The algebraic sum of the readings of the wattmeters will represent the impedance loss of the transformer. The sign of the readings must be carefully noted, since the reading of one wattmeter may be reversed. To test for this, open line No. 1 and if the reading for wattmeter No. 3 is positive, the needle will drop to some value above zero. If the needle drops off the scale below zero, the reading must be recorded as negative. If the first meter tested reads positive, the sign of the other meter should be determined by this method.

An impedance curve should be taken from 50 per cent to 125 per cent full load.

In making the short circuit test on ABH (Fig. 57) transformers, each phase must be short circuited independently of the other. In taking readings, hold the current constant in one line from the testing table. Read the three-phase volts and the two wattmeters. Hold the voltage constant across one phase and read the current in the other phases.

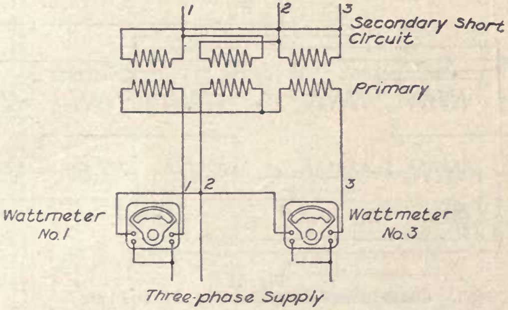


Fig. 60
Connections for Impedance Test

Core Loss

In the core loss test, wattmeter readings are taken in the same manner as for the impedance test. The same precautions must be observed in regard to fastening up the primary leads so that there is no chance of danger. Take core loss curve from 50 per cent to 125 per cent normal voltage.

In ABH transformers, with the middle points of each phase connected together to form a neutral for a three-wire direct current system, some confusion may result as to the proper method for measuring core loss. If the neutral connection is broken (as is sometimes necessary for the heat run), the secondaries may be connected in delta and three-phase voltage applied. This voltage is the same as the diametrical voltage, or that of each phase. If the neutral can not be broken, the secondaries may be connected in Y, the neutral connection forming the Y point. In this case the voltage corresponding to the normal voltage of the transformer will be $\frac{\sqrt{3}}{2}$ times the diametrical voltage. It should be remembered that the middle set of coils should be connected so as to be reversed with respect to the other two, in order to obtain the proper magnetic flux in all parts of the core.

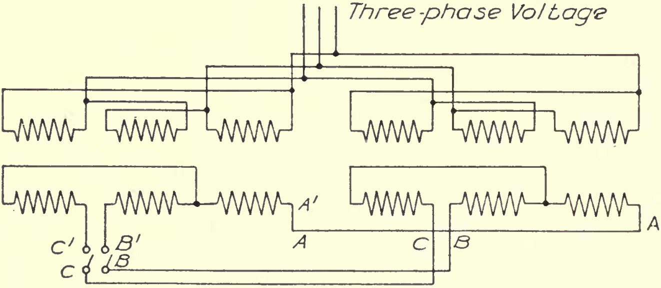


Fig. 61
Connections for Parallel Run, Three-Phase

Hold the voltage constant and take readings as in impedance test. There will be a slight unbalancing of the magnetizing currents due to the unequal magnetic reluctances in the different parts of the core. For this reason the alternator for core loss tests must be operated at normal voltage so as to balance the three-phase voltage as nearly as possible.

Parallel Run

The parallel run checks ratio and polarity on a three-phase transformer in the same way that it does on a single-phase transformer.

Connect the secondary circuits of the two transformers in multiple, and the primaries as shown in Fig. 61.

Connect between *A* and *A′* and try the fuse wire from *B* to *B′*; if no spark is obtained, connect from *B* to *B′*, leaving the first connection, and try the fuse wire from *C* to *C′*. If no spark results here, the parallel run is satisfactory. The voltage must be taken off before any connections are changed.

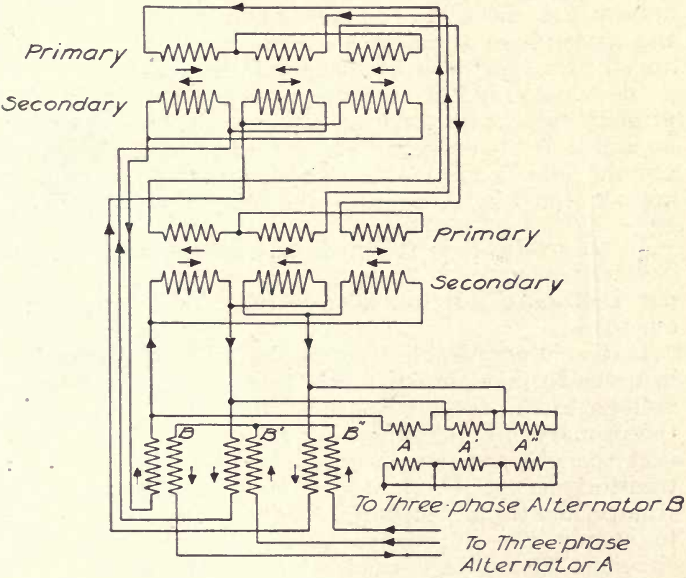


Fig. 62
Connections for Heat Run, Three-Phase

Heat Run

The method described for the three single-phase transformers is the one ordinarily used. If two or more transformers are to be run simultaneously, connect the transformers in multiple on the secondary side and the primaries all in series. The same general instructions for the heating of single-phase transformers will apply; in fact, each phase of a three-phase transformer must be treated as a single-phase transfromer. Use as many thermometers on one three-phase transformer as on three single-phase transformers. A higher pressure is necessary to force air through the ducts in the iron of the three-phase transformer than in the single-phase, and the damper must be carefully adjusted.

In calculating the voltage required to supply the primary current for the heat run, the following rule may be used: If the primaries are connected in delta, multiply the impedance voltage by three; if the primaries are connected in Y, multiply the impedance voltage by $\frac{3}{\sqrt{3}}$. If overload is required, add 50 per cent for 50 per cent overload and 25 per cent for 25 per cent overload.

If it is impracticable to open the primary connection in order to take the heat run by applying three-phase voltage to the secondaries and single-phase current to the primary, the following method may be used: Connect the transformers as shown in Fig. 62. Auxiliary transformers A, A', A'' are used to supply secondary voltage, and transformers B, B', B'' as series transformers to supply the impedance voltage to the secondary circuits. The voltage necessary to supply full load current is twice the impedance voltage of one transformer. The impedance voltage is the same percentage of the total voltage, irrespective of the circuit to which it is applied. The figure shows two three-phase alternators, one supplying core loss and exciting current, and the other the copper losses. When two alternators are used they must be run at nearly the same frequency, otherwise the superposition of the impedance voltage on the core loss voltage will impart a slight swing to the meter needles. Instead of the three transformers B, B', B'', a three-phase transformer or an induction regulator may be used. If a regulator is used, all the losses may be supplied from one alternator.

Double Potential Test

If any repairs or alternations are required, such as making primary delta or Y connections permanent, or connecting up the secondary neutral, the double and high potential tests should be omitted until everything is completed. If double potential can not be obtained from a three-phase alternator on account of the high magnetizing current. the test can be made on one phase at a time. Double potential for one minute should always be followed by one and one-half times normal potential for five minutes.

High Potential

The high potential should always be applied after all changes have been made, such as tightening loose iron, connecting primary delta or Y. The polarity should always be tested after the delta or Y connection has been made.

Other tests, such as overhead heat run, hot resistance, and air readings, are made in a manner similar to that followed for single-phase transformers.

CHAPTER XXII

OIL-COOLED, AND OIL-AND-WATER COOLED TRANSFORMERS

The order of tests on oil-cooled transformers is the same as that for air blast transformers. The transformer should, if possible, be filled with oil at least four hours before starting the tests; if not possible, the cold resistance, polarity, ratio, checking of taps and impedance tests may be taken before. Under no condition, however, must an oil-cooled transformer of over 10,000 volts be operated at normal potential without being filled with oil.

Cold Resistance

If the transformer has not been filled with oil, a thermometer should be suspended inside the tank to measure as nearly as possible the temperature of the windings. If filled with oil, record the temperature of the oil. Always use a spirit thermometer to obtain the temperatures inside the tank. As the leads are not brought out in the same manner as in the air blast type, the circuits should be carefully checked before starting the tests.

Heat Run

The method and connections used are practically the same as for air blast transformers, except that oil-cooled transformers should be started at an overload, so as to heat them up rapidly and thus shorten the run. Where practicable, they should be run with 50 per cent excess current for two hours, and 25 per cent excess voltage for three hours. In some cases the time of the overload run must be shortened, though occasionally a longer time is required. When normal voltage is applied, the alternator must be operated at normal voltage.

During the heat run, a careful search should be made for oil leaks in the tank and oil gauges. If the transformer has been filled so full of oil that it is likely to overflow, draw off some oil. The leads coming from the transformer must not siphon the oil. In locating thermometers on the outside of the tank, place one at the top, about the height of the oil line, and on very large transformers, one near the bottom of the tank, always using the putty provided. As it is not possible to get the temperature of the core, the oil temperature must be carefully obtained. Whenever possible, place one thermometer near the center of the transformer so as to measure the temperature of the oil as it comes from the coils. The bulb of the thermometer should be about two inches under the oil. Place one thermometer in the oil about three inches from the side of the tank.

Oil-cooled transformers usually require a very long heat run, varying from six to fifteen hours depending on the size. The heat run should be continued until the temperature rise is less than one degree in two hours. Do not make a short circuit heat run on an oil-cooled transformer if it can be avoided; if unavoidable, make a short circuited heat run on the coils to constant temperature, then take double potential for one minute, one and one-half potential for five minutes, and one and one-quarter potential for three hours.

High Potential or Insulation Test

Many oil-cooled transformers are built for 50,000 to 100,000 volts and require a correspondingly high insulation test. The wiring from the high potential transformer to the transformer to be tested should be arranged so that no one can possibly come in contact with it. It must be securely strung to prevent its falling on any one.

The voltage applied is controlled either by varying the field of the alternator supplying power to the low potential side of the testing transformer; or, if the power is taken from the constant potential shop circuit, by a single-phase potential regulator. The spark gap should always be used and, if the power is supplied from a separate alternator or is controlled by a potential regulator, a high resistance consisting of two or more glass tubes filled with clean water should be placed in series with the spark gap. This limits the flow of current across the gap at the instant of arcing over and prevents a sudden discharge of the transformer windings.

The transformer windings act as the plates of a condenser; if suddenly discharged, or brought to the same potential, adjacent turns may easily short circuit. The same phenomenon occurs when potential is suddenly applied to a transformer. To reach the interior of the windings, the charging current must either follow the conductors, or break down the insulation between adjacent turns. The end coils are therefore all strongly reinforced to prevent short circuits. The general instructions already given for high potential test on air-blast transformers also apply here.

Double Potential

On transformers built to operate at 50,000 volts or over, the double potential should be the last test applied, in order to discover if any breakdown has occurred between turns under the high potential test.

OIL-AND-WATER COOLED TRANSFORMERS

Oil-and-water cooled transformers are identical in construction to the oil-cooled type, except that, instead of being placed in corrugated tanks to radiate the heat, they are placed in smooth tanks and have a cooling coil immersed in the oil to carry away the heat generated by the losses. The cooling coils are usually made of wrought iron pipe made up in coils of proper size by the pipe manufacturers. In special cases, however, where salt water is used for cooling, copper pipes are employed to avoid the action of the salt on the cooling coils. In most transformers these coils are placed in the upper half of the tank, but sometimes the cooling coils are made of flattened brass or copper tubing, placed between the primary and secondary coils. In large water-cooled transformers with low secondary voltages, the secondary winding is made of flattened copper tubing, through which water circulates.

The tests on water-cooled transformers are the same as for other types, but special instructions are necessary for handling the water. The oil in the transformers should completely cover the cooling coils. The cooling coils are tested by the plumbers to several hundred pounds per square inch, but they should also be tested by the testing department at the water pressure available. Allow water to flow through the coil until no air is left; then close the overflow, allowing the pressure to rise. Note whether there are any leaks, and if not, close the inlet valve. If the pressure drops rapidly, a leak is present. If the outside plumbing and valves are tight, test the oil at the bottom of the tank for water by drawing some off in a test tube. If water is present, it will settle to the bottom of the tube. If water is found, the cooling coil must be taken out and repaired. If, however, the pressure does not fall, leave the transformer under pressure for two hours. After all the tests are finished, the oil should be tested for water. With wrought iron pipe very little trouble is experienced.

Make all tests except the heat run according to the instructions already given for other types. At the start, run at normal rating without water until a rise of 20 deg. C. by resistance is reached. The oil should have a rise of about 15 deg. C. The ingoing water should be heated up to 20 deg. C. by using a steam heater; this is about the average temperature found in practice. The water should then be adjusted so as to have 10 deg. C. rise. Temperature readings should be made every fifteen minutes, in order that the quantity of water may be properly adjusted without loss of time. As soon as the transformers have nearly reached constant temperature, the quantity of water should be noted and a record made every half hour. The water may be weighed or measured.

The amount of water required is estimated as follows: One gallon of water will require about 2650 watts to raise it 10 deg. C. in one minute, or one gallon of water raised 10 deg. C. in one minute will carry away the heat generated by 2650 watts loss.

For a rough estimate, use one gallon of water for each 2500 watts loss—a small portion of the heat will be radiated from the outer surface of the tank. When the load is taken off the transformers for resistance measurements, always shut off the water. Complete the tests as on other transformers, making careful inspection for oil leaks. As the leads of many of these transformers are brought out through the cover, care must be taken when making connections to avoid dropping tools on the porcelain bushings.

These transformers are usually made for very high voltages, and are often filled with oil that has been specially refined. The tank is exhausted of air while the transformer is hot, and the hot oil allowed to slowly flow in at the bottom of the tank. To heat up the winding of these transformers, put one-half the full load current through the primary winding, carefully measuring the cold resistance. Take readings every half hour and calculate the rise of temperature by resistance. When a rise of 50 deg. C. is reached, decrease the current to maintain the temperature while the tank is exhausted of air.

In water-cooled transformers with secondary coils made of flattened copper tubing through which the water flows, the amount of water flowing through each section should be measured if all the sections are fed from the same water head. If each section has a regulating valve, these valves should be fully opened. Put on a low reading pressure gauge, hold the pressure constant by means of the valve in the main pipe and carefully measure the quantity of water from each section for a given time. Record the pressure and quantity per minute through each section. Never apply a pressure of over 10 pounds per square inch to a transformer of this type, as there is danger of opening the soldered joints. In taking overload heat runs, always use the same amount of water as for the normal load heat run.

Oil-cooled and oil-and-water cooled transformers built for voltages above 75,000 have special high tension leads which are filled with insulating material. These leads must be carefully filled before potential is applied to the transformer, and they must be kept filled. They should be carefully watched for leaks.

CHAPTER XXIII

EFFICIENCY, REGULATION, AND SPECIAL TESTS ON TRANSFORMERS

Efficiency Tests

The efficiency of a transformer is the ratio of its net power output to its gross power input, the output being delivered to a non-inductive circuit. The power input includes the output together with the losses, which are as follows: (1) The core loss, which is determined by the core loss test at rated frequency and voltage, and (2) the I^2R loss of the primary and the secondary calculated from their resistances. As the losses in the transformer are affected by temperature and the wave form of the e.m.f., the efficiency can be accurately specified only by reference to some definite temperature, such as 25 deg. C. and by stating whether the e.m.f. wave is sinusoidal or otherwise. The formula for efficiency may be written

$$\text{Per cent efficiency} = \frac{\text{output}}{\text{output} + \text{core loss} + I^2R \text{ loss}}$$

Regulation Tests

In constant potential transformers, the regulation is the ratio of the rise of secondary terminal voltage from rated non-inductive load to no load (at constant primary impressed terminal voltage) to the secondary terminal voltage at rated load. Regulation may be determined by loading the transformer, and observing the rise in the secondary voltage when the load is thrown off. This method is not satisfactory on account of the expense of making the test, and the small difference between no load and full load secondary voltages. Much greater reliance can be placed on results calculated from separate measurements of impedance drop, and resistance drop, than on the actual measurement of increase in secondary voltage.

The following method is used by the General Electric Company:

Let IR = Total resistance drop due to load current expressed in per cent of rated voltage.

Let IX = Total reactance drop due to load current expressed in per cent of rated voltage.

$$IX = \sqrt{(\text{per cent impedance drop})^2 - (IR)^2}$$

Let p = Power-factor (*Cos* 0)

Let w = Wattless factor (*Sin* 0)

$$\text{Per cent regulation} = (IR)p + (IX)w + \frac{[(IX)p - (IR)w]^2}{200}$$

This formula is approximate, but is satisfactory in all practical cases.

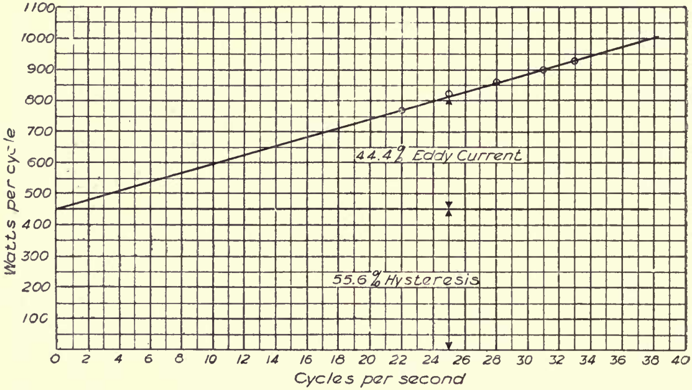


Fig. 63
Separation Curve

Special Engineering Tests

The separation of the core loss from copper loss may be considered as a special test on constant potential transformers. The core loss of a transformer consists of hysteresis and eddy current losses. The hysteresis loss is that due to cyclic reversals of the magnetism of the core, its value depending on the quality of the iron, and in a given transformer varies directly as the frequency and as the 1.6 power of the magnetic density. Eddy current loss is due to electric currents flowing in the iron, and varies with the conductivity of the iron, the thickness of the laminations, and the square of the frequency.

The method for separating the losses is as follows: Since the hysteresis loss varies directly as the frequency and the eddy current loss as the square of the frequency, by maintaining a given density in the core and varying the frequency, data can be obtained from which a separation curve can be plotted. The voltage to be applied varies directly with the frequency at which it is applied; thus 100 volts at 60 cycles becomes 200 volts at 120 cycles. Plotting watts per cycle as ordinates and cycles per second as abscissæ, curves similar to those shown in Fig. 63 are obtained. At least four points should be taken to determine the curve. By comparing the losses at normal frequency and density, the quality of the iron and the insulation between laminations can be deduced.

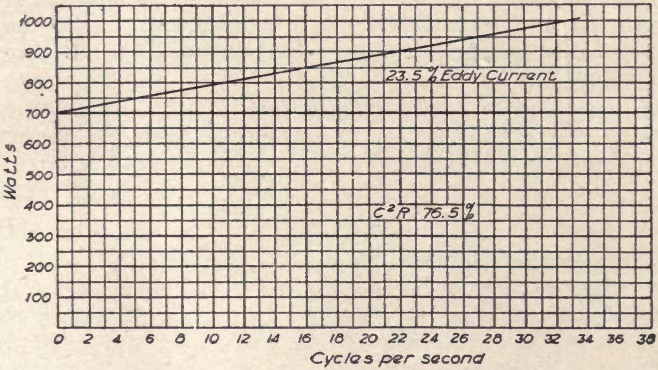


Fig. 64
Separation Curve

The eddy current loss in the copper conductors of a transformer may be separated from the ohmic loss in the following manner: The ohmic loss is independent of frequency, while the eddy current loss varies with the square of the frequency. Hold the current constant and take readings of watts, volts and speed while varying the frequency. Plot watts loss as ordinates and cycles per second as abscissæ, and project the curve back to the zero line. At zero frequency, the total loss will represent the true ohmic loss or I^2R. (See Fig. 64.)

In very exceptional cases, short circuit tests are taken on transformers to determine their behavior in case they are accidentally short circuited in service. This test is obtained by connecting one winding of the transformer to the power source, which should be of four or five times the capacity of the transformer, and short circuiting the other windings. The tendency of the ends of the coils to flare out due to the excessive magnetic repulsion is the important point in this test. The test should be short, as the current is from 15 to 30 times normal.

CHAPTER XXIV

SERIES TRANSFORMERS

Series transformers designed to supply current for operating meters and relays are generally tested in groups of ten to twenty at a time. The tests made are: Cold resistance on the secondary winding (one out of every five), polarity, ratio, heat run and insulation. To test the insulation between layers, the transformers are run for one minute at full load primary current with the secondary open. The primary and secondary windings must be carefully distinguished. In series transformers the winding that is to be connected in series with the circuit is called the primary, and the primary leads are nearly always brought out through much larger bushings than the secondary leads.

Cold Resistance

When several transformers are tested at the same time, a measurement of cold resistance on the secondaries need only be taken on about one-fifth of the transformers in the group. The primary resistance is too low to be measured accurately, and this test is usually omitted. The same precautions must be observed on these transformers as on large transformers.

Polarity

Polarity should be carefully taken. If the polarity is not correct, trouble will be experienced in making connections for polyphase meter circuits.

Ratio

Instead of actually determining the ratio, the transformers are checked with a standard. The one selected as standard must be sent to the standardizing laboratory to be carefully checked for ratio at proper load and frequency. Having selected one of the group as a standard, connect the primaries of all the transformers in series. Short circuit all the secondaries as shown in Fig. 65; then connect the ammeter to the secondaries of the standard and check the transformer. This connection must be made with lamp cord or other suitable wire, and must be sufficiently long to allow the ammeter to be at least ten feet from the primary circuit in order to avoid the effects of stray field. Check the reading of the ammeter connected to the standard by means of another ammeter, bring the current up to normal and note the reading of the check ammeter. Now transfer the ammeter on the standard to another transformer and bring the current up to the reading previously noted or the check ammeter. When correct, read the ammeter on the transformer in test; if this reading agrees with the reading when the ammeter was on the standard the ratio is correct. Proceed in this manner until all the transformers have been checked with the standard.

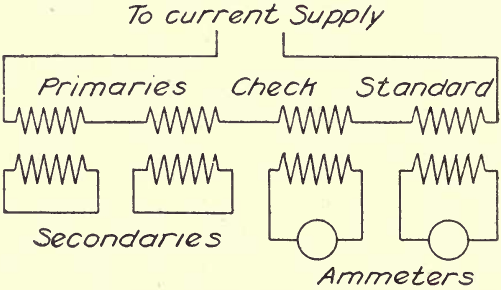


Fig. 65
Connections for Ratio of Series Transformer

New check readings are often necessary, due to unequal heating of meters and lines. Ratios should check within one per cent. Keep all secondaries short circuited except those to which the meters are connected. A few transformers of this type are built with two sets of windings; these should be tested as through they were two separate transformers.

Heat Run

On a new design of transformer a heat run should be made at normal primary current with the secondary short circuited until constant temperature is reached. Temperature rise by resistance should be taken hourly on one transformer out of every five, and thermometer temperatures on each one. When constant temperatures are reached, the transformer should run for two hours at the thirty minute load, which will be found stamped on the name plate. On transformers that are duplicates of some that have been previously built, a two hour heat run at the thirty minute load is sufficient. Measure hot resistances on one out of five and take thermometer temperatures on all. They should then be run for one minute at the thirty minute load with the secondary open to test the insulation between turns and between layers. This corresponds to the double potential test on other transformers.

The high potential test may be taken on several transformers at the same time. See that all secondaries and cases are properly connected together. Series transformers used in connection with potential regulators have the same characteristics as constant potential transfomers and are tested as such.

CHAPTER XXV

SINGLE-PHASE REGULATORS

The IRS, or single-phase induction regulator is built for use with electric furnaces and for the control of single-phase lighting feeders. It comprises a primary and a secondary winding, the former being placed in slots on a moveable core and the latter in slots on a stationary core. The regulator may be wound with two poles, four poles, six poles, or with any even number of poles; it may be cooled by an air blast, or it may be placed in a tank and cooled by oil, or by oil and water.

The voltage induced in the secondary winding depends upon the relative position of primary and secondary windings, the primary being in shunt and the secondary in series with the circuit to be controlled. Single-phase as well as polyphase regulators have a distributed winding for both primary and secondary, but the maximum pole face which can be covered by an active winding in a single-phase regulator, in order to produce the best results, is approximately 60 per cent. In the neutral position of the regulator, the secondary winding therefore encloses an area on the primary core not enclosed by an active primary winding, and the impedance would be extremely high if no auxiliary winding were provided. The slots of the primary which are not used for an active winding are therefore filled with a short circuited winding so that in the neutral position of the regulator the current in the secondary induces a current in the short circuited winding, thus reducing the impedance.

The tests required are cold resistances, "boost" and "lower," core loss, impedance, heat runs and insulation. Cold resistance is measured as on transformers. The "boost" and "lower" test is made at the full potential of the regulator and therefore requires care, as the magnetic leakage is greater at normal potential than at a lower potential. Connections for this test are shown in Fig. 66.

The volts primary and volts secondary should be read on the same voltmeter by using a double-throw switch. Throw the switch to the primary and bring the voltage up to the correct reading on the check voltmeter B. Throw the switch to the secondary, bring up the voltage to that noted on the check voltmeter, and read the secondary voltage. Take these readings at maximum "boost," neutral, and maximum lower positions. The turns of the handwheel from maximum "boost" to neutral and from neutral to maximum lower should be counted and recorded. The induced secondary voltage must be added to the primary voltage at maximum boost and subtracted from it at maximum lower.

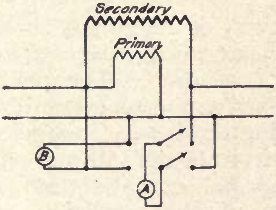


Fig. 66
Connections for Boost and Lower on Regulator

Check the index plate on the handwheel to see if it is correct; that is, see that the voltage is boosted when the index is turned in the direction indicated by "raise." In addition to the boost and lower test, the induced voltage of the secondary coil should be taken at maximum boost and maximum lower with full voltage on the primary coil. This is to act as a check on the boost and lower test. In taking readings for the boost and lower curve, great care should be taken in obtaining points near the end of the segment. About twenty points in all should be taken from maximum boost to maximum lower, holding the primary voltage constant and reading secondary volts at different positions of the armature.

Impedance

Impedance is always measured on the secondary winding, as it is impossible to force full load current through the primary winding when at the neutral position. In taking the curve, supply full load current to the secondary, with the primary short circuited through an ammeter, and take readings of watts secondary, and amperes primary at various positions of the armature. At maximum boost position take an impedance curve from 50 per cent full load to 150 per cent full load. The full load point of impedance for general tests should be taken at the maximum boost position, unless other instructions are given. Always record the temperature.

Core Loss

On the IRS type of regulator with the permanent short circuit on the armature, the core loss must be taken from the primary winding. The power-factor will be low, due to the air gap, hence considerable care must be taken in making the test. Take a core loss curve at maximum boost from 50 to 150 per cent normal potential, also hold normal potential and take readings at various positions of the armature, reading amperes and watts primary. In taking single point core losses for general tests, the armature should be in the maximum boost position.

Normal Load Heat Run

The heat tests are usually made by pumping one regulator back on another; they may, however, be loaded on water boxes or pumped back against a suitable bank of transformers. The permanent short circuit on the armature introduces complications in the heat run, since at any position except maximum boost and maximum lower, the short circuited coil carries some current if the impedance voltage is supplied from the secondary.

The amount of current in the short circuited coil depends upon the position of the armature; hence, in taking a heat run, connect the primaries of the regulators in multiple and apply primary voltage at the proper frequency. Ammeters should be placed in each primary circuit and the secondaries should be connected in multiple through an ammeter. Place the armature of one regulator in the maximum boost position and shift the other until full load primary and secondary is obtained on the first regulator. The other regulator will have full load secondary current and a partially loaded primary; the short circuited winding on the armature accounting for the current not appearing in the primary. Both regulators would generally pass on the results of these heat runs. When special guarantees are required, however, the heat run should be finished on the first regulator, and then the second regulator should be run with the armature in the maximum boost position.

Overload heat runs are usually taken as a continuation of the normal load heat run. To shorten the heat run, the regulator, if of the air blast type, may be operated for a short while without air; if oil cooled, it may be operated at an overload; while if oil and water cooled, it may be operated for a time without water. Careful inspection should be made for oil leaks and other mechanical defects. Hot resistances should be taken in the same manner as on transformers.

The insulation tests consist of double and high potential tests and are taken in the usual way. Although only a low voltage is induced in the secondary coil, it is in series with the circuit to be controlled, and should, therefore, have the same potential applied as is applied to the primary winding.

Operating Motor Tests

If the regulator is provided with an operating motor and limiting switch, they should be tested during the early part of the heat run so as to avoid rewiring after the heat run is finished. The motor and limiting switch should be connected according to the proper sketch, and readings of the current should be taken at normal potential and frequency, with the motor disconnected from the shaft and with the motor operating the regulator in both directions at no load and at full load. When the regulator is under full load, the motor should operate it from one extreme position to the other. To keep load on the regulators while this is being done, the handwheel of only one regulator need be turned. The time required to travel from one end of the segment to the other should be taken and recorded. The limit switch should be adjusted so as to work properly.

CHAPTER XXVI

POLYPHASE REGULATORS

Induction regulators of the polyphase type are used principally with rotary converters, but are well adapted to control polyphase transmission circuits. As in the IRS type, they may be either air blast cooled, oil cooled or oil and water cooled. The primary winding is connected in shunt and the secondary in series with the circuit. In the polyphase induction regulator, the voltage induced in each phase of the secondary is constant, but by varying the relative positions of the primary and secondary, the effective voltage of any phase of the secondary is varied from maximum boost to zero, and from zero to maximum lower.

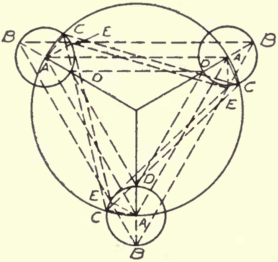


Fig. 67
Regulator Diagram—Three-Phase

Referring to Fig. 67, which represents graphically the voltage of the three phases of a three-phase or IRT regulator, let AAA = the line voltage or the e.m.f. impressed on the primary. This is shown by the large circle. Let BA, BA and BA equal e.m.f. generated in the secondary coils, which is constant with constant impressed e.m.f. This is shown by the three small circles on the circumference of the large circle. *BBB* shows e.m.f .induced in secondary coils directly in phase with the primary impressed e.m.f. This is the position of maximum boost. Positions *CCC* represent the neutral position, and *DDD* the maximum lower position. *EEE* represents a position between neutral and maximum lower.

By changing the position of the armature with respect to the field the secondary voltage may be made to assume any phase relation with respect to the primary e.m.f.; it can be in series with it or directly opposed to it. This movement of the armature is obtained by means of a segment on the shaft which meshes with a worm on the small operating shaft. The regulator may be arranged for hand operation only, or can be motor operated. Either a direct current or an induction motor may be used. The motor is controlled by a small double-pole double-throw switch on the switchboard, by means of which the voltage is raised or lowered as desired.

To stop the regulator on reaching the limits of regulation when moving in either direction, a limiting switch is provided which opens automatically. If properly connected, however, this automatic cut-off does not interfere with movement in the opposite direction, which can be obtained by the double-pole double-throw switch.

The winding of the primary and secondary is similar to that of a Form M induction motor the primary being placed on the movable core. For a three-phase or six-phase regulator the primary may be Y or delta-connected; for an IRH six-phase regulator, the primary may be connected diametrically. The secondary or stationary winding is placed on the stationary core and is an open winding, each section or phase being connected in series with the corresponding phase of the line to be controlled.

The tests required are cold resistance, boost and lower, core loss, impedance, heat run, hot resistance, double potential for one minute, one and one-half potential for five minutes, and high potential test. If the regulator is motor operated, the motor should be tested during the heat run to save rewiring. Air readings should be taken on the air blast regulators.

Cold Resistance

Before starting the tests, carefully check all circuits. If the secondary coils have two studs on each end per phase, test to see if the studs are connected in multiple or if each secondary consists of two separate coils which are connected in multiple by the cable lugs. If the regulator is six-phase IRH, test to see if these are two primary circuits. On diametrically-connected IRH's (Fig. 68), primaries 1–3–5 should be one set, and 2–4–6 the other.

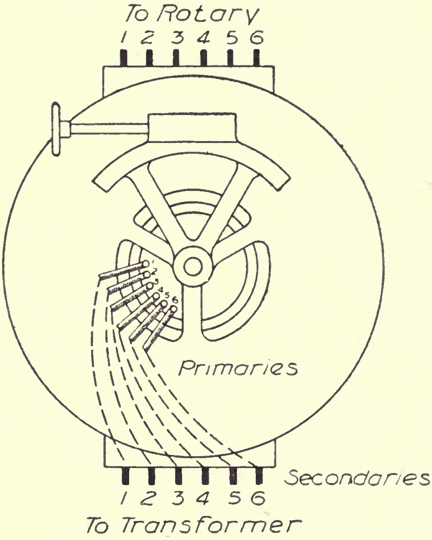


Fig. 68
Six-Phase Regulator

On a delta-connected IRH regulator, 1–4, 2–5 and 3–6 should give proper circuits. If each secondary circuit has two coils that are connected in multiple by the cable lugs, the top stud on one side is generally connected to the bottom stud on the opposite side, and vice versa.

Measure the resistance as on a transformer. In recording the secondary resistances, a note should be made of the place on which the drop lines were placed.

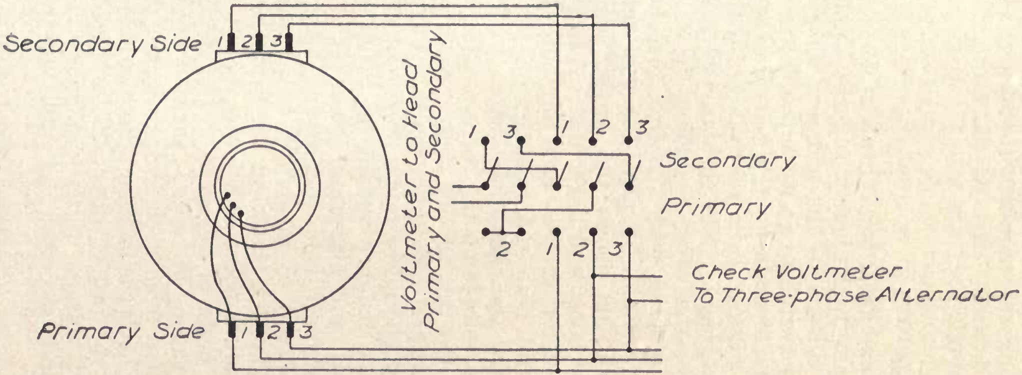


Fig. 69
Connections for Boost and Lower—Three-Phase Regulator

Take the resistance of each secondary coil and make a sketch showing the numbers that have been given to the various circuits. Record the temperature of each coil, or of the oil.

Boost and Lower

The boost and lower test is made at normal voltage and frequency. On three-phase regulators, apply a balanced three-phase voltage to the primary using a three-pole double-throw switch to transfer the voltmeter from the primary to the secondary. (Primary and secondary here refer to the voltage to be controlled and the controlled voltage respectively.) The regulator must be connected as in service, the primaries being in shunt and the secondaries in series with the circuit to be controlled. A voltmeter should be placed across one phase for a check. Fig. 69 shows the proper connections for a three-phase boost and lower test. Adjust the voltage by the voltmeter that is used on both primary and secondary, and note the readings on the check voltmeter. Throw the three-pole switch to the secondary and read the voltage on the corresponding phase of the secondary. Do this for all three phases at maximum boost, neutral and maximum lower. A curve of about twenty points should be taken on one phase.

The voltage balance should be taken at maximum boost, neutral, and maximum lower. Count the turns of the handwheel from maximum boost to neutral and from neutral to maximum lower and record the number to afford a check on the mechanical construction. Maximum boost and lower do not always come at extreme ends of segment. The voltage readings should be taken at every turn of the handwheel for a few turns from each end, to locate the maximum positions. Check the index on the handwheel to see that it indicates the proper direction for boost and lower. The induced voltage in the secondary coil should be measured and recorded, as well as the boost and lower.

In some types of IRH regulators, the terminals of the secondary coils are crossed instead of being directly opposite each other. (See Fig. 70.) In such cases take care to properly record the boost and lower and make a clear sketch showing the arrangement of the secondary terminals. Boost and lower may be taken on six-phase IRH regulators as though they consisted of two separate regulators; that is, the test may be made on 1–3–5 and then on 2–4–6. Six-phase voltage must, however, be applied and a set of six-phase boost or lower readings taken to determine if the regulator is satisfactory.

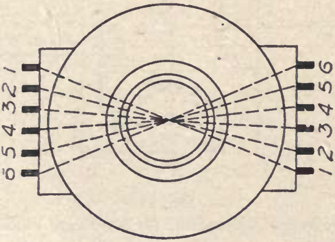


Fig. 70
Regulator—Six-Phase

Fig. 71 gives the method of obtaining six-phase voltage which should be tested before proceeding. With the connections shown, the voltages corresponding to the six sides of a hexagon can be obtained by reading 1–2, 2–3, 3–4, 4–5, 5–6 and 6–1. Unless six-phase voltage is used, don't try to make a boost or lower test. The induced secondary voltage of each secondary coil should be recorded.

The boost and lower test on IRH, or diametrically connected regulators, must be made by applying a six-phase diametrically connected voltage, tested as previously described. The transformer connections are shown in Fig. 72, a neutral point being made so that six-phase voltage may be read. In making boost and lower, read the diametrical voltage, carefully checking the six-phase boost or lower and recording it as the diametrical boost or lower. Measure and record the induced voltage across each secondary coil.

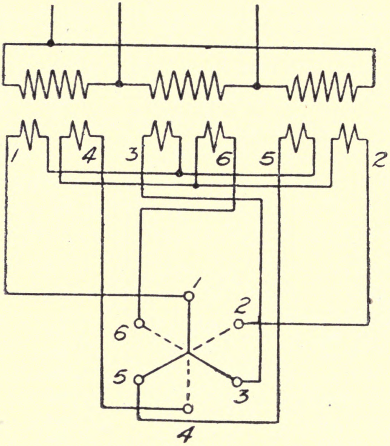


Fig. 71
Method of Connecting for Six-Phase Voltage

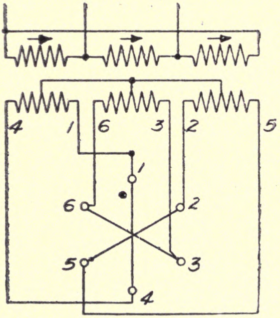


Fig. 72
Connections for Six-Phase Boost and Lower

Core Loss

For low potential three-phase regulators, core loss is measured in the usual way by applying normal potential to the primary winding. For regulators the primary voltage of which exceeds 1100 volts, core loss should be measured on the secondary winding.

For six-phase two-circuit primary regulators, one set of core loss readings on lines 1–3–5 and another on 2–4–6 should be taken. Either set should give the correct core loss. For six-phase diametrically connected regulators, core loss may be determined by applying six-phase voltage, reading the core loss in each phase and taking the sum of these losses. It may also be taken by connecting the primaries in delta, reversing one primary coil to maintain the proper distribution of magnetic flux. Apply the rated primary voltage and determine the core loss by the two wattmeter method. Another method of determining core loss is by connecting the primaries in Y and applying 1.73 times the rated potential. One coil must be reversed for the Y connection, as is done for the delta connection.

In making a core loss test, record the voltage, exciting current and wattmeter readings. The test must be made at the proper frequency and the generator supplying the loss must operate at normal voltage. The magnetizing current will vary from 20 to 40 per cent, depending upon the air gap. A curve should be taken beginning at 50 per cent normal voltage and increasing to at least 125 per cent normal voltage. Whenever possible, neither potential nor current transformers should be used with the wattmeter, in consequence of the very low power-factor. During the core loss tests the armature should be in the maximum boost position. A curve should also be taken by holding normal voltage and varying the position of the armature.

Impedance

Impedance is usually measured by short circuiting the secondary and applying sufficient voltage to the primary winding to give full load current. The impedance voltages varies from 15 to 20 per cent. This test should be made on three-phase regulators by using three-phase voltage, and on six-phase regulators by using six-phase voltage. Wattmeter readings are not required, as the efficiency is calculated, using the I^2R losses as computed from the resistances. When calculating the full load primary current for this test, assume that the regulator operates at a power-factor of 80 per ecnt.

In special cases, impedance may be taken from the secondary side, in which event connect the secondaries in Y and apply rated current. An ammeter should be placed in one phase of the short circuited primary. If the primary is permanently connected to the secondary inside the machine, each secondary coil must be short circuited on itself. On all other types, the secondary is short circuited by connecting all the secondary terminals on either side with a copper bar.

A curve should be taken ranging from 50 to 150 per cent full load, with the armature in the maximum boost position. A curve should also be taken while holding full load current and varying the position of the armature. This curve should be very carefully taken over one-half of the segment, to obtain the maximum impedance.

Heat Run

Whenever possible, heat runs should be made with full load on the regulator, either by pumping one regulator back on another, or by pumping back against a bank of transformers. The heat run on two regulators of the same size and type is made by connecting the primaries in multiple through a dynamometer board. One end of the secondary coil of the regulator is connected to the end of the secondary coil of the other by short circuiting bars. The other ends of the secondary coils of one regulator must be in multiple with corresponding coils of the other regulator. Normal voltage of the proper phase and frequency is applied to the primaries of the two regulators. The handwheel of one regulator must be turned so as to cause sufficient phase displacement of the secondary voltages of the two regulators to produce full load current in the secondary winding.

In pumping back against a bank of transformers, the same general method is used. The ratio of transformation of the transformers should be about equal to that of the regulator. The same readings of temperature should be taken as on a transformer using a similar method of cooling. Carefully observe if there is any noise while under load; if humming is noticed during the core loss test, the cable lugs connecting the two secondary circuits

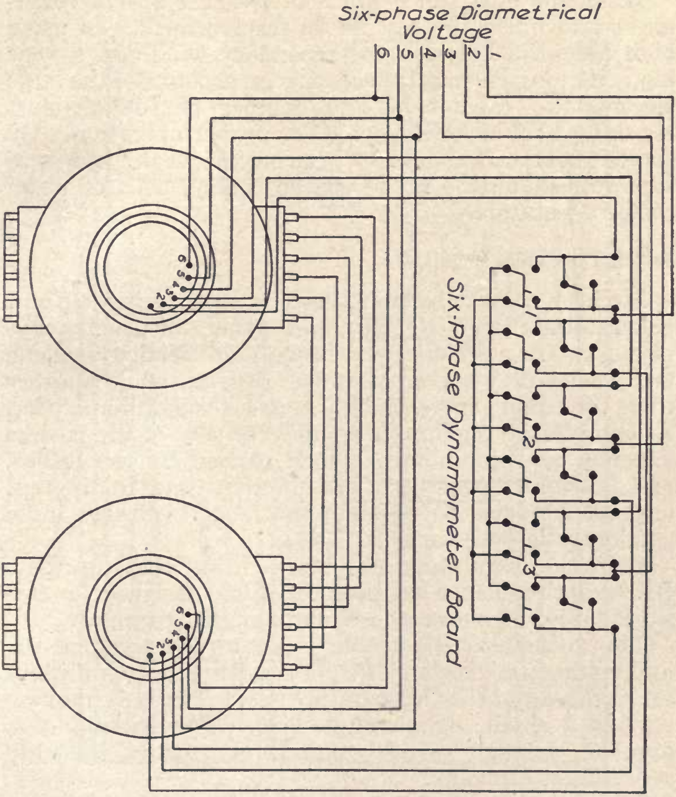


Fig. 73. Connections for Heat Run on a Six-Phase Regulator

in multiple should be removed to see if the noise is caused by exchange current.

Fig. 73 shows the connection for the heat run on two IRH regulators.

When the heat run is finished, measure all hot resistances and finish the test as on transformers. In using high potential between the secondary windings, a very high charging current is necessary on account of the large electrostatic capacity. The damper of the air-blast regulator should be inspected for proper operation. Oil cooled regulators should be inspected for leaks and pressure test should be made on the cooling coils of water cooled regulators.

Switch Type (BR) Regulator

Modern central stations employ alternating current generators of large capacity, each generator usually supplying two or more districts through independent feeders. One feeder may serve a business district, while another from the same generator may feed a residential district. As the voltage regulation required on any of the feeders depends on the amount of load carried by the feeder, and as the load peak occurs at different times in different feeders, a device to regulate the feeder voltages independently is necessary.

Induction regulators may be used, but the automatic BR feeder regulator has been expressly designed for this work. Fig. 74 shows the circuits of this regulator.

The automatic BR feeder regulator can change the line voltage quicker and with a smaller power consumption than any other automatic type. The only moving part is a small, light switch arm. The friction of a number of small switch contacts constitutes the only resistance to turning.

The moving part of the switch carries a series of fingers the majority of which are always in contact. (See Fig. 75.) Each finger is connected to a stationary collector ring by a brush, and the collector ring is connected to the line through a preventive resistance. The resistances connecting the fingers to the line prevent excessive exchange currents as the fingers pass from contact to contact,

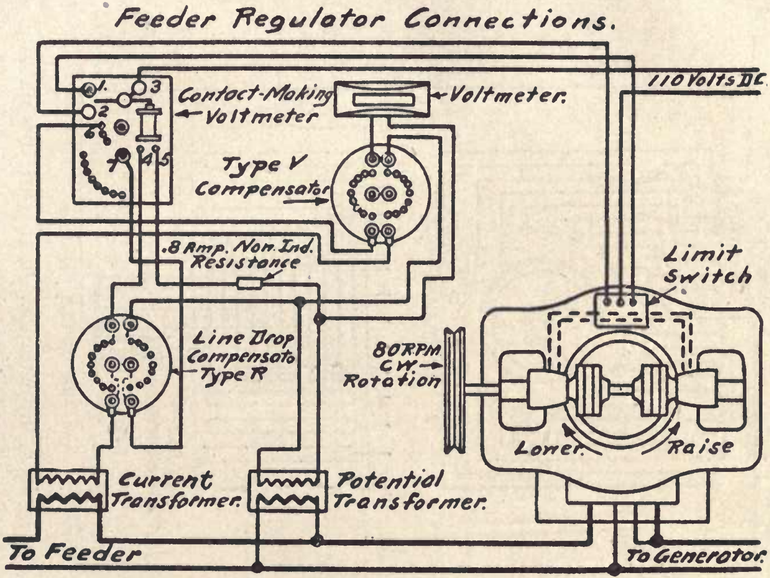


Fig. 74. Connections for BR Regulator

and the line voltage is varied uniformly. The regulator transformer is oil cooled.

The test required are: resistances, tap voltages or ratio, core loss, impedance, heat run, insulation, and checking of clutch coil and limit switch circuits.

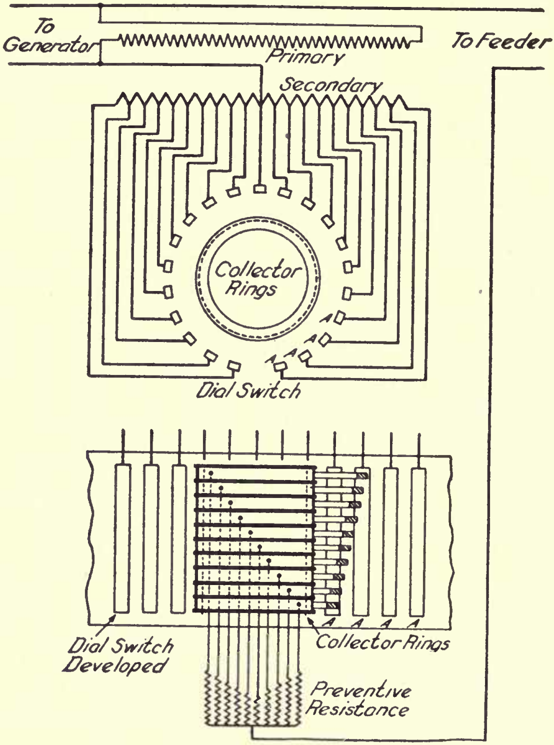


Fig. 75. BR Regulator

Cold Resistance

Measure the cold resistance of the primary winding, each half of the secondary, and the iron grids. To obtain the resistance of each half of the secondary winding, turn the switch to the extreme position and take readings, showing the switch position by a sketch. Then throw the switch into the other extreme position and measure the other half of the secondary winding.

Tap Voltage or Ratio

When the switch contacts are accessible, full voltage should be applied to the primary winding, reading the voltage between the steps on the switch. This test will show any wrong switch connections immediately. Correct connection can also be checked by a polarity test on each step. If properly connected all steps will have the same polarity; that is, the voltmeter deflections are all in the same direction.

If the contacts of the switch are inaccessible, the step voltages may be taken as follows: Throw the switch to the neutral position, apply full voltage to the primary, and connect the voltmeter across the secondary. When the switch is in the neutral position, no secondary voltage will be obtained. Move the switch one step and read the secondary voltage. Then move the switch to the next step when the reading obtained should correspond to two steps in series. Continue until the switch has reached the extreme position. Bring the switch back to the neutral, then test the steps on the other half. If the sections of the secondary winding are properly connected to the dial, the voltmeter readings should increase in equal increments.

Core Loss

Core loss may be determined from the primary but is more satisfactorily determined from the secondary winding. Throw the switch to the extreme position and apply the rated boost or lower voltage, reading watts input and exciting current at the proper frequency. The per cent loss and exciting current will be about the same as for Type H transformer of the same kilowatt capacity. Throw the switch into the other extreme position and repeat the test.

Impedance

Supply current to the primary, with the secondary and iron grid short circuited through an ammeter, the switch being in one extreme position. Increase the primary current until full rated current is obtained on the short circuited secondary, and read amperes, watts and volts primary at the proper frequency. Throw the switch into the other extreme position and repeat the test. Impedance must be taken with the switch in both extreme positions, as in either position only one-half of the secondary winding is short circuited.

Heat Run

If two regulators are in test at the same time they may be "pumped back" on each other; if only one is in test, it may be pumped back on a suitably arranged bank of transformers, or loaded on a water box. In the latter case apply voltage to the primary, connecting the secondary to a water box and adjusting until full load secondary current is obtained. The switch must be in one of the extreme positions. Read and record the temperature and also record the temperature of the iron grid resistance.

Start the test at overload so as to shorten the length of the heat run. Finish as if testing on a transformer. Throw the switch in the other extreme position and run at 50 per cent overload current for one hour to test the other half of the secondary.

Insulation Tests

Apply double potential for one minute and one and one-half potential for five minutes. High potential tests on regulators are similar to those made on transformers. If the primary is connected to the secondary inside the tank it is not possible to test between the primary and secondary windings. If the clutch coils, relay coil, and relay voltmeter operate on a circuit of 125 volts or less, test with 500 volts between the winding and frame. The tank and oil gauges should be inspected for leaks.

CHAPTER XXVII

STARTING COMPENSATORS

Compensators for starting squirrel-cage induction motors, synchronous motors, and rotary converters are built for voltages from 110 to 13,200 volts. The switching mechanisms constitute the chief difference between the various types. One of the principal types has a double-throw oil switch and is so connected that when the motor is thrown on the line, the fuses are in circuit. Figs. 76 and 77 show the wiring for quarter-phase and three-phase compensators of this design.

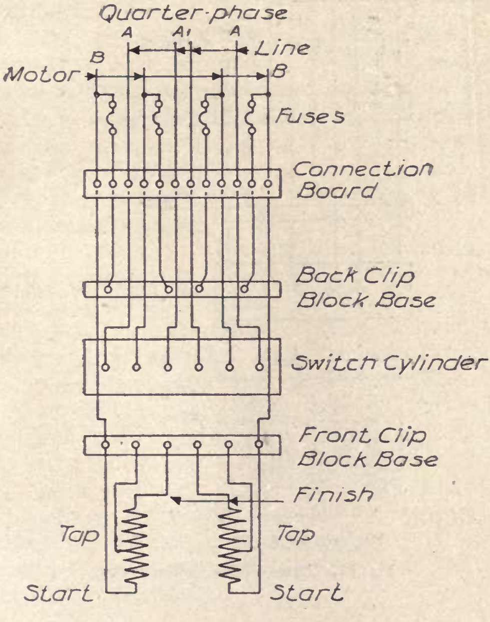


Fig. 76. Quarter-Phase Compesator

Complete tests on compensators consist of commercial tests, heat runs, impedance, and insulation tests. Commercial tests consist of ratio of taps, exciting current at normal voltage, and insulation tests. Insulation tests consist in applying high potential between windings and ground for one minute, operating the compensator at double potential for one minute, and also at 50 per cent above normal potential for five minutes.

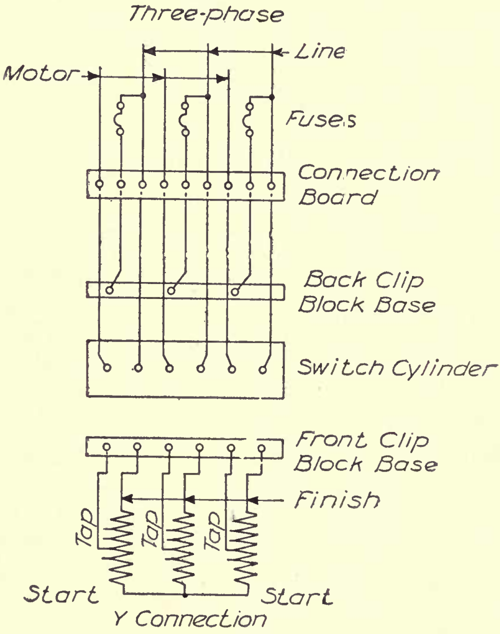


Fig. 77. Three-Phase Compensator

Ratio

Connect the leads to the line terminals of the compensator and apply about 100 volts to the lines, throwing the switch on the compensator to "starting" position and leaving all others in the "off" poistion. On the three-phase compensator read the voltages between the taps; the lowest voltage tap is next to the core. Standard compensators for motors up to and including 17 h.p. have 50, 65 and 80 per cent taps; those for motors above 17 h.p. have 40, 58, 70 and 85 per cent taps. The ratios obtained should agree to within 3 per cent of the above values.

In determining ratios see that both the primary and secondary meters are on the same phase. In checking the ratio of quarter-phase compensators, apply 100 volts to the lines *A* and *A* (Fig. 76) and read the voltage on the taps between the motor lead *B* and the taps. These compensators are tested open-delta.

Magnetizing Current

Magnetizing current is measured at normal primary voltage and normal frequency. The alternator used should operate at about its normal voltage. On 60 cycle compensators, the magnetizing current should not exceed 25 per cent, on 40 and 25 cycle compensators it should not exceed 30 per cent of the full load current of the motor, assuming the latter to operate at 75 per cent *apparent* efficiency.

On compensators that are not standard, the magnetizing current should be measured at 20 per cent above the normal potential, as well as at normal. In making this test, hold the volts constant across one phase and read the current in all three legs; then hold the current constant in one leg and read the three-phase voltage. Instead of holding the current in one leg, two voltmeters may be used, one to hold the volts constant and the other to read the three-phase voltage. Since a high magnetic density obtains in the core, see that the voltage and frequency are correct, as a slight change in either will change the magnetizing current considerably. Quarter-phase compensators are tested as though they were connected open-delta.

Heat Runs

Short circuit the leads to the motor and apply sufficient voltage to the line leads to force the required current through the coils for one minute. Place a thermometer on the coils to obtain the temperature. Thirty minutes should elapse between successive heat runs on the same compensator and after each heat run the tap leads should be changed to the next tap. On very large compensators it is often necessary to wait several hours between heat runs, otherwise the compensator will run hot and smoke. The heat run at normal rating cannot always be taken on all legs at the same time on account of insufficient power. In such cases run at reduced current and increased time or bare the Y connection, short circuiting the tap to the Y.

On compensators not standard, or those covered by special instructions, the impedance volts should be measured. See that frequency is correct for this test. When the heat runs have been finished, inspect the oil boxes for leaks; if they are tight, empty the oil out and turn them upside down to drain. Connect the inside motor leads to the second lowest tap, replace the oil boxes, tape and insulate all the connections, and replace the covers. All cast iron oil boxes are tested for leaks by filling with oil for ten hours. Pressed steel boxes are tested before delivery to the testing department and therefore need not be removed from the compensator.

Insulation Test

Double potential should always be applied after the compensator has been completely assembled and the taps insulated with tape. Double voltage is applied to the line terminals for one minute, the frequency being high in order to keep the magnetizing current below the normal current of the compensator.

If the compensator is designed for high voltage, double potential may be applied on the taps for one minute. The high potential test is made in the usual way, with all leads connected together. Compensators up to and including 600 volts are tested at 2500 volts.

ROTARY CONVERTER REACTANCES

Reactances are generally used in compounding rotary converters. They are placed between the secondary of the step-down transformer and the collector rings of the rotary.

The ratio of conversion of rotary converters, except those of the split pole type, is practically constant for all field strengths. Therefore, to increase the direct voltage, the alternating voltage must also be increased. In large systems, with a number of substations receiving current from the same generating station, any given substation voltage must be varied independently of that of the others. Several methods are possible: for lighting systems an induction regulator is often employed, or the step-down transformers may be provided with a dial switch to vary the ratio of transformation. These devices do not operate automatically, whereas the compounding of a rotary converter is automatic.

The excitation of the shunt field is adjusted at no load to a value which causes the machine to take a small lagging current. This lagging current, flowing in the reactive coil, reduces the voltage at the collector rings below that at the transformer terminals. As the rotary takes load the current through the series field first reduces the wattless current through the reactive coils and at higher loads forces a leading wattless current through them. When the current becomes leading, the voltage at the collector rings is higher than at the terminals of the transformers.

Rotaries may be made to over compound; that is, increase the continuous current voltage as the load increases.

Reactive coils are often placed in multiple with long distance, high voltage transmission lines to compensate for capacity; they are also used as dimmers, for the lighting of theaters, etc.

Complete tests on reactive coils for rotaries consist of measurements of resistance, reactive drop, and heat runs at normal and overload, polarity and insulation tests. Reactive drop is usually taken during the heat run. These coils have the same heating guarantees as the transformers with which they operate.

For the heat run, connect the coils in Y and supply full current at proper frequency, taking precautions to see that the meters are protected from stray fields. The transformer cables should be kept close together, to prevent high impedance and unbalancing. Heat runs on air blast reactances should be started without air at normal load for about thirty minutes before the air blast is put on. Oil cooled reactances should be started at overload to shorten the heat run as much as possible.

In making heat runs on reactances designed for six-phase circuits, connect the coils in series and make the heat run on a three-phase circuit. Reactive coils cannot betested by the motor-generator method (Hopkinson method), hence, the test must be run from an alternator capable of supplying full kilovolt-amperes. If an alternator of sufficient capacity is not available, use two in multiple. They can be run as generators, but after the alternators have been synchronized, it is better to pull the breaker of the driving motor of one of them. By proper adjustment of the field current, the one running light will operate as a rotary condenser.

In measuring reactive drop, take the volts across each coil, holding full load current in one leg; then hold the volts across one coil constant and read the current in all three legs; after which take the drop across each leg, holding full load current on all legs. This test must also be made at 50 per cent overload. The frequency must be held constant while the drop is being taken, as the reactance depends directly on the frequency. When the reactive coil has reached constant temperature at normal load, run for two hours at 50 per cent overload.

When the heat run is finished take air readings and test the insulation. The insulation tests consist of double potential for one minute, and one and one-half potential for five minutes, and high potential tests. The high potential test must be applied between the winding and core, between the winding and frame, and between the phases.

Polarity Test

The polarity test is made by supplying direct current to the middle phase and so connecting a voltmeter to the terminals as to get a positive deflection; the drop lines are then transferred to the corresponding terminals of the other phases and the direction of kick on breaking the current in the middle phase is noted.