Student Manual

ALTERNATING CURRENT-1

COYNE
ELECTRICAL AND
RADIO-TELEVISION
SCHOOL
CHICAGO 12, ILLINOIS

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ALTERNATING CURRENTS

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F O R E W O R D

This manual contains basic technical and practical information based on the curriculum outline for the Alternating Current Department of this school. The subject matter covered in this manual is necessary information that the student must learn in order to master the jobs that will be presented in this department and in following departments.

The purposes of this instructional manual are as follows:

1. To provide a guide for the student in his class and shop work.

2. To supply information in outline form to which the student may add supplemental notes in his own words as the different points are explained by instructors.

3. To service as a reference both to the student in school and to the graduate after he enters the field.

Appreciation is extended to the Alternating Current personnel and to the entire faculty for developing the material for this manual.

B. W. Cooke,
President

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FUNDAMENTALS OF ALTERNATING CURRENT

Objective

To learn the fundamental principles of Alternating Current and the terms used to express the characteristics of AC phenomena.

References:

Lesson Content

A. General

In reviewing the terms discussed and explained in previous departments, it may be brought to mind that DC is a continuous current which remains constant in value when the voltage E, and the resistance R, remain unchanged, and also that AC can be considered as a constantly changing current both in value and direction. Nearly all of the material and discussions in this department will be in addition to the single and split phase experiments and discussions that have been studied previously. It is the purpose of this department to acquaint you with three-phase equipment, its design, operation, maintenance hints, and some of the many other factors which will enable you to understand fully WHY a machine works, or possibly more important, just why it acts as it does under controlled conditions.

Before proceeding, however, it may be well to review some of the common definitions and their meanings, as applied to alternating current. Since your training is of a non-engineering nature, we will approach our studies in a practical "down-to-earth" discussion.

B. Definitions

1. ALTERNATING CURRENT is a periodic current the average value of which over a period is zero, ASA 05.20.070.

   It can be expressed, also, as continually changing in value and periodically reversing in direction of flow. Commercial AC is sine wave in form, Fig. 1A, and almost perfect in structure. Should an imperfection be detected, it would likely be attributed to harmonic action.

2. A CYCLE, ASA 05.05.185, is the complete series of values of a periodic quantity which occur during a period. We can also define a cycle as a complete series of events continually repeated in the same definite order. One cycle is equal to 360° electrical.

3. AN ALTERNATION is actually $\frac{1}{2}$ cycle or the number of degrees passed by a conductor to make 180° electrical.

4. FREQUENCY is the number of periods occuring in unit time, in which the time is the independent variable of the periodic quantity, ASA 05.05.180. It could also be stated that frequency is the number of cycles per second (CPS) including such common frequencies as 60-50-40-30-20-16 2/3 in which case each frequency is put to its own use. The most common frequencies now used are 25 and 60. The 25 cycle system is used for high power transmission to reduce the line and copper losses; also the inductive effect that would be more noticeable in higher frequencies. The most common frequency in use is 60 cycle because of its satisfactory frequency response for lighting loads, etc.

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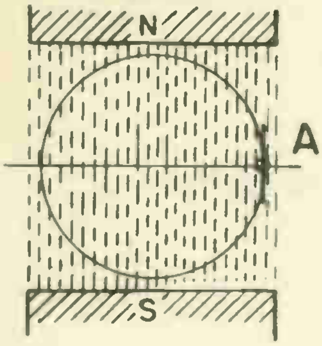
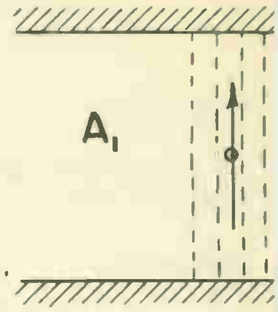
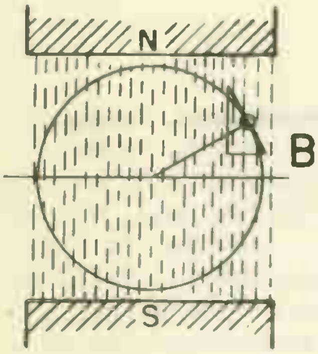


When a conductor moves in a magnetic field, the voltage induced in it depends upon:

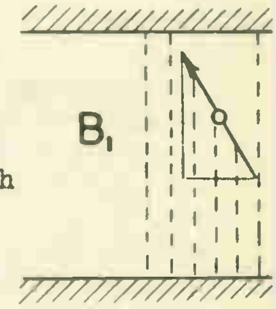
1. Strength of the magnetic field
2. Speed of the conductor
3. The direction of motion of the conductor with respect to the magnetic field.

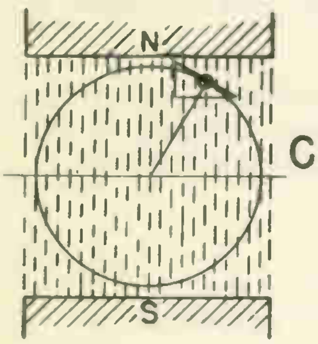
In all diagrams on this sheet, the conductor is assumed to move at a constant angular velocity. In diagram A, the conductor is moving parallel to the field and at this instant there is no voltage generated.



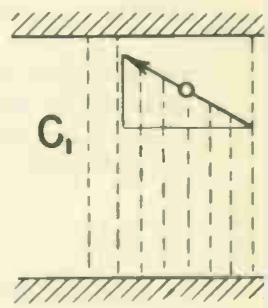


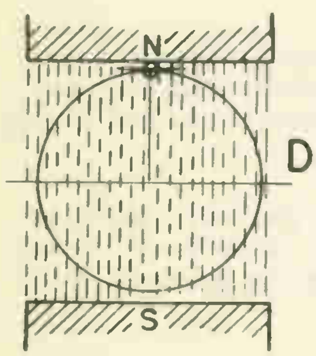
In diagram B, the conductor is moving through the field flux at an angle of 30° electrical and the rate of cutting lines of force has increased. Sketch B1 shows the effect of the changing direction of conductor motion, which has proved through this angle of 30°.



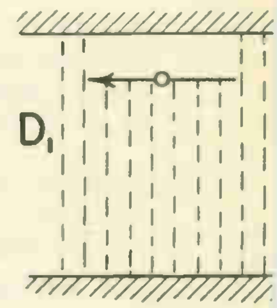


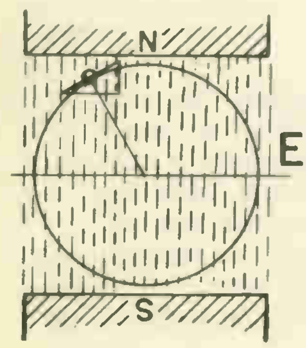
In Figure C, the conductor is moving across the flux at a different angle and, as can be seen readily by referring to Fig. C1. The number of lines of force cut per degree of angular motion has increased, because the degree of cutting has now increased to 60° electrical.





In Figure D, the conductor is moving at right angles to the field flux and is, therefore, cutting lines of force at the maximum rate. The induced voltage at this point in the rotation, therefore, is maximum because it has moved through 90° electrical.





In Figure E, the angle at which the conductor is moving with respect to the lines of force is diminishing. The rate of cutting lines of force is, therefore, reduced, and the generated voltage is less than in Fig. D. The manner in which the voltage varies from point to point is shown in Fig. 1A and 1B. The conductor, which is now at 120°, gives a similar value as at 60° electrical.

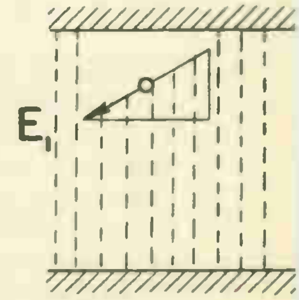


Fig. 1

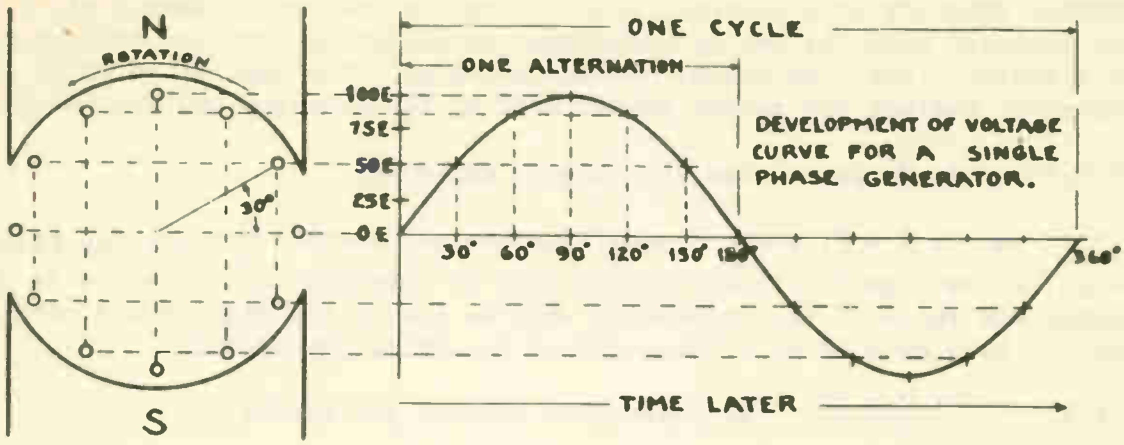
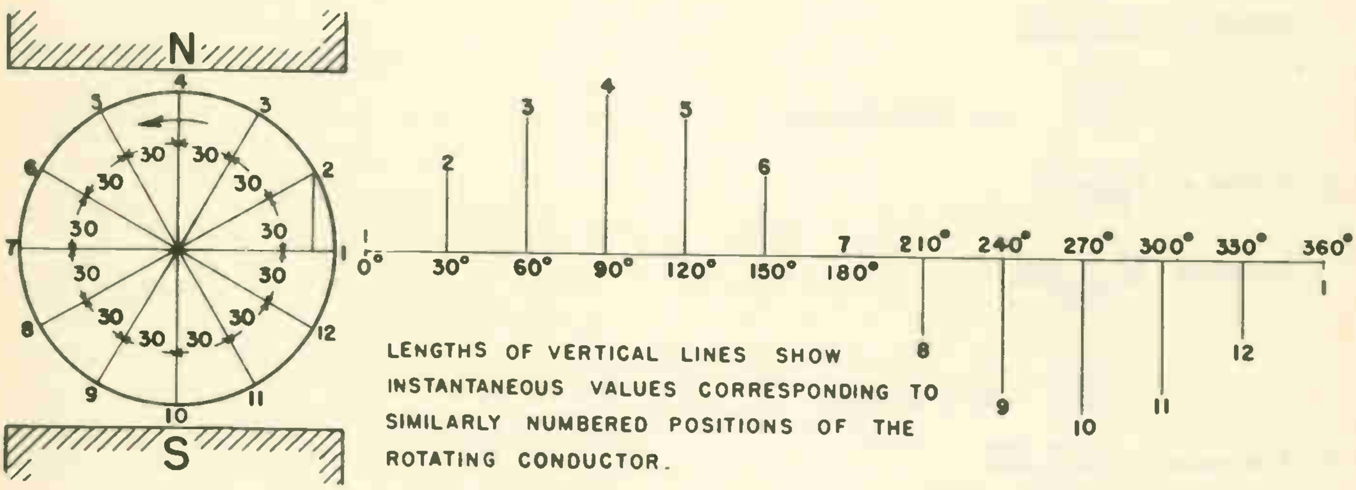
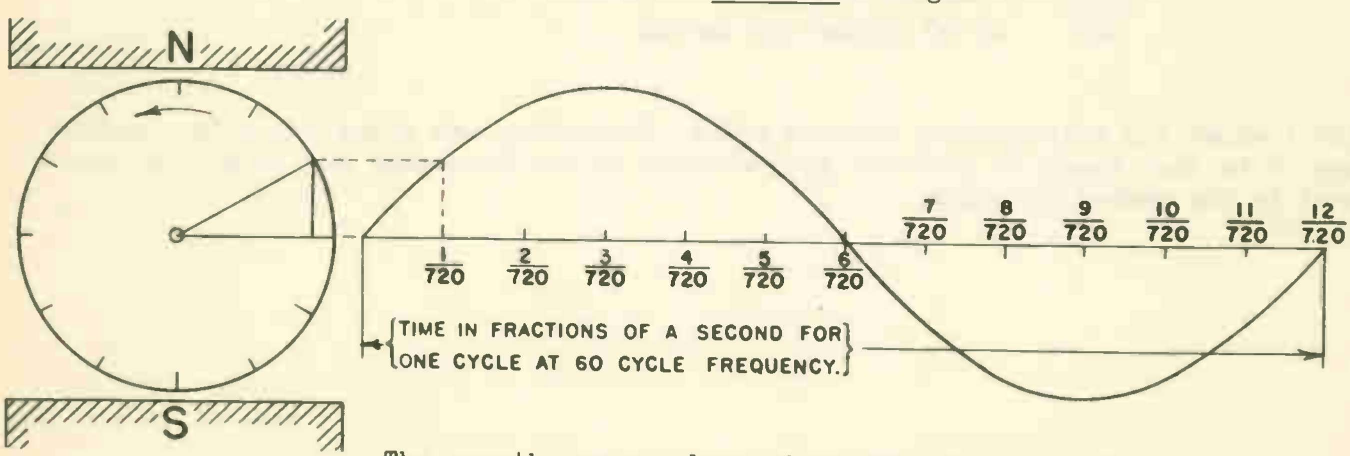


Fig. 1A



These values are based on the assumption that the conductor moves at constant angular velocity thru a magnetic field of uniform strength.



The smooth curve above shows the manner in which the generated voltage varies from instant to instant. The distance of the curve from the base line at any point is a measure of the voltage generated at that instant.

Fig. 1B

5. ANGULAR VELOCITY of a periodic quantity equals frequency times 2 pi, 6.28. If the periodic quantity can be considered as resulting from the uniform rotation of a vector, (for + rotation, counterclockwise), the angular velocity is the number of radians per second passed over by the rotating vector, ASA 05.05.185.

C. The Relationship Between Poles, Frequency, and Speed.

1. R.P.S. equals $f \div \frac{P}{2}$, where f equals cycles per second, $\frac{P}{2}$ indicates pairs of poles, since a pair of poles is required to complete one cycle. We do not change the value of the expression when we invert the divisor and multiply, for a 2 pole machine at a frequency of 60 cycles per second.

2. R.P M. = $\frac{f \times 2 \times 60}{P}$ (60 represents seconds per minute)

$$\frac{f \times 120}{P}$$

example $\frac{60 \times 120}{2}$

$\frac{7200}{2}$ or 3600 R.P.M.

3. Poles = $\frac{f \times 120}{RPM}$

example $\frac{60 \times 120}{3600}$

$\frac{7200}{3600}$ or 2 poles

4. Frequency = $\frac{P \times RPM}{120}$

example $\frac{2 \times 3600}{120}$

$\frac{7200}{120}$ or 60 cycles per second

Table I shows the relationship between poles, frequency, and speed for a few typical cases. Note that speed is directly proportional to the frequency and inversely proportional to the number of poles.

D. Maximum Value

Maximum value is the greatest value of instantaneous current or voltage that occurs in one alternation or change. There are two maximum values per cycle which appear at the angles of 90° and 270° electrical.

Some conversion factors to find this value are:

Maximum equals effective times 1.414 (rms x 1.414)
Maximum equals average times 1.572 (ave x 1.572)

NOTE: Crest and peak values are the same terms as maximum value.

Angular position of conductor	Sin (Sine or reactive factor)	Cos (Cosine of the angle)	e (100 Em)	e (240 Erms)	2 (10KV m)	e (________)
0 - 180 - 360	.0000	1.0000	00.00v	00.000v	0000.v	
10 - 190	.1736	.9848	17.36	59.022	1736.	
20 - 200	.3420	.9397	34.20	116.061	3420.	
30 - 210	.5000	.8660	50.00	169.680	5000.	
40 - 220	.6428	.7660	64.28	218.141	6428.	
*45 - 225 *	.7071	.7071	70.71	240.000	7071.	
50 - 230	.7660	.6428	76.60	259.950	7660.	
60 - 240	.8660	.5000	86.60	293.866	8660.	
70 - 250	.9397	.3420	93.97	318.897	9397.	
80 - 260	.9848	.1796	98.48	334.197	9848.	
90 - 270	1.0000	.0000	100.00	339.360	10000.	
100 - 280	.9848	.1736	98.48	334.197	9848.	
110 - 290	.9397	.3420	93.97	318.897	9397.	
120 - 300	.8660	.5000	86.60	293.886	8660.	
130 - 310	.7660	.6428	76.60	259.950	7660.	
*135 - 315 *	.7071	.7071	70.71	240.000	7071.	
140 - 320	.6428	.7660	64.28	218.141	6428.	
150 - 330	.5000	.8660	50.00	169.680	5000.	
160 - 340	.3420	.9397	34.20	116.061	3420.	
170 - 350	.1736	.9848	17.36	59.022	1736.	

Table I

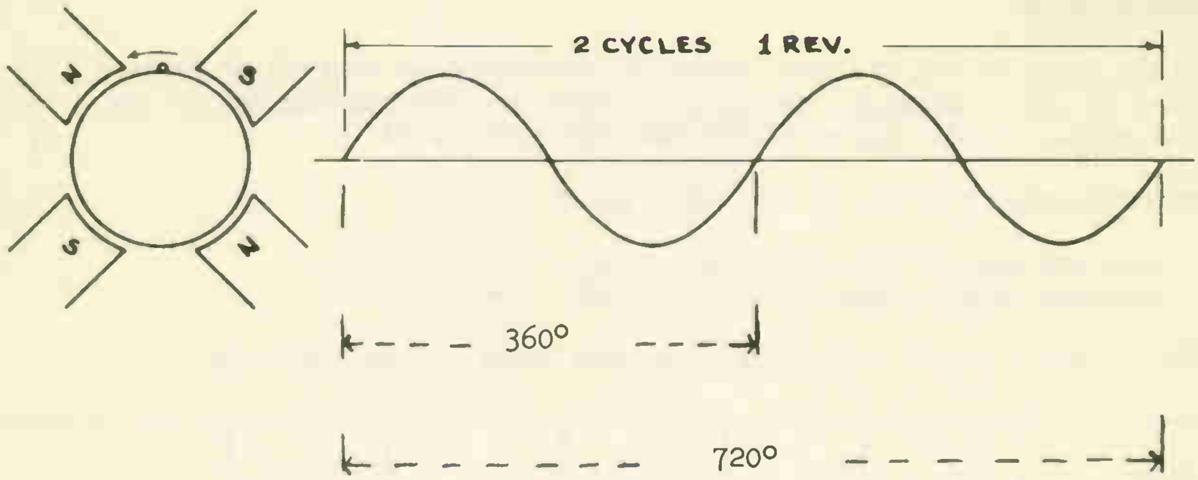
(e) Instantaneous voltages
(m) maximum value
(*) Effective or rms values which are instantaneous

For a better understanding of the above chart, let us try a few examples: Suppose we take an angle of 30° whose sine is .5, and suppose also that we know the Em to be 100 volts. At this angle, the "e" is found by:

e= Em x Sin of angle
= 100 x Sin of 30° or .5
= 100 x .5 = 50 volts

At the same angle what would be the voltage if Erms equals 100?

e = (Erms x 1.414) x Sin of angle
= (100 x 1.414) x Sin of 30° or .5
= 141.4 x .5 = 70.7 volts



P	CPR	REV. PER SEC.		REV. PER MIN.		60~ Induction Motors	
		25~	60~	25~	60~	Field RPM	Rotor RPM
2	1	25	60	1500	3600	3600	3450
4	2	12	30	750	1800	1800	1740
6	3	8.3	20	500	1200	1200	1160
8	4	6.25	15	375	900	900	860
10	5	5	12	300	720	720	690
12	6	4.25	10	250	600	600	580
30	15	1.4	4	100	240	240	230
40	20	.16	1.5	75	180	180	168

TABLE II

P - Number of poles in the machine
CPR - Cycles per revolution
RPS - Revolutions per second
RPM - Revolutions per minute
~ - Cycles

$$\text{Poles} = \frac{120 \times \text{frequency}}{\text{RPM}}$$

$$\text{RPM} = \frac{120 \times \text{frequency}}{\text{poles}}$$

$$\text{Frequency} = \frac{\text{Poles} \times \text{RPM}}{120}$$

E. Effective Value

Effective value of a periodic current is the square root of the average of the squares of the instantaneous values of the current taken throughout one period, ASA 05.20.095. Sometimes the above term is called "effective current, or Root-mean-square current". With the exception of a peaking meter and perhaps the oscilloscope, all measuring instruments used in AC, measure the effective value. Example of proof of this definition is shown in the accompanying chart. It may be noted, however, that for absolute accuracy intervals of at least two degrees must be taken, but in order to avoid unnecessary mathematical calisthenics, the chart is given in twenty degree intervals beginning at ten degrees.

ANGLE IN DECREES	SIN OF ANGLE	( ) VOLTAGE (100 Em)	VOLTAGE SQUARED
10	.1736	17.36	301.3696
30	.5000	50.00	2500.0000
50	.7660	76.60	5967.5600
70	.9397	93.97	8830.3719
90	1.0000	100.00	10000.0000
110	.9397	93.97	8830.3719
130	.7660	76.60	5867.5600
150	.5000	50.00	2500.0000
170	.1736	17.36	301.3696

SUMS OF COLUMNS - - - - - - - - - - - - - - - 575.86 - - - - - - -44998.6020 - - - -

Therefore, the average square of the squares equals $\frac{44998.6030}{9}$ or 4999.851144 *

(*) Since this is a geometric variation, we must extract the square root of the above figure in order to get the actual effective or RMS value.

$$\begin{array}{l} \;\;7\;\;0.\;\;7\;\;0\;\;9\;\;6 \\ \sqrt{49'99.'85'11'44'00} \end{array}$$

Thus we find our effective (rms) value is equal to 70.7096 or 70.71.
This accuracy is better than 95% with even these intervals, but 100% accuracy may be obtained when intervals of at least 2 degrees are taken.

F. Average Value

Average value of a periodic current is the algebraic average of the values of the current taken throughout one period, ASA 05.20.100.

Let us prove that this statement is true by adding the column marked "voltage (100 Em)". The answer for these nine figures, we see, is 575.86. Therefore, if we take this number, divide by nine our answer comes to 63.98, which is slightly in error since the actual average value is 63.6. The inaccuracy of .38 may be attributed to only four place sine function and also to comparatively few numbers used. For a greater degree of accuracy, a two-degree or less interval should be used.

G. Form Factor

Form factor of a Symmetrical (uniform) alternating quantity is the ratio of the effective value of the quantity to its half-period average value, ASA 05.05.260. If the form is different from that of sine wave, form factor is also different.

If the voltage is sine wave in form: Form Factor $= \frac{\text{Effective Value}}{\text{Average Value}} = \frac{.7071}{.636}$ or 1.11

NOTE: Form factor must be considered in design calculations of a-c equipment but, has little practical application for the average man.

The ratio of RMS to Max. is $\frac{RMS}{Max}$ or $\frac{70.71}{100}$ = .7071 (RMS= Max x .7071)

The ratio of Max to RMS is $\frac{Max}{RMS}$ or $\frac{100}{70.71}$ = 1.414 (Max = RMS x 1.414)

The ratio of Ave to Max is $\frac{Ave}{Max}$ or $\frac{63.6}{100}$ = .636 (Ave = Max x .636)

The ratio of Max to Ave is $\frac{Max}{Ave}$ or $\frac{100}{63.6}$ = 1.572 (Max = Ave x 1.572)

H. Phase

Phase is a periodic quantity, for a particular value of the independent variable, the fractional part of a period through which the independent variable has advanced, measured from an arbitrary orgin. In the case of a simple sinusoidal (linear variation quantity), the orgin is usually taken as the last previous passage through zero from the negative to positive direction. The origin is generally so chosen that the fraction is less than unity, ASA 05.05.280.

Though the above definition seems to be complex, it really means that the word "phase" is, in reality, an expression for a period of time, usually in electrical degrees, that elapses after one a-c quantity passes through a corresponding reference value.

2. Single Phase consists of one individual voltage or current, Fig. 2. Applications are: small motors, generators, transformers, etc.

3. Two-Phase or Quarter-Phase is a combination of circuits energized by alternating electromotive forces which differ in phase by a quarter of a cycle or 90° but in actual practice the phases may vary several degrees from the specified angle, ASA 35.40.040, Fig. 3. Applications: power and lighting circuits, etc.

   NOTE: The use of two-phase equipment has been largely superceded by three-phase equipment which will be discussed in detail in the following paragraphs and the remainder of this manual.

4. Three-Phase is a combination of circuits energized by alternating electromotive forces which differ in phase by one-third (1/3) of a cycle or 120 degrees. In actual practice, the phases may vary several degrees from the specified angle, ASA 35.40.060. Applications: motors, generators, power, transmission, and lighting circuits.

   NOTE: This is the only 3 wire system or circuit which has the same voltage value between any pair of line wires, Fig. 4.

5. In Phase is an expression which means the voltage and current of a given example are "in step" with each other. That is to say, the current and voltage of a circuit or a portion of a circuit reach maximum and minimum at precisely the same instant. This condition is true where the opposition to AC is due to resistance only, or where opposition to current is due to equal quantities of coil and capacitor opposition to flow.

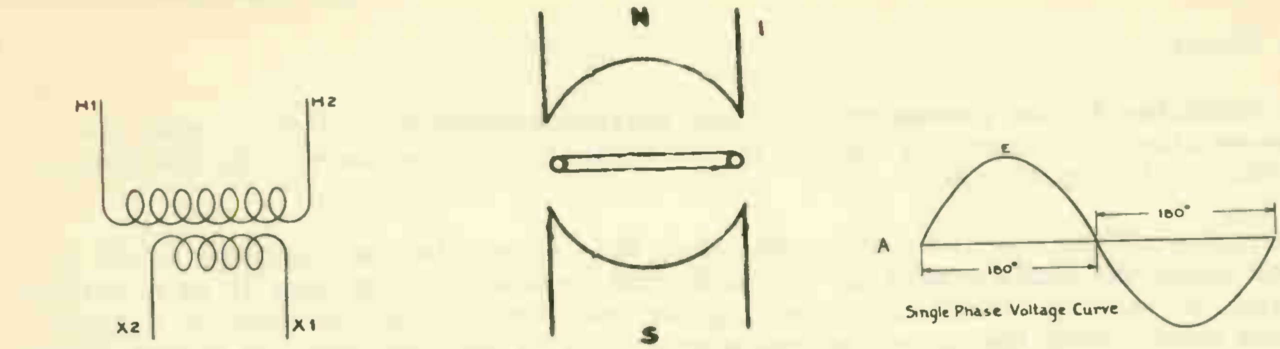


Fig. 2

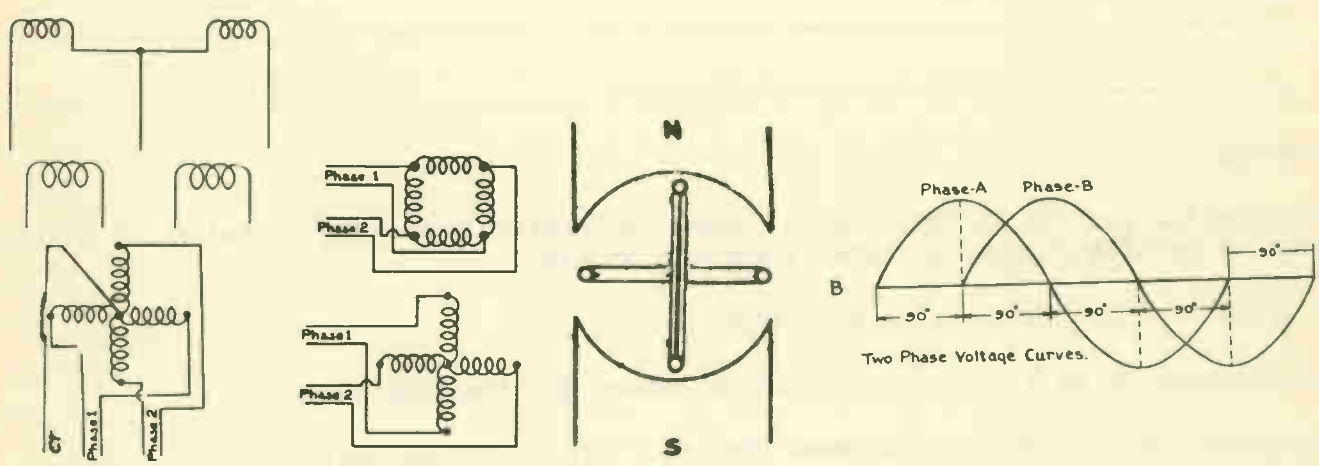


Fig. 3

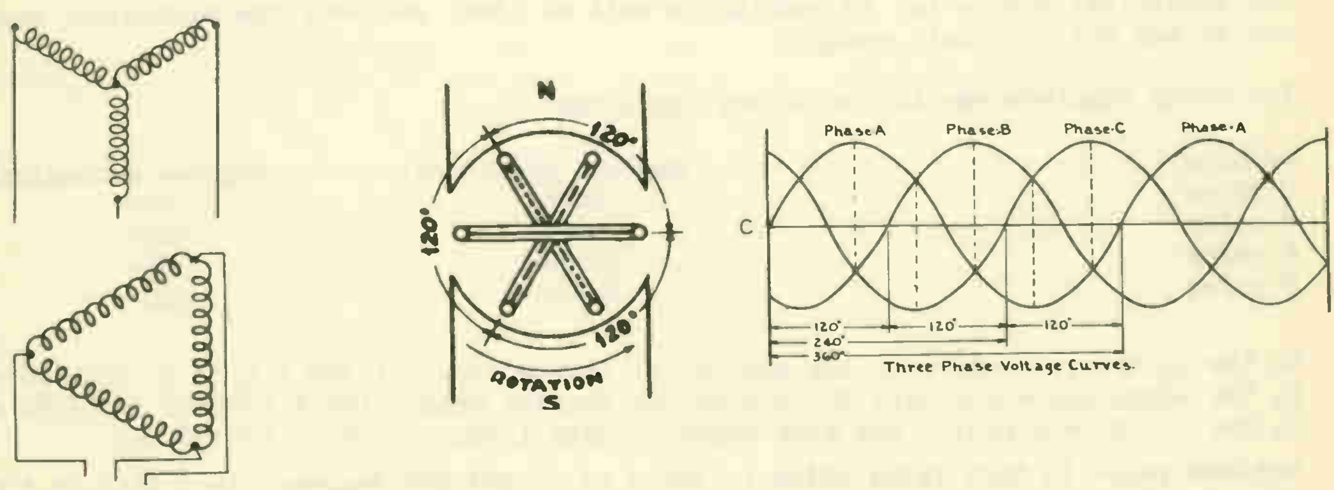


Fig. 4

I. Skin Effect

In a conductor is the phenomenon of a non-uniform current distribution over the cross-section of a conductor caused by the variation of the current in the conductor itself, ASA 05.40.110.

We can also add to the above statement that this effect is that tendency of AC to travel along the surface area of the conductor, rather than through it at a uniform density. It has the effect of increasing the resistance of a conductor to a given current rate. Thus the effective resistance will be greater than the actual ohmic resistance (determined by molecular construction of the conducting medium). This "skin effect" is greatly minimized by the use of stranded or tubular conductors, however, it is present, to some extent, in all a-c circuits.

J. Summary

Alternating Current is that current which is constantly varying in value and direction at certain regularly stated intervals of time.

A cycle is a complete series of events.

An alternation is $\frac{1}{2}$ cycle or a complete change in direction only.

Frequency can be construed to mean number of cycles per second.

Angular velocity means the speed of an angle in electrical degrees.

The voltage induced in a conductor depends upon: field strength, speed of cutting that field, and the direction of angular motion in relation to the field.

The electrical degree is, in reality, a unit of time, whereas, the mechanical degrees may or may not be equal; example:

For every complete revolution of one conductor:

Machine	degrees electrical	degrees mechanical
2 poles	360°	360°
4 poles	720°	360°
6 poles	1080°	360°
8 poles	1440°	360°

In the sixty cycle circuit, one electrical degree equals 1/360 x 1/60 or 1/21600 sec.
In the sixty cycle circuit, 120 electrical degrees equals 120 x 1/21600 or 1/180 sec.
In the 25 cycle circuit, one time degree equals 1/360 x 1/25 or 1/9000 sec.

Maximum value is that value which is found at 90 and 270 degrees electrical on the sine curve.

Max. or peak value equals 1.414 times effective or rms value.
Max. or peak value equals 1.572 times average value.

Effective value is the value read on all common a-c meters. When current is named, the effective value has the same heating effect as a corresponding value of DC.

rms or eff. value equals .707 times the maximum value.
rms or eff. value equals .636 times 1.11

Average value is the average of the instantaneous values taken throughout one period of time.

Ave. value equals .636 times the maximum value.
Ave. value equals .707 divided by 1.11

Form factor is the ratio of rms to average value.
Formulae to be remembered in regards to poles, frequency, and speed are:
RPS equals $f \div \frac{P}{2}$; RPM equals $\frac{120f}{P}$; POLES equals $\frac{120f}{RPM}$; FREQUENCY equals $\frac{P \times RPM}{120}$

Phase is an expression of time that elapses after one a-c quantity passes through a corresponding value or reference. In phase means current and voltage reach max. values at precisely the same time.

Single phase is a single time value of voltage or current.

Two phase is two phases displaced 90° from each other.

Three phase is three single phases displaced by 120° electrical.

Skin effect is the tendency of AC to travel along the outside surface of the conductor, thereby, increasing the effective resistance of the circuit.

K. Summary Questions

1. Explain the difference between AC and DC
2. What is "phase"?
3. In a 32 pole 25 cycle machine used for a steel mill roll application, what is the CPR? RPM? (rotating magnetic field).
4. In a 60 cycle circuit, 90 electrical degrees equals ________ seconds.
5. Compare 60 and 25 cycle as to advantages, disadvantages, applications etc.
6. Why is the effective resistance of an a-c circuit greater than the true ohmic
7. Which 3 wire a-c system has the same voltage between any pair of lines?
8. What two factors determine the frequency of an a-c generator.
9. A 24 pole generator produces 60 cps. What is the RPM of this machine?
10. If an alternating voltage and current pass through corresponding values at the same instant, are they in or out of phase?
11. What is the definition of effective AC?
12. If an ac voltmeter reads 120 volts, what is the maximum value of the voltage applied to it?
13. If an a-c ammeter indicates 15 amperes, what is the maximum value of the current passing through it?

14. In a 3 phase, 3 wire system, the voltages are displaced by ________ degrees between different pairs of wires.
15. Can more than one phase be transmitted over two line wires?
16. What effect does speeding up the generator have on the generator frequency?
17. What effect does increasing the frequency applied to an induction motor have on its speed?
18. What is the RPM of a 16 pole, 60 cycle generator?
19. How many poles must a conductor pass to generate one cycle?
20. What does the "frequency of an a-c circuit" mean?
21. Does the rotor of the induction motor turn at the same speed as the revolving magnetic field set up in the stator?
22. What is the meaning of the word "polyphase"?
23. Is it possible to operate single phase equipment off any two wires of a three phase circuit?
24. Is it possible to get single phase, quarter phase, and three phase from one three phase 4 wire system?
25. When would you use form factor? Average Value? Maximum Value? Effective Value?

THREE PHASE STATOR WINDING

Objectives

1. To learn the rules pertaining to rewinding of three-phase, lap-wound, two layer winding.

2. To learn a standard procedure on developing a three-phase stator winding.

References

Lesson Content

A. Review

1. Coil-group

A "coil-group" is the number of coils for one phase for one pole. The number of coils which must be connected in series to form a "coil-group" can be found by using the following equation -

$$\text{Coils per group} = \frac{\text{slots}}{\text{poles x phase}}$$

2. Full pitch coil span

"Full pitch coil span" refers to a coil which spans from a slot in one pole to a corresponding slot or position in the next adjacent pole. Another way to express "full pitch coil span" is "a coil which spans a distance which is equal to the distance from the center of one pole to the center of the adjacent pole."

The formula for determining full pitch coil span is as follows:

$$\text{Coil span} = \frac{\text{slots}}{\text{poles}} + 1$$

Full pitch is also known as 100% pitch. In some cases a coil may be more than full pitch, but should never exceed 150% pitch.

The term fractional pitch applies to coils which span less than full pitch. A fractional pitch winding should never be less than 50% of full pitch.

A "chorded" winding usually applies to a winding whose coils are less than full pitch, (fractional pitch) but it may be either less than full pitch or more than 100% pitch.

3. Electrical degrees per slot

This term is commonly used to express that portion of the pole which one slot covers. It is abbreviated "E° per slot."

There are 360° per pair of poles, therefore, one pole represents 180 E°.

$$E^{o}/\ slot = \frac{180}{slots/pole}$$

4. Lap winding

A lap winding is one in which all the coils in a coil-group can be traced through before leaving that coil group.

B. Applications, Ratings, and Cost

1. Approximately 85% of all motors in industrial applications are three-phase.

The two-layer winding is most frequently used. It is easy to manufacture, assemble, and repair. All coils are alike. The number of coils is equal to the number of slots.

2. The ratings of three phase motors for industrial applications will vary from approximately one-sixth horsepower up to thousands of horsepower.

To give an idea of the cost of the more common ratings, the following list is presented.

G.E. GENERAL PURPOSE, 60 CYCLE, OPEN TYPE 40° CENTIGRADE TEMP. RISE

1/6 H. P.	@ 1800 R.P.M.	$ 20.00		
1 H. P.	@ 3600 R.P.M.	40.00	@ 514 R.P.M.	$100.00
5 H. P.	@ 3600 R.P.M.	75.00	@ 514 R.P.M.	250.00
10 H. P.	@ 1800 R.P.M.	125.00	@ 514 R.P.M.	350.00
25 H. P.	@ 3600 R.P.M.	200.00	@ 514 R.P.M.	580.00
50 H. P.	@ 3600 R.P.M.	410.00	@ 514 R.P.M.	850.00
100 H. P.	@ 3600 R.P.M.	850.00	@ 514 R.P.M.	1350.00
200 H. P.	@ 3600 R.P.M.	1500.00	@ 514 R.P.M.	

The above prices are list prices, and are approximate.

Wound rotor motors will cost approximately two to three times as much as the above list at the same horsepower rating.

Totally enclosed motors will be about 130% of the above prices.

1. Coils

a. Stators of 15 horsepower and under, and for less than 550 volts, usually have partly closed slots and are commonly wound with "fed in" or "threaded in" windings. For this type of winding we can use any one of the types of coils shown in Fig. 1.

b. The "mush" type of coil is used whenever and wherever possible. Most coils not wound in layers fall under the classification of mush coils. They are sometimes referred to as "hit and miss" coils. One type of diamond coil is wound, shaped and the ends taped with half-lapped cotton tape before the coil is fed into the slots. The "plain mush" (d) is the most simple of all to wind. It is used mostly in bi-polar d-c machines. The "basket coil" (b) is simply wound to the approximate shape, and to the proper length and size, but is usually left untaped. The leads can be twisted together to hold in place. In winding the "plain flat diamond mush" (a) the leads are left loose. When winding the (c) coil, the leads are tied to the body of the coil which saves time for the winder. The basket coils are generally used only for "one coil per slot" windings and small two-layer windings. The diamond coils whether flat or pulled are used on large machines.

c. The untaped sides of either of these types of coils makes it possible to feed the wires one or two at a time into the narrow slot openings.

d. After the coils have been placed in the slots, the ends may or may not be taped. Whether or not you tape the coil ends will be determined by the size of the motor and the voltage at whi h it is to operate. Sometimes the coil ends are shaped with a fibre drift and a rubber or rawhide mallet, to allow the coils ends to pass over each other more easily.

2. Slot insulation

a. Before we can begin the actual placing of the coils in the slots, we should check the condition of the stator laminations. The stator should be clean. Remove any burrs or sharp edges in the slots. A file can be used. The slot insulation may now be placed in the slots.

b. The slot insulation, when used properly, should be so placed that there will be no electrical contact between windings or between windings and frame. The insulation provides a mechanical separation between coils and core which in itself is sufficient insulation. The insulation on the wire and the wrapping of the tape on the coil, if used, constitutes the major portion of insulation and any other material which is placed between the coils, or between the coils and the core, is mainly for mechanical reasons.

c. Many different types of materials are used for slot insulation. Manning-paper, fish-paper, fuller board, pressboard manila paper, mica paper, mica cloth, micanite, and glass insulating materials represent a few of the materials used for slot insulation. The above materials may be purchased at a wide range of thicknesses, from approximately four mils to one-hundred-fifty mils in thickness.

d. Cut the slot insulation to size and place it in the slot. Make sure the insulation extends beyond the length of the slot, 1/8" to 3/8" for small and medium size machines. Make a "cuff" on the slot insulation. See Fig. 2.

3 Layout

We shall now consider the development of a winding for a 36 slot stator which we will wind for six poles, three-phase.

a. Coil-group = $\frac{\text{slots}}{\text{poles x phase}} = \frac{36}{6x3} = 2.$

This means, we must connect two coils in series to form each coil-group.

b. Coil span = $\frac{\text{slots}}{\text{poles}} + 1 = \frac{36}{6} + 1 = 7.$

Therefore, a coil will be in slots one and seven, or their equivalent such as slots four and ten. This is full pitch (100%) coil span.

4. Placing coils in slots.

After the slots have been insulated, we may begin the actual placing of the coils in the slots.

a. Place one side of the first coil in any slot, with the leads of the coil toward the winder.

b. One side of the next coil is then placed in the slot to the right of the first, which will make the winding progress in a counter-clockwise direction around the stator. Four more coils are then placed in the slots in a similar manner, leaving the topsides of all of the coils out of the slots.

c. We now have six coils placed in slots. They are upright in the stator, that is, they have not been laid down and placed in proper slots. It is best, on the smaller machines, to connect the coils into the coil-groups as they are placed in the stator. See Fig. 3. You will notice by referring to Fig. 4 that the bottom lead of the first coil is connected to the top lead of the second coil.

NOTE: The bottom lead from a coil is that lead which comes from that side of the coil which is lying in the bottom half of the slot.

The top lead from a coil is that lead which comes from that side of the coil which will, or is going to lie, in the top half of the slot.

The top lead of the first coil and the bottom lead of the second coil are identified with sleeving of the same color (red).

The splice, which was made between coil one and coil two, is called a stub connection, Of course the insulation on the wire must be removed and a good electrical connection made. On the smaller and medium sized machines the stub connection can be a two-wire pigtail type of splice.

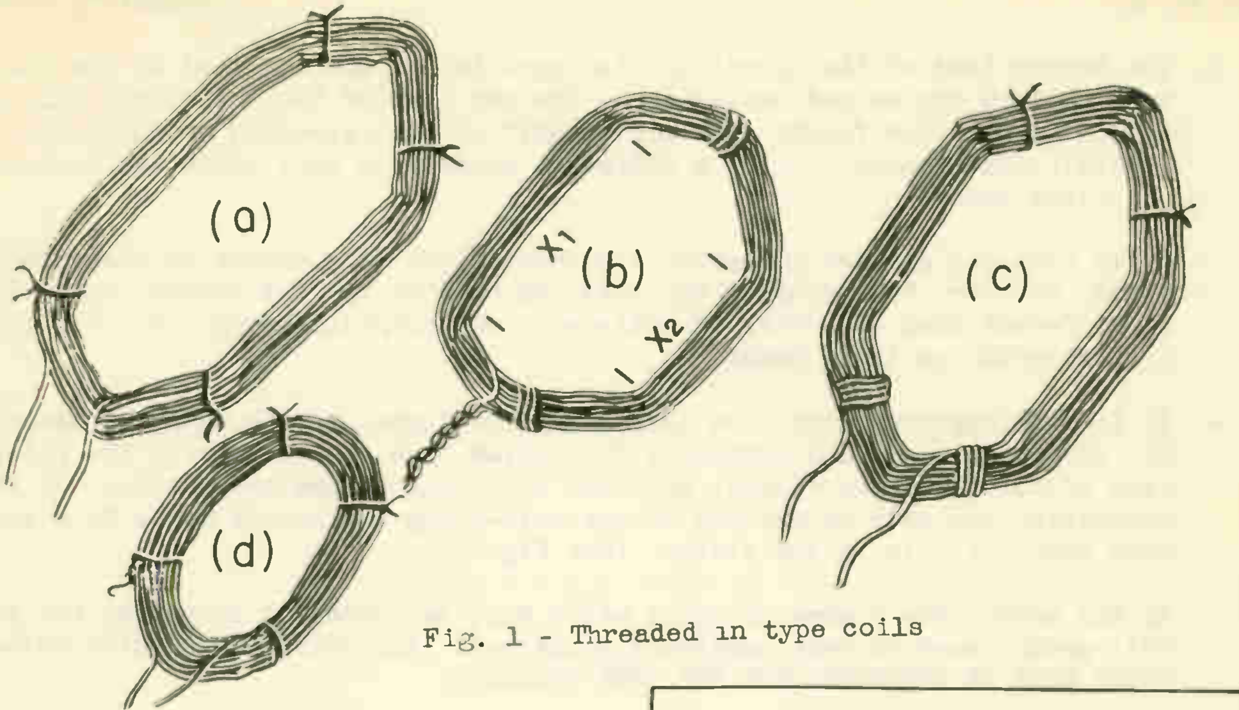


Fig. 1 - Threaded in type coils

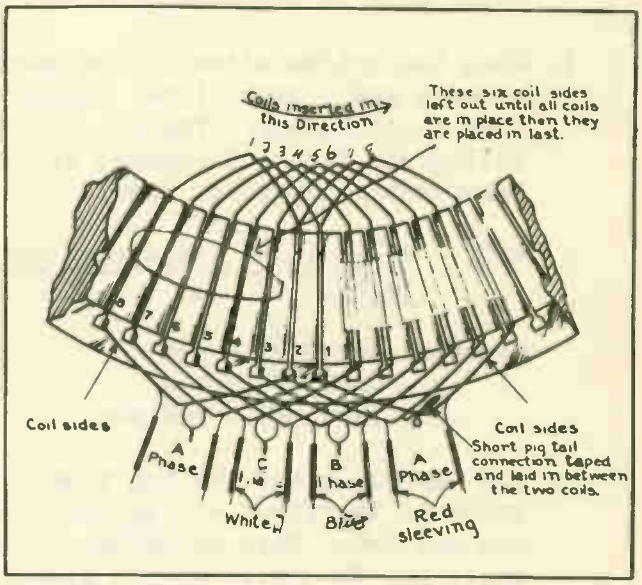


Fig. 3

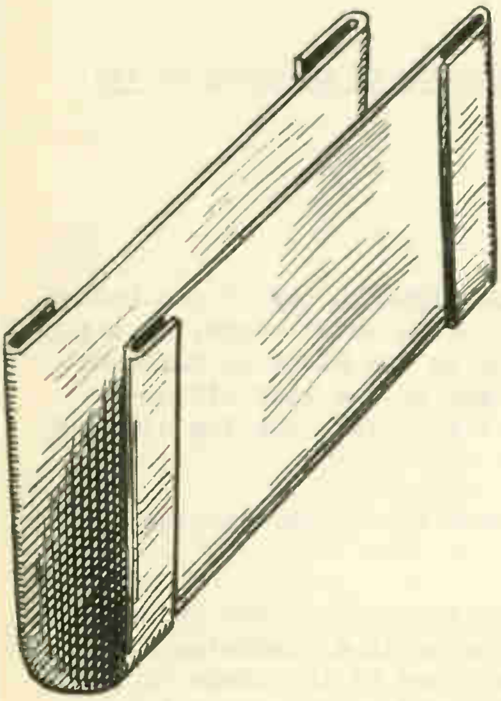


Fig. 2 - Slot insulation with cuffs

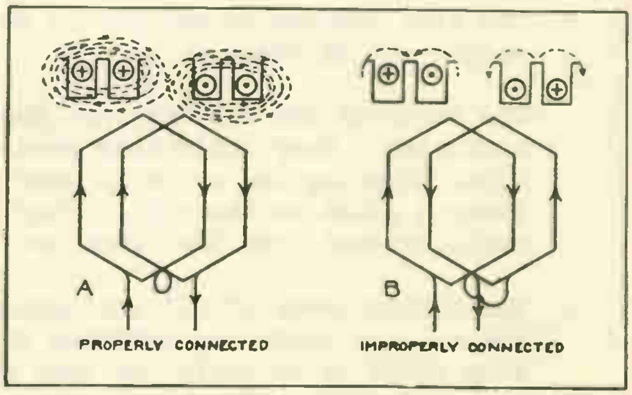


Fig. 4

d. The bottom lead of the third coil is connected to the top lead of the fourth coil to form the second coil-group. The top lead of the third coil and the bottom lead of the fourth coil are identified with sleeving of one color, (white). This color will be a different color from that which was used in the first group.

Coils five and six are connected together in the same manner as presented above, however, the color of the sleeving used on the coil-group leads will be different than the color on coil-group one and coil-group two. Place blue sleeving on these leads.

e. It is very important that the coil-groups be formed in the manner presented. If, for example, we had connected the bottom lead of coil one to the bottom lead of coil two, the fluxes, when set up, would oppose one another. If this connection was made by mistake in one coil-group the result would be a very weak magnetic pole in the stator. (See Fig. 4).

In any motor, the number of coils which must be connected in series for one coil-group, must be very carefully connected. ALL COILS OF THE SAME COIL-GROUP MUST BE CONNECTED FOR THE SAME POLARITY.

f. When the bottom sides of the seventh and eighth coils are placed in the seventh and eighth slots, respectively, they can be connected together to form a coil-group. The color of the sleeving used on the leads from this coil-group (4th coil-group) will be the same color as the sleeving used on the first coil-group. (red).

NOTE: Every third coil-group will have the same color of sleeving on its leads.

Example: Group #1 - red
Group #4 - red
Group #7 - red etc.

g. You may now place the top side of coils seven and eight on top of the bottom sides of the first and second coil respectively, or in other words, in slots one and two. This procedure of placing the coils in the slots is followed until all the coils are in place. The bottom sides of the last six coils will be placed under the top sides of the first six coils. The top sides of the first six coils are to be laid down last.

h. The slot insulation can now be trimmed, folded over the coils, and the slot wedges put in place.

The coils of the winding just described were laid in to the right or counter-clockwise. They could have been placed in the stator in a clockwise direction. Placing the coils in many stators is determined by the shape of the diamond point on the coil. They are called right hand coils and left hand coils, viewed from the front end which is the lead end of the coil.

i. The bottom leads of all coil-groups are bent out around the edge of the frame and all top leads are arranged straight out from the stator core. The next step would be to strip the ends of these leads and temporarily connect them in bunches for making a ground test from the coil leads to the stator.

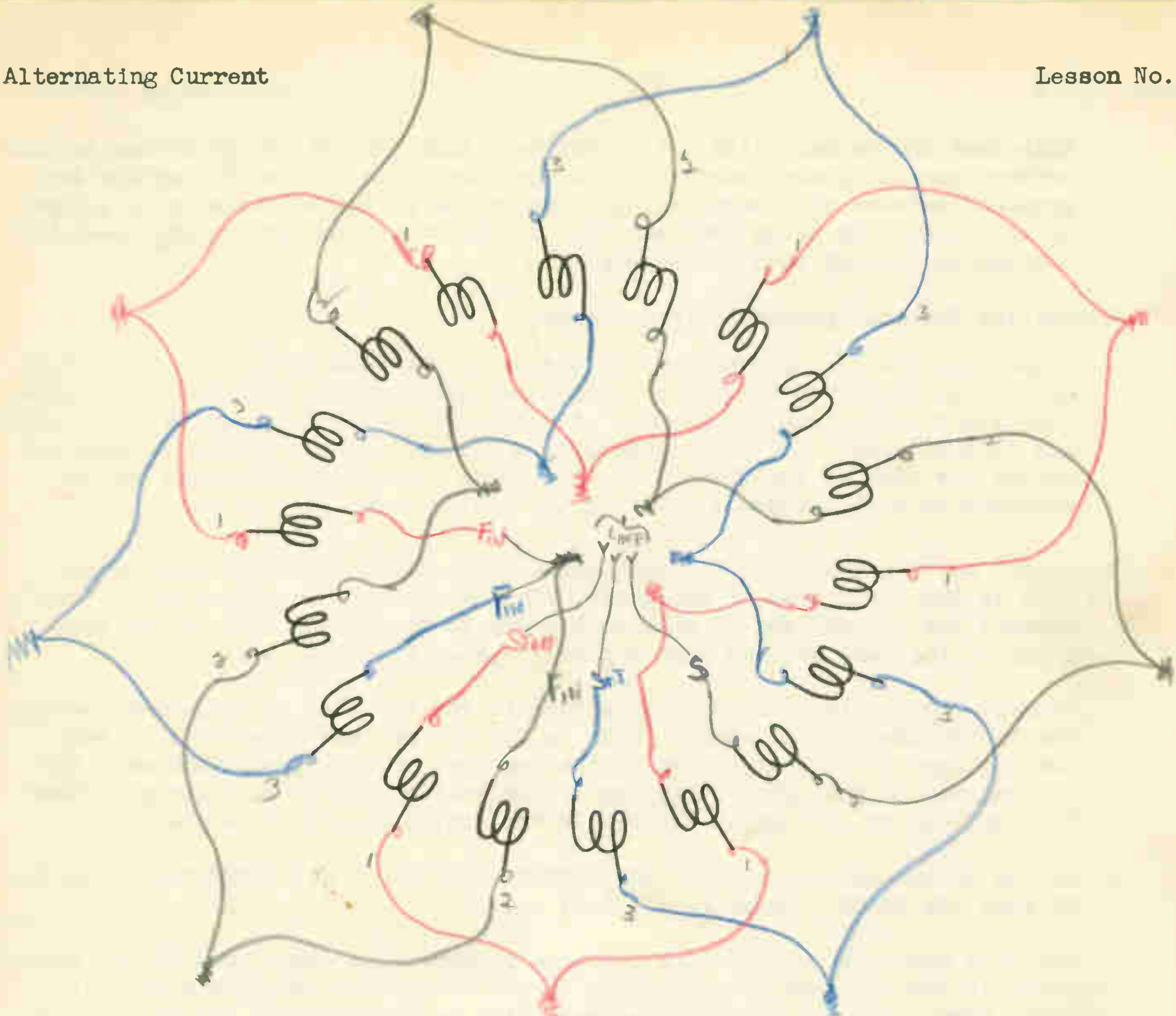


Fig. 5

Fig. 6

This test can be made with a 110 volt test lamp, and it should always be done before connecting any phases to make sure that none of the coil-groups are grounded because of damage to their insulation while they were being placed in the slots. By using the test lamp or the volt-ohmmeter you can check for continuity through each coil-group.

5. Connecting the coil-groups to form phases.

a. Connecting the coil-groups to form phases can be done as soon as the wedges are in the slots and the above tests have been applied. You should now have thirty-six leads from the stator. Eighteen of them are top leads and eighteen are bottom leads. The bottom leads from all coil-groups should be bent out around the edge of the frame. The top leads from all coil-groups can be arranged to stand straight out from the stator core.

b. Select any top lead from any coil-group close to the terminal housing and call it the start lead of one phase. This group will be called group "one". Connect the bottom lead of this coil-group to the bottom lead of the next group of the same colored sleeving (coil-group #4), Fig. 5.

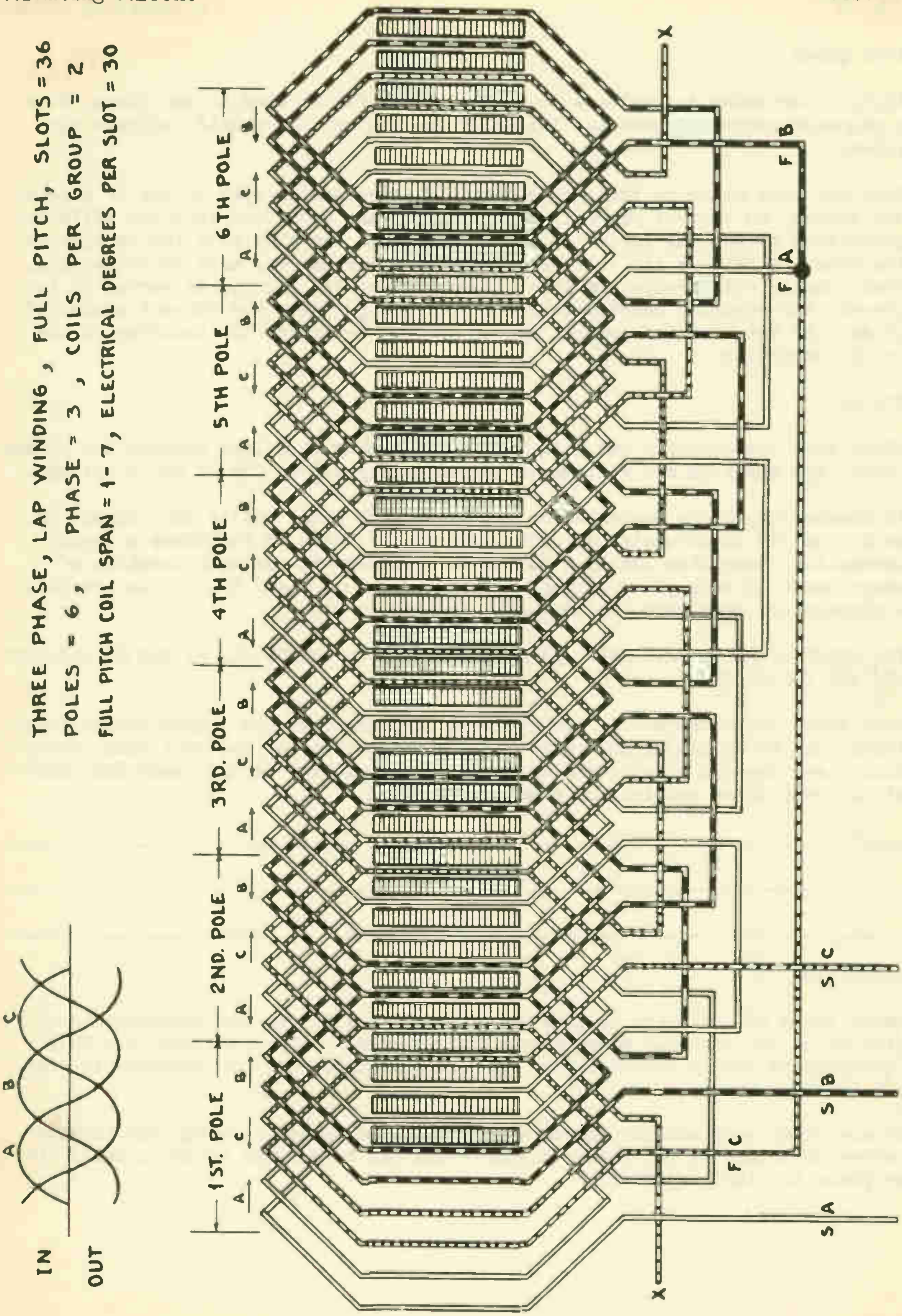
Connect the top lead of coil-group four to the top lead of coil-group seven; the bottom lead of coil-group seven to the bottom lead of coil-group ten; the top lead of coil-group ten to the top lead of coil-group thirteen; the bottom lead of coil-group thirteen to the bottom lead of coil-group sixteen. The top lead on coil-group sixteen is the finish lead of this phase.

c. Notice in the above paragraph that EVERY THIRD GROUP WAS CONNECTED IN SERIES TO FORM ONE PHASE. Thus: 1-4-7-10-13 and 16.

The next phase is connected in the same manner. The start lead of the second phase is the top lead of coil-group three. Therefore, starting with coil-group three, the following coil-groups will be connected in series - 3-6-9-12-15-18 bottom to bottom, top to top, etc.

d. The next phase to be connected will start with the top lead of coil-group five. Continue through coil-groups 8-11-14-17 and 2. The connections just made, between the coil-groups, are called jumper connections.

NOTE:
1. The three starts, for the three phases, were taken from groups #1, #3 and #5 near the terminal housing, and are displaced 120° electrical.
2. The finish lead of the third phase (top of coil-group two) falls between coil-groups #1 and #3.
3. All start and finish leads of the phases are top leads of the coil-groups.



THREE PHASE, LAP WINDING, FULL PITCH, SLOTS = 36
POLES = 6, PHASE = 3, COILS PER GROUP = 2
FULL PITCH COIL SPAN = 1 - 7, ELECTRICAL DEGREES PER SLOT = 30
IN
OUT
A
B
C
1ST. POLE
2ND. POLE
3RD. POLE
4TH POLE
5TH POLE
6TH POLE
X
FB
FA
FC
SA
SB
SC
LINE WIRES

1. Each phase

Apply a low value d-c voltage to the start and finish lead of one phase. Move a magnetic compass around the inside of the stator. It should indicate six poles.

Test out each phase in the same manner. If there was an open in one or more of the phases, no current would flow and the compass would not indicate different polarities around the inside of the stator. You can also test for an open in the phase by using a 110 volt test lamp. If a mistake was made in connecting, when forming coil-groups, or when connecting the coil-groups in series to form phases, the magnetic compass will not indicate properly the correct number of poles. By watching the compass needle you can determine the location of the wrong connection.

2. Stator

After each phase checks out with the proper number of poles, connect the phases "star" and apply an a-c voltage of approximately 20% to 25% of rated voltage.

An ammeter should be connected in series in each line. Notice the current in each line. If an excessive current flows in any phase, it indicates a wrong connection, more than likely a 60° phase displacement. Recheck location of start leads of each phase (should be coil-groups 1, 3 and 5). It is possible a mistake was made when checking each phase with DC.

THE START LEADS OF EACH PHASE SHOULD BE FROM COIL-GROUPS #1, #3 and #5 and THEY ARE ALL TOP LEADS.

When above tests check O.K. you can fold or press down the jumper connections (They must be insulated and taped) around the outside of the coil ends, which must clear the end shields and the rotor. The winding is now ready for insulating compound or varnish and possibly baking.

E. Summarization

The mush types of coils are increasing in popularity due to the improvements in insulation on the wire and other insulating materials. They are simple. They are quickly and easily manufactured, thereby decreasing cost of assembly in comparison to other types.

There are other ways and procedures of developing a three phase winding, however, the above procedure is one which is simple and can be applied to practically all three phase two-layer windings.

OPPOSITION TO AC

Objective

To learn what constitutes opposition to AC and upon what factors this opposition depends; to become familiar with inductance and how it varies with an applied AC.

References

Lesson Content

A. General

Resistance, R, is opposition to DC, but in AC, current may encounter opposition in other forms which cause phase displacement between, voltage, E, and current, I. Thus, opposition offered by inductive or capacitive circuits will be out of phase with the effects of resistance.

1. Ohmic resistance - means the actual opposition to current because of the physical molecular construction of the conducting media.
2. Effective resistance - sometimes called the apparent resistance is higher in value than if the same unit is placed across a d-c circuit because of the non-uniform distribution of current in a conductor which is caused by "skin effect". The flux concentration at the conductors center is maximum, therefore, the CEMF at that point is maximum.
3. Equivalent resistance - means the total opposition to current in a given circuit which may or may not be the same for DC as for AC.

B. Resistance to AC

Comparing the effects on an a-c circuit with that of DC, Fig. 1, we see that in d-c circuits, ohmic resistance is the only opposition encountered by current; thus we see that Ohm's Law applies to d-c since the current is proportional to the voltage applied, and inversely proportional to the circuits total resistance. This same law of proportion also applies to a-c circuits containing resistance only, and is approximately correct.

C. Inductance

Inductance is the (scalar) property of an electric circuit, or of two neighboring circuits, which determines the electromotive force induced in one of the circuits by a change of current in either of them, ASA 05.20.165.

Since inductance is a property of the circuit and not of current or voltage, we will speak of circuit characteristics rather than either voltage or current characteristics.

The inductance of a circuit is entirely dependent upon size and shape of the circuit and of course, upon the permeability of the surrounding medium which may or may not include the core. However, when the conductors are shaped as a group in the form of a coil, the Core is Always a factor.

In Fig. 2A, it will be noted that two wires are placed closely together for a 1000 foot distance. Notice the resulting total flux linkages are nearly zero because of the closeness or shape of the circuit, Fig. 2 A1. The reason for this near zero flux linkages is that the cross sectional flux path is small.

In Fig. 2B, the wires have been spaced equidistant (10') for the entire length and we notice in B1 and B2, which are the cross sectional and sideviews respectively, that the number of linkages has not been cancelled.

In Fig. 2C, we use the same wire as at A and B and again change the shape of the circuit. Now the flux linkages per ampere increase over that of B; increasing turns increases total flux density. This increased flux density now links with the circuit an increased number of times, as each line of flux tends to link with other lines, the flux density between circuit and field increases, Fig. C1 and C2.

In Fig. 2D, we find maximum flux linkages because of the circuits shape. In D1 we see the cross sectional coil view which shows coil sides working together.

In Fig. 2E, we find the addition of an iron core, (providing a low reluctance path for flux) which will give maximum flux density and linkages per ampere.

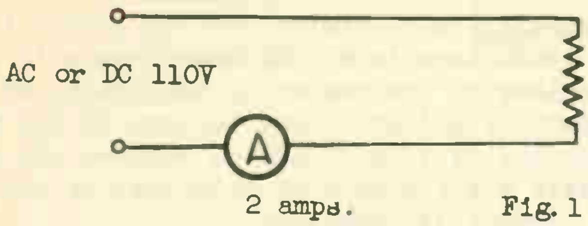
NOTE: When a circuit produces 100,000,000 (10^8) linkages per ampere, it has an inductance (L) of one Henry.

Whenever the current in an inductive circuit changes, the flux changes. This changing flux cuts the wires and induces in the circuit, a voltage that OPPOSES the CHANGE. In a circuit that has an inductance of one Henry, current changing at the rate of one ampere per second, will produce in it a self-induced emf of one volt.

When current value does not vary, there is no inductive effect. Often times the effects of inductance will be more important than those produced by the ohmic resistance, as we shall see in our continued studies.

Before continuing it may be well to review what happens to total inductance as the individual inductors are connected in series and parallel, Fig. 3.

Now, let us concentrate on the perfect inductance (having no resistance, which, is not found in actual practice because all wire has some resistance) and see its effect on the phase displacement of current and voltage. Fig. 5B shows that the impressed voltage leads the current by 90°, or the current lags this voltage by 90°. Our explanations will assume the inductances to be perfect, i.e., no resistance.



55 ohms $R = \frac{E}{I} = \frac{110}{2}$ or 55R

Fig. 1

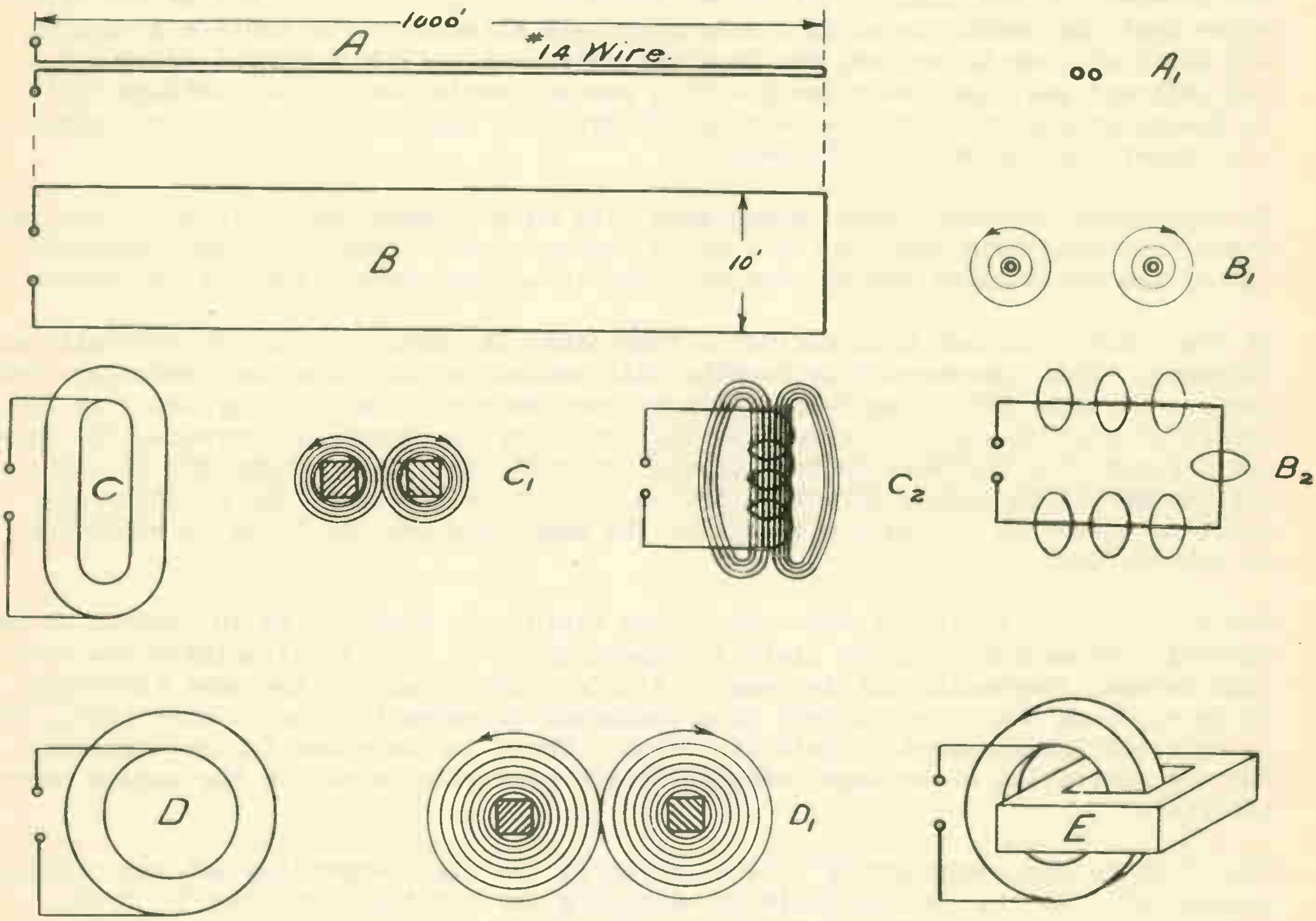


Fig. 2

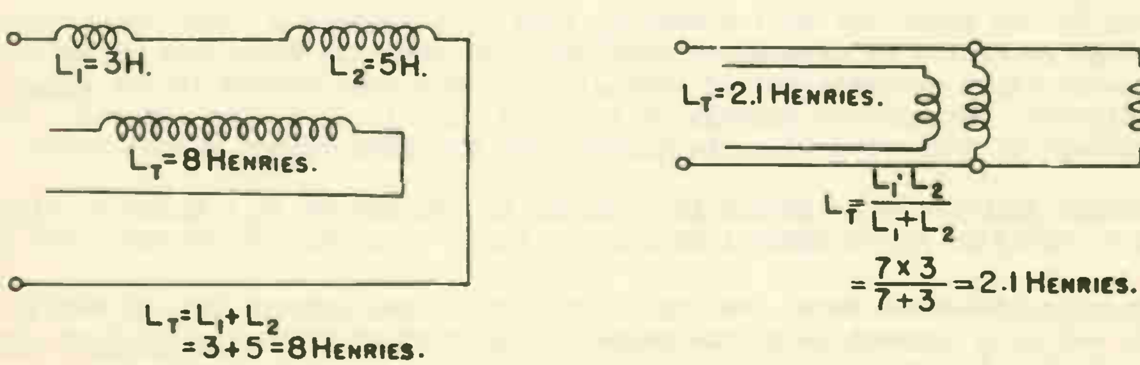


Fig. 3

The basic theory of inductance can be explained by reference to generator action, which is the action of a conductor in a magnetic field. (Refer back to lesson 1). As you will notice, a number of stationary conductors in a stationary magnetic field will generate no electromotive force, regardless of the number of conductors or the field's flux density. If, however, the magnetic field is caused to move in any manner past the conductors, difference of potential will be generated between the ends of the conductors. Thus we see that we create a difference of potential or voltage which will cause current to flow, when the circuit is completed.

The movement of the magnetic field may be caused by mechanically moving the field poles past the conductor as in a rotating-field alternator, or the field winding and the conductor to be cut, may be stationary, and the field caused to expand and contract past the conductor due to a current variation in the windings. This is the principle of operation used in all types of transformers including commercial power and control transformers.

In explaining the conditions associated with an electromagnetic field, it has been shown that the field density for a given number of turns and a constant permeability of the surrounding medium, varies directly as the current through the turns.

If the current through a conductor is increased, the magnetic flux density will also increase. This increased flux density will expnad outward from the conductor, and induces in it a CEMF of self-induction or reactance voltage which opposes the increase of current. If the current in the conductor is caused to decrease, the magnetic field will decrease in density and contract toward the conductor. If, in the two mentioned cases, direction of the current is the same, the polarity and rotation direction of the field will be the same, whether the field is expanding or contracting.

The direction of motion of the contracting field will however, be in reverse of the direction of motion when the field is expanding. Fig. 4 will illustrate the relation between increasing and decreasing fields with current in the same direction. It is apparent that when current in a conductor pulsates (varies in amplitude), there is an established magnetic field in motion. There is one other factor necessary for the generation of voltage, namely, that a conductor be cut by the moving magnetic field.

Fig. 5 shows the conductor "B" which is cut by the field expanding and contracting around "A". In Fig. 5a the field is expanding and cutting conductor "B" from left to right. In Fig. 5b the field is collapsing and cutting conductor "B" from right to left. Conductor "B" has not moved and the polarity has not changed, but the direction of motion of the field has been reversed.

According to the generator action theory, this will produce a polarity reversal of the voltage generated or induced in conductor "B" when the direction of motion of the magnetic field reverses and if conductor "B" has been formed in the shape of a closed circuit, the current through this closed circuit will also reverse. This basic concept of inductive circuits agrees with the LENZ theory which states:

"THE CURRENT INDUCED IN A CIRCUIT AS A RESULT OF ITS MOTION IN A MAGNETIC FIELD, IS IN SUCH A DIRECTION AS TO EXERT A MECHANICAL FORCE OPPOSING THE MOTION", ASA 05.40.02

The foregoing statement means that the direction of the induced EMF is such that it tends to set up a current path, the magnetic field of which always <u>opposes</u> <u>any</u> <u>CHANGE</u> in the existing field.

Fig. 4 During a given alternation the flux rotating direction and current direction will remain constant, even when the field expands and contracts.

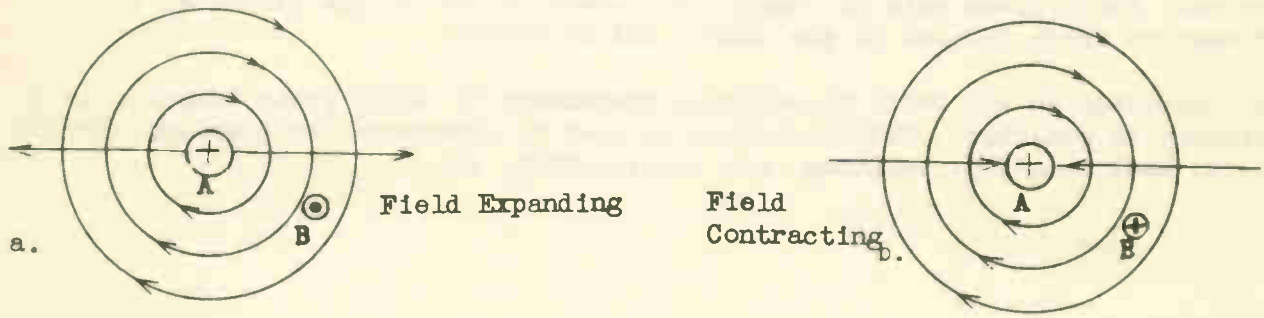


Fig. 5 Notice the effect of current direction at "B" when entering a magnetic field which expands and collapses.

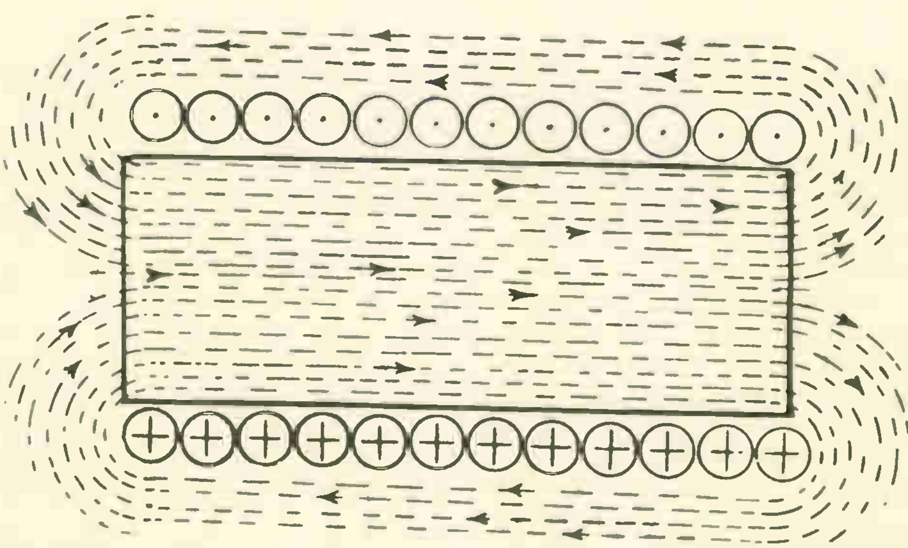


Fig. 6 A cross section of a single layer coil, tightly wound, and showing by diagram what happens as fluxes are added.

Lenz's Law does not state that the field of the induced current always opposes the field of the inducing or primary current. The law states that it always opposes any CHANGE in the field of the existing current. The word "Change" is an important word associated with the phenomena of inductance and when used with inductance it always implies a changing current. One more point, inductance effects are due to current variations; voltage variations have no effect on inductance except for the proportional current amplitude variations which are brought about by these voltage changes.

Self-Inductance is the property of an electric circuit which determines, for a given rate of change of current in the circuit, the electromotive force induced in the same circuit, ASA 05.20.170.

Fig. 6 is a cross section of a single-layer coil in which all turns are in series and the spacing between turns is minimum. If an alternator is connected across the terminals of this coil, there will be a continually increasing and decreasing current value.

Mutual Inductance is the common property of two associated electric circuits which determines, for a given rate of change of current in one of the circuits, the electromotive force induced in the other, ASA 05.20.175.

Mutual induction is the basic operational phenomenon by which power transfer in a transformer is possible. This induction is used to advantage for coupling circuit sections, heat treating, smelting, ore distillation, etc.

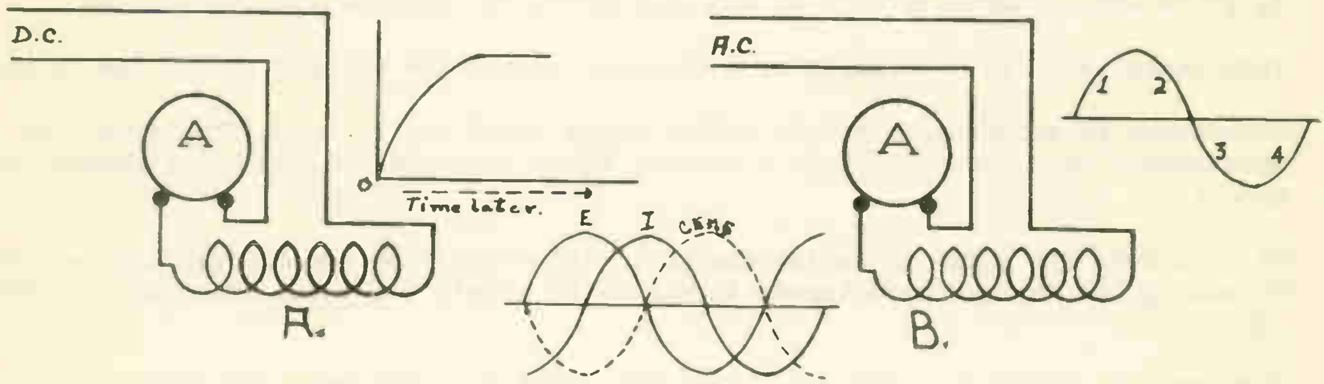


Fig. 7 Figure "A" shows the graphical effect of DC applied to a coil' "B" shows the same coil connected to an AC source. Note the curves showing the angular displacement between the voltages, E, current, I and the counter-electromotive-force (CEMF).

D. Summary

Phase displacements between E and I are caused by counter voltages which may lead or lag the current by an angle of 90°.

The non-uniform current distribution in a conductor is caused by skin effect. It is prevalent in circuits with AC but negligible in circuits with DC applied.

Inductance, which is a property of a circuit, causes the current to lag the voltage.

Inductance is measured in a unit called Henry which is, in actuality, a unit of measurement which is applied to a circuit which produces 100,000,000 linkages per ampere.

As inductors are added in series the total inductance for the circuit may be found by adding the various inductances in series to obtain the total inductance of the circuit.

Inductors in parallel, will cause the circuits total inductance to decrease in proportion to the relative sizes of the inductors. (Effects on totals in series and parallel can be likened unto resistors correspondingly connected.)

Lenz Law states the current induced in a circuit will be in such direction as to exert a force opposing the motion of the force.

E. Questions

1. State briefly what constitutes "opposition to AC".
2. What is inductance?
3. What is the effect on phase displacement with inductance only in a circuit?
4. How is total inductance affected when coils are connected in parallel? In series?
5. What is meant by self-inductance? Mutual inductance?
6. In your own words, state Lenz Law.

OPPOSITION TO ALTERNATING CURRENT II

Objective

To study reactance, inductive reactance, and some of the characteristics of capacitor action in an a-c circuit.

References

Lesson Content

A. Reactance, X

The reactance of a portion of a circuit for a sinusoidal current and potential difference of the same frequency is the product of the sine of the angular phase difference between the current and potential difference, times the ratio of the effective potential difference to the effective current, there being no source of power in the portion of the circuit under consideration. The reactance of a circuit is different for each component of an alternating current. NOTE: The reactance for the entire periodic current is not the sum of the reactances of the components. A definition of reactance for a periodic current has not yet been agreed upon, ASA 05.20.205, see Fig. 1.

In a circuit carrying unvarying current, the only opposition to the current is the resistance of the conductors. In a circuit carrying AC or varying DC, other kinds of opposition, in the form of opposing voltages, may appear. These voltages may be responsible for the greater part of the opposition offered to current. For example, if a current such as that shown in Fig. 2-A were forced through a coil of one Henry inductance, the average value of the self-induced voltage would be 240 volts; and for Fig. 2-B, it would be 480 volts. These high values of voltage result from the high rate of CURRENT CHANGE in amperes per second. While Fig. 2-A represents a rate of change of 240 amperes per second, the curve in Fig. 2-B represents 480 amperes per second. The curve shown in Fig. 2-C depicts a pulsating DC which would create the self induced voltage three times the value of one Henry inductance shown in Fig. 2-A.

Ohmic resistance gives opposition to current while reactance gives reactive opposition to flow. A reactive circuit first produces within itself a reactive or counter voltage which is out of phase with the supply voltage and the resistance voltage drop, but it combines with those voltages causing a resultant voltage which is the determining voltage for the amount of current that will flow. In other words, reactance is a property other than ohmic resistance which limits the circuits current. Although it is measured in ohms, it does not act as a direct-current limiter, however, in a coil or capacitor, it opposes the flow of current. Fig. 2-E shows 2 volts opposing which is similar in action to reactive voltage.

B. Conductance - Admittance - Susceptance

1. Conductance - could be defined as the reciprocal of resistance, $\frac{1}{R}$. Its symbol is usually "G". It is the rate at which electric energy is converted into radiant or heat energy, and even though, as a general case, this word conductance is a function of the electromotive force or potential difference, it is not so associated here.

2. Admittance - could be defined as the reciprocal of impedance, $\frac{1}{Z}$. This definition takes into consideration the various reactances which may be present in the circuit.

3. Susceptance - is that component of the admittance of a circuit which is assumed to carry current dephased by 90° from the impressed electromotive force. It is the reciprocal of reactance (formula - $\frac{1}{X}$).

NOTE: The triangular position of each is shown Fig. 3A and B.

C. Inductive Reactance, X_L.

Inductive reactance is the opposition to alternating current which is caused by self-induction. Sometimes it is spoken of as the counter voltage produced by a continually varying current flowing in an inductive circuit.

Inductive reactance is measured in ohms and the formula is shown below:

$X_L = 2\pi F_L$

$L = \frac{XL}{2\pi F_L}$

$f = \frac{XL}{2\pi L}$

Where:

f equals cycles per second
L equals inductance in Henries
X_L equals inductive reactance in ohms
π equals 3.1416

NOTE: Fig. 1, shows a coil connected to an AC source.

D. Capacitance

Capacitance is that property of a system of conductors and dielectrics which permits the storage of electricity when potential differences exist between the conductors. Its value is expressed as the ratio of a quantity of electricity to a potential difference. A capacitance value is always positive, ASA 05.15.050.

This definition also means to imply that for a given time rate of change of potential difference between the conductors, there is a displacement of currents in the system, Fig. 4.

NOTE: Fig. 5 shows a capacitor in various conditions of charge.

We see in Fig. 6, what happens to total capacitance when the capacitors are connected in series or in parallel.

E. Distributed Capacitance, Cd.

Distributed capacity may be considered as that capacity which exists between lines, windings, or conductors. This distributed capacity is of little consequence in low frequency low energy utility circuits, but is an important factor on high voltage transmission lines.

We must remember that a capacitor is formed when two conductors are separated by an insulating material called a dielectric. Though this may be inconsequential in low voltage low frequency circuits, it will be discussed in the chapter on transmission of electrical energy.

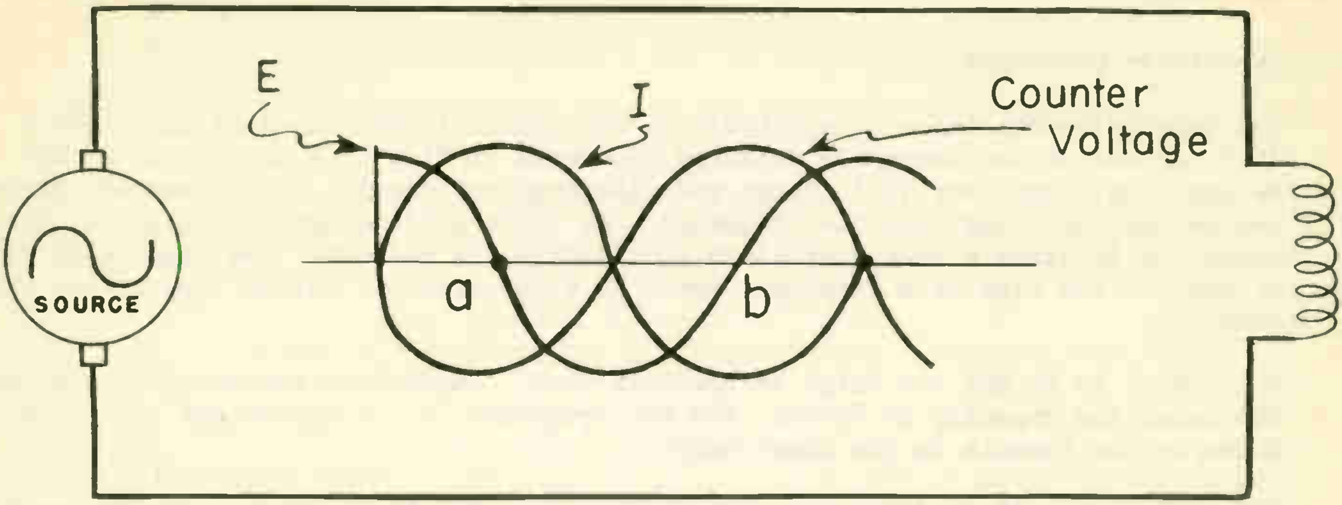


Fig. 1

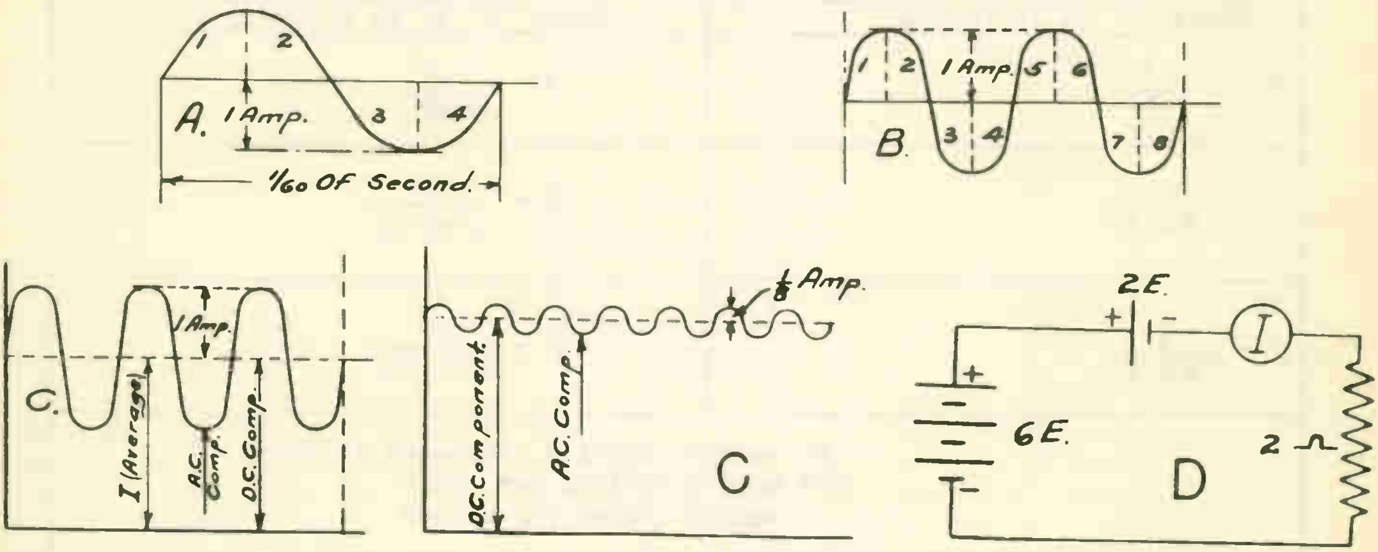


Fig. 2

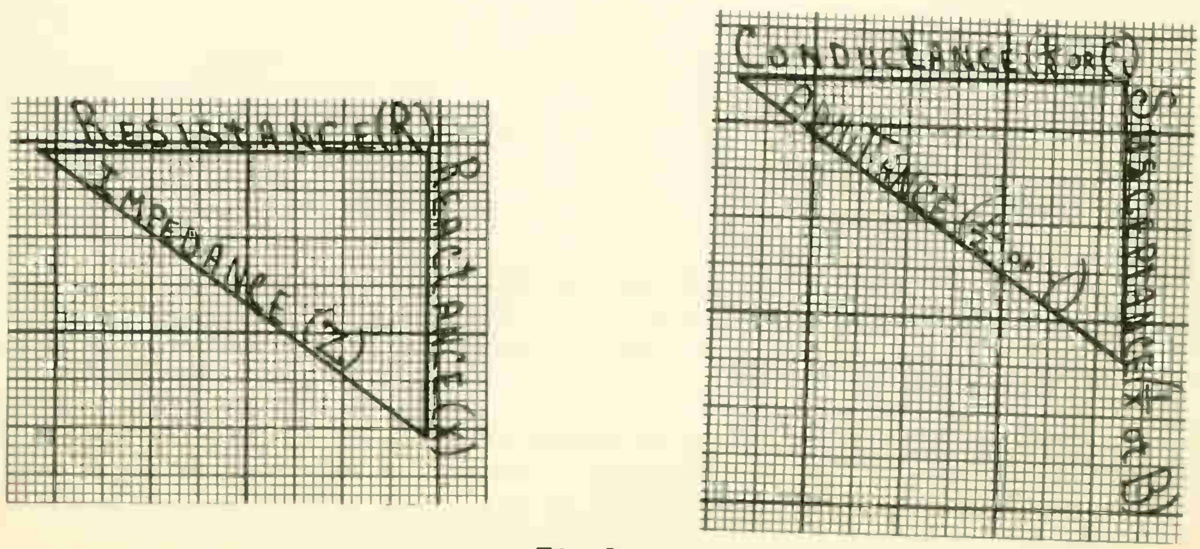


Fig. 3

F. Capacitive Reactance, Xc.

The capacitive reactance of a circuit is the apparent resistance of the circuit. If a current of the character depicted by curves in Fig. 4 is applied to a capacitor, that capacitor will charge and discharge repeatedly, the number of charges per second depending upon the frequency. As these actions are taking place, the capacitor develops a counter-voltage that limits the current. The opposition effect offered to the flow of a varying current by a capacitor is called "capacitive reactance".

Its symbol is Xc and its value is given in ohms. Capacitive reactance depends upon the capacitor capacity in Farads, and the frequency, f, in cycles per second as shown by the formula in the chart below.

You will notice in studying the various formulae that the frequency is inverse to Xc and too, that the greater the capacitors capacity or higher the frequency the lower or smaller will be the Xc.

Where "C" is in farads	Where "C" is in microfarads
$Xc = \frac{1}{2\pi fC}$	$Xc = \frac{10^6}{2\pi fC}$
$C = \frac{1}{2\pi f\ Xc}$	$C = \frac{10^6}{2\pi f\ Xc}$
$f = \frac{1}{2\pi C\ Xc}$	$f = \frac{10^6}{2\pi C\ Xc}$
Xc equals capacity reactance in ohms 2π equals radians per cycle f equals cycles per second	

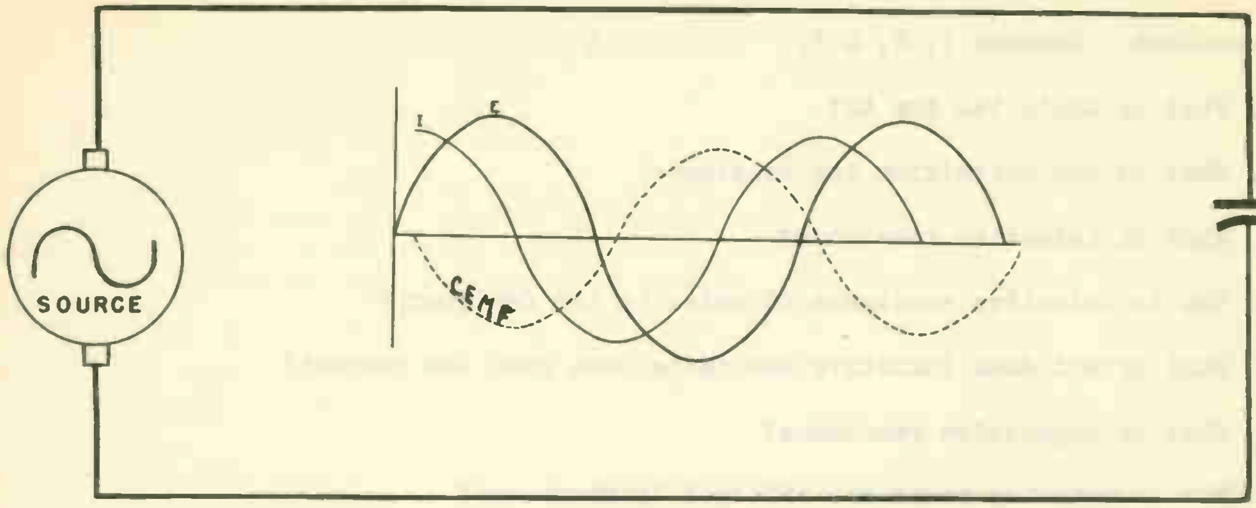


Fig. 4 A capacitor connected to an a-c source.

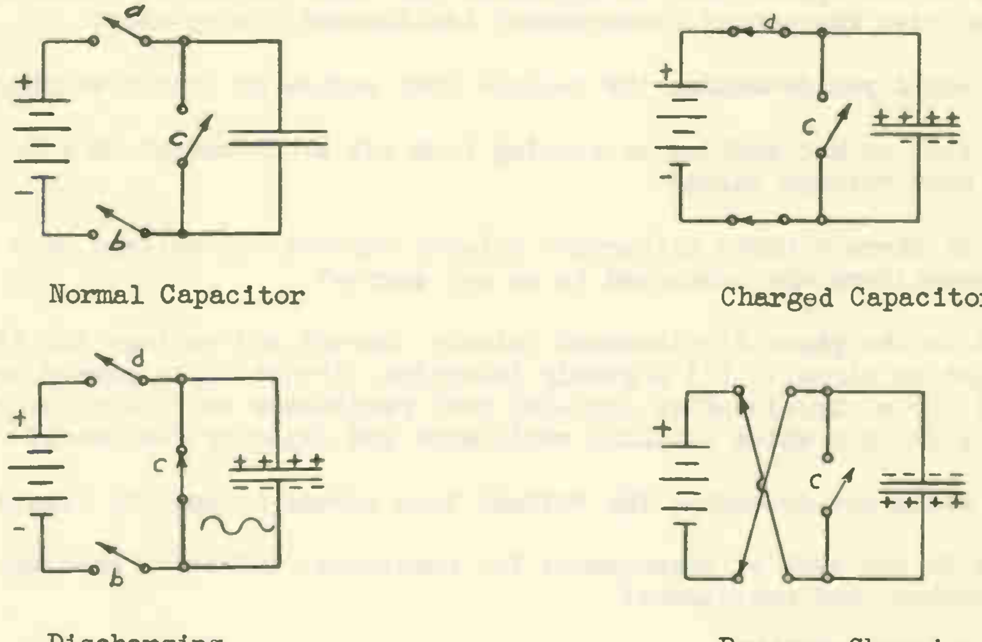


Fig. 5

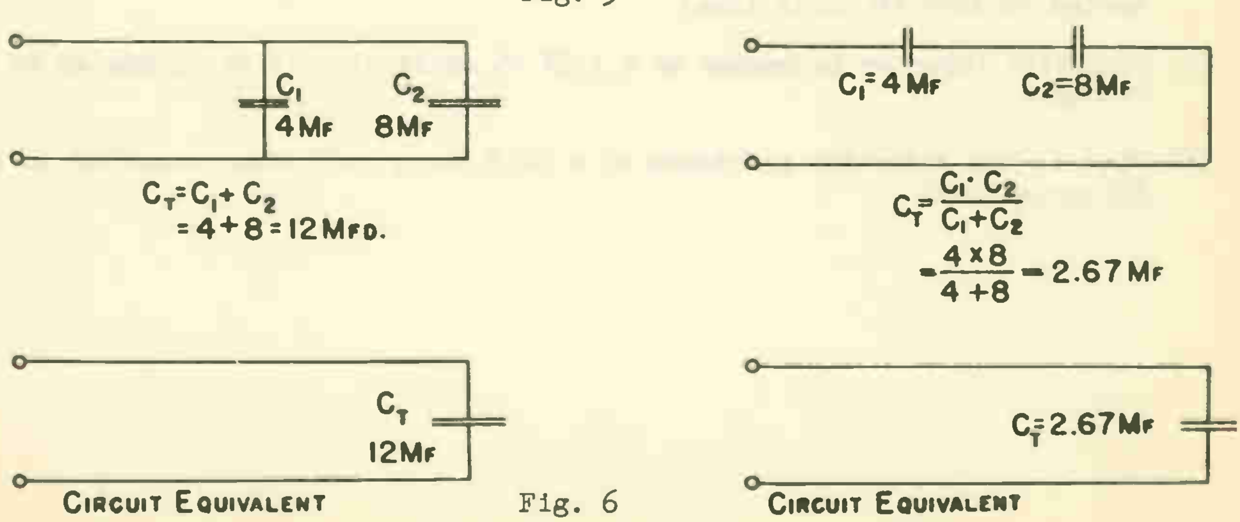


Fig. 6

G. Questions - Lessons 1, 2, & 3.

1. What is Ohm's law for AC?

2. What is the definition for reactance?

3. What is inductive reactance?

4. How is inductive reactance affected by the frequency?

5. What effect does inductive reactance have upon the current?

6. What is capacitive reactance?

7. How is capacity reactance affected by frequency?

8. What effect does capacity reactance have upon the current?

9. What is the symbol used to represent the term reactance? Inductive reactance? Capacitive reactance? Conductance? Admittance? Susceptance?

10. How would you determine the voltage drop across an inductive reactance?

11. Why will an a-c machine or winding burn out if connected on a d-c circuit of the same voltage value?

12. Why is there a phase difference between current and voltage when either coils or capacitors are connected to an a-c source?

13. What is the phase displacement between current and voltage in: (A) a purely resistive circuit; (B) a purely inductive circuit (C) a purely capacitive circuit (D) a circuit which contains both resistance and inductive reactance, (E) a circuit which contains resistance and capacity reactance?

14. How would you determine the voltage drop across a capacity reactor?

15. What is the unit of measurement for reactance, inductive reactance, capacitive reactance, and resistance?

16. What is the Xc of a circuit which contains two 4 mf capacitors in parallel connected to 120V 60 cycle line?

17. What size inductor is needed on a 115V 25 cycle circuit which has an Xc of 22 ohms?

18. What is the inductive reactance of a 10.5 henry coil when connected to a 220V 60 cycle line?

OPPOSITION TO ALTERNATING CURRENT III

Objective

To learn about impedances and the effects of connecting them in series or parallel. To learn how to calculate total impedances, and factors of resonance.

References

Lesson Content

A. Impedance (Z)

The impedance of a portion of an electric circuit to a completely specified periodic current and potential difference is the ratio of the effective value of the potential difference between the terminals to the effective value of the current, there being no source of power in the portion under consideration. ASA 05.20.195.

Impedance is the total opposition to current encountered by an AC or the AC component of a continually varying DC. Its value is measured in ohms. It may consist of R only, X_L only, or Xc only, or any combination of these opposition effects. The formula for this expression of Ohm's Law for AC follows:

E - Electromotive force in volts
I - Intensity of current in amperes
Z - Impedance in ohms

or

$Z = \frac{E}{I}$ $I = \frac{E}{Z}$ $E = I \times Z$ or IZ

The above formula may be summarized as Ohm's Law for AC:

The current (I) is directly proportional to the applied voltage (E) and inversely proportional to the impedance (Z) of the circuit."

In studying over Fig. 1 we come to the following conclusions:

X_L is 90° out of phase with R.
X_C is 90° out of phase with R.
X_L is 180° out of phase with Xc.

AC quantities must be added geometrically when out of phase with each other. They may be added by simple arithmetic only when they are in phase with each other. It is customary to start beginners with right angle components.

1. R and L in Series

If the arithmetical sum of E_R and E_L is compared with the applied line voltage, it will be found that the former is considerably greater than the latter. This is due to the fact, that voltages E_R and E_L do not reach their maximum values at the same instant. As shown by the curves and the vector diagrams, these voltages are actually "out of phase" with each other by one-quarter ($\frac{1}{4}$) cycle or 90° electrical. It is because of this phase difference that the opposition effects encountered in the a-c circuit cannot be added arithmetically but must be combined by means of formulas such as those shown in the sketches. See Fig. 2.

2. R and C In Series

The conditions shown in Fig. 3 are similiar to those in Fig. 2 except that the voltage Ec lags E_R by the same amount that E_L leads E_R in the preceding figure. The voltage across a pure resistance is always "in phase" with the current through it. E_L leads the current by 90° and Ec lags the current by 90°. The term "out of phase" is used to indicate that two periodically varying quantities do not pass through corresponding values at the same instant. The formula shows how the sum of the effects of resistance and capacity reactance must be obtained. Note that these quantities have direction as well as value. This explains why arithmetic is not used for addition, but addition must be vectoral or goemetric or possibly algebraic.

3. R, L, & C in Series

In Fig. 4 the phase relations are shown for R, L, and C in series. E_L leads E_R (or I, for E_R is always in phase with the I), by 90°, while Ec lags behind by 90° consequently voltages E_L and Ec are 180° out of phase with each other and, if they are equal in value, will cancel. Under such conditions the only remaining opposition in the circuit is due to R. This condition is necessary for series resonance. Note carefully, the phase relations shown by the vector diagrams and sine curves in this figure.

For a comparison which may be more easily understood, we will take for example, some d-c sources, Fig. 5, and show that even for d-c it is possible to have voltages in the circuit which are greater than that of the source. Note that E1 and E2 are 90 volts each and are tied in direct opposition to each other or opposing. This is to say, those voltages are considered 180 degrees out of phase with each other. Notice too that the applied voltage is 6 volts which is the algebraic total circuit voltage.

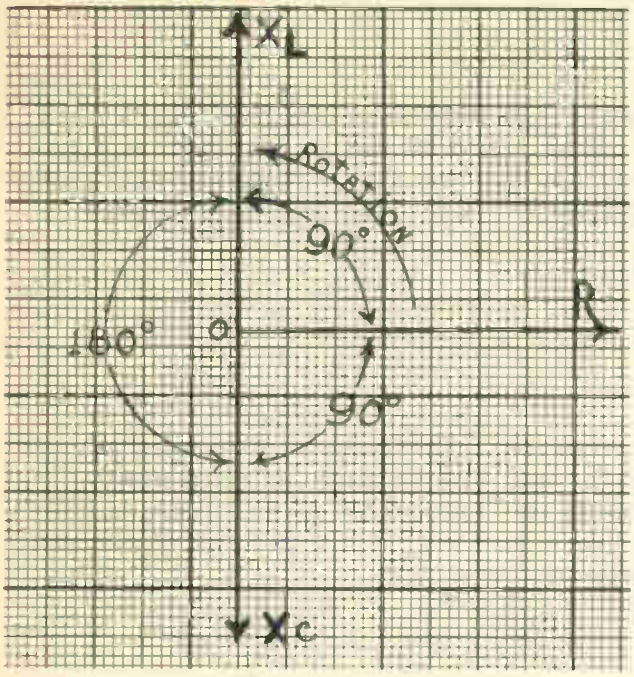


Fig. 1

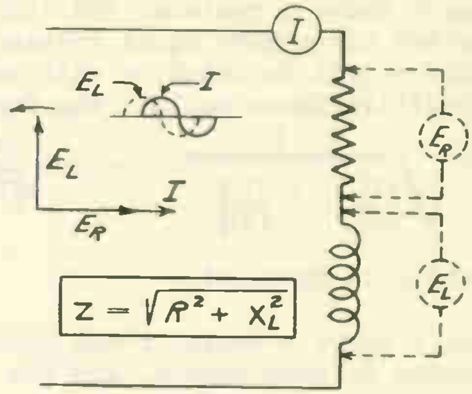


Fig. 2

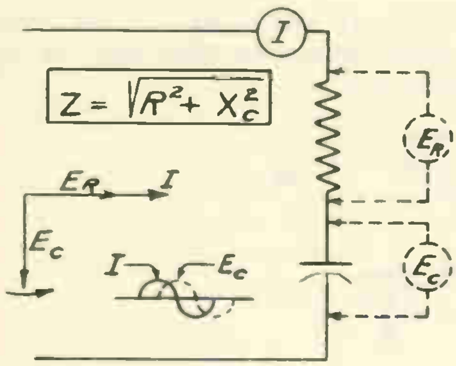


Fig 3

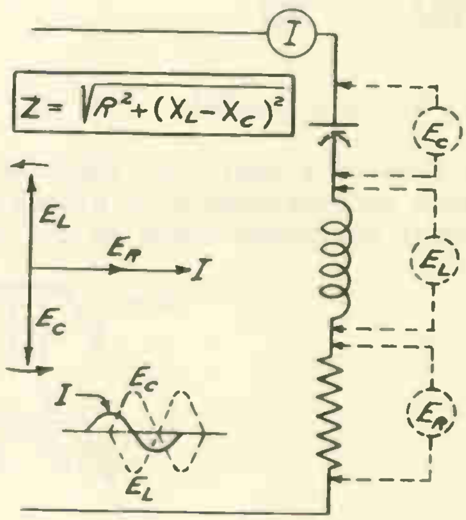


Fig. 4

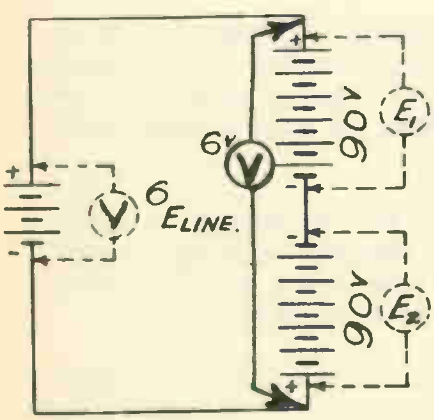


Fig. 5

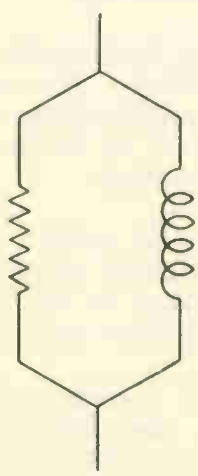


Fig. 6

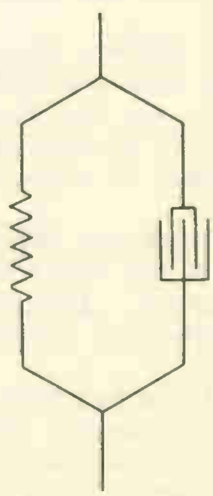


Fig. 7

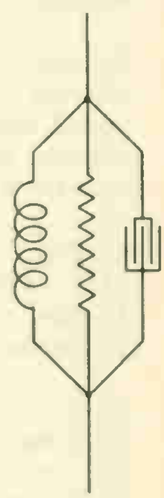


Fig. 8

4. R and L in Parallel

Fig. 6 shows a resistor and inductor connected in parallel. It is evident that the two units have equal voltage applied. The currents may or may not be equal. Since a coil or inductor will cause the current to lag the voltage it will mean a positive phase angle. The formula for impedance for this figure is given:

$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{XL}\right)^2}} \quad \text{or } Z = \frac{R \times X_L}{\sqrt{R^2 + XL^2}}$$

5. R and C in Parallel

Fig. 7 shows a resistor and capacitor in parallel. Since equal voltages are applied to each branch, and the current will lead the voltage by some angle, it means a negative phase angle. The formula for impedance in this case is:

$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{Xc}\right)^2}} \quad \text{or } Z = \frac{R \times Xc}{\sqrt{R^2 + Xc^2}}$$

6. R, L, & C in Parallel

Fig. 8 shows a resistor, inductor, and capacitor all in parallel.'It is possible to have an overbalance of either inductance or capacitance or they may be equal. If equal the phase angle is 0^o. Formula for impedance

$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{XL} - \frac{1}{Xc}\right)^2}} \quad \text{or}$$

$$Z = \frac{R \times X_L \times X_C}{\sqrt{XL^2 \; Xc^2 + R^2 \left(XL - Xc\right)^2}}$$

B Resonance

1. Comparing Mechanical and Electrical Resonance

Resonance in any system, mechanical or electrical, is always accompanied by a change in energy from one form to another. The swinging pendulum, the balanced wheel and spring, and the electrical combination of a coil and a capacitor are common examples. If energy is introduced to such systems, it will change from one form to another at a definite frequency.

In Fig. 1A, both systems are shown in the normal state, for no energy is stored with either. In B the wheel has been turned clockwise, thereby storing energy in the coiled spring. Applying a voltage to the capacitor has a similar effect. It causes the capacitor to store electrical energy in electrostatic form.

When the wheel is released as at C the energy stored in the spring is converted to momentum in the wheel. Similarly, when the switch is closed, the electrostatic energy in the capacitor is converted into electromagnetic energy in the field built up around the coil as the capacitor discharge flows through it.

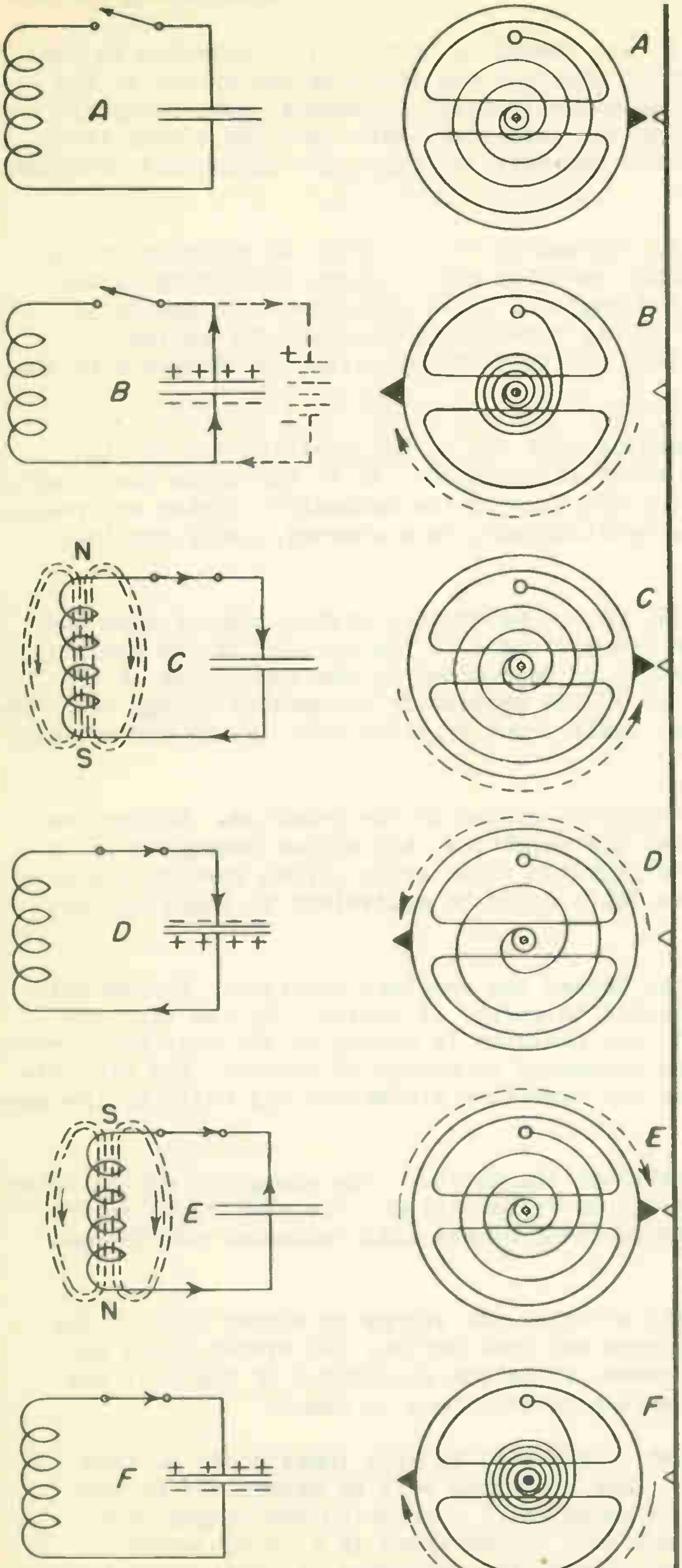


Fig.1

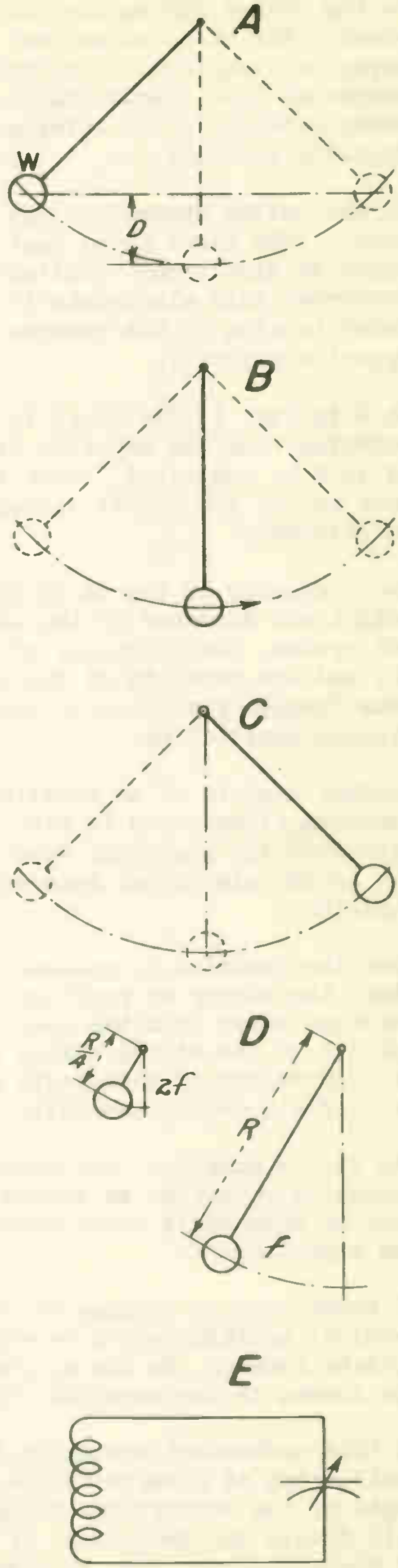


Fig. 2

As the coiled spring unwinds as at D, its energy is converted to momentum in the wheel. The wheel moves past the normal position and tensions the spring in the opposite direction. Similarly, as the magnetic field collapses, its energy is converted into electrostatic energy in the capacitor. Note that the spring is under tension in the reverse direction, and that the capacitor is charged with the opposite polarity.

As the coiled spring unwinds as at D, its energy is converted to momentum in the wheel. The wheel moves past the normal position and tensions the spring in the opposite direction. Similarly, as the magnetic field collapses, its energy is converted into electrostatic energy in the capacitor. Note that the spring is under tension in the reverse direction, and that the capacitor is charged with the opposite polarity.

At E in Fig. 1, the wheel is again moving past the normal position due to its momentum, and the magnetic field is about to collapse. At F, the cycle that started at B is completed. Were it not for friction in the mechanical system and resistance in the electrical system, these oscillations, once started, would continue indefinitely.

The frequency of the oscillation will, in the mechanical system, depend upon the weight and diameter of the wheel and the stiffness of the spring. In the electrical system, the frequency of oscillation is determined by the inductance of the coil and the capacity of the capacitor. If the externally introduced energy is of the same frequency as that of the system, small input impulses will create and sustain violent oscillation.

Another example of an oscillating mechanical system is the pendulum. Moving the pendulum sidewise as in Fig. 2A raises the weight, W, and stores energy in it by virtue of its position. Note that the pendulum is actually lifted through distance, D. In the electrical resonant system, this would be equivalent to charging the capacitor.

When the pendulum is released it moves toward the original position. During this time, the energy of position is converted to energy of motion. By the time the position shown in B has been reached, the pendulum is moving at its most rapid rate, and all of its stored energy has been converted to energy of motion. The electrical equivalent of this would occur as the capacitor discharged and built up the magnetic field around the coil.

Due to its momentum, the pendulum continues its motion. The energy of motion being gradually converted to stored energy due to its position. The electrical equivalent of this would occur as the magnetic field of the coil collapsed and charged the capacitor.

If there were no windage of frictional effects, the swings on either side of the vertical position would be equal and, once set into motion, the system would oscillate forever. In the electrical system, it is the resistance of the coil and the losses in the capacitor that cause the oscillations to cease.

If this mechanical system is disturbed in any way, it will immediately go into oscillation at a definite frequency. This frequency will be determined by the length of the supporting string, R. As shown at D, quartering the length of R will double the frequency. If the electrical system shown in E is subjected to an electrical impulse, it also will oscillate, the frequency of oscillation being determined by the setting of the variable capacitor.

If the pendulum is subjected to several equal sets of externally applied impulses, each set having a different frequency, it will be found that only the set whose frequency closely approximates that of the system will be effective in producing oscillation. If the length of the string is varied, the system may be "tuned" to accept one set of frequencies and reject the others. In this way, the system may be made resonant to any frequency within its range.

By varying the capacity of the variable capacitor, the electrical system shown at E may be tuned to respond to electrical impulses of a pre-selected frequency. If several sets of electrical impulses are applied to such a circuit, the circuit will respond only to those frequencies that closely approximate the frequency for which the circuit has been adjusted.

Comparison of Series and Parallel Resonant Circuits.

1. Series resonant circuit.

   a. The R, L, and C are in series with the source voltage.

   b. Resonance occurs when X_L equals Xc.

   c. Z is minimum and equal to R at resonance.

   d. I is maximum and equal to E/R at resonance.

   e. The circuit acts like a resistor of low value and has unity power factor (current and voltage in phase) at resonance.

   f. The current through L and C is the same as the line current.

   g. At resonance the voltages across L and C are approximately equal and nearly 180 degrees out of phase with each other and 90 degrees out of phase with the supply voltage.

   h. Increasing R increases the impedance, thereby decreasing the line current and the reactive voltages.

   i. For frequencies above resonance, the circuit is inductive and the current lagging. For frequencies below resonance, the circuit is capacitive and the current leading.

2. Parallel Resonant Circuit

a. The LC and the source voltages are in parallel.

b. Resonance occurs when X_L equals Xc. Z=R.

c. The line current is minimum and equal to E/Z at resonance.

d. The circuit acts like a resistor of high value and has unity power factor (current and voltage in phase) at resonance.

e. The voltage across L and C is the same as the supply voltage.

f. At resonance, the current through L and C is approximately equal and nearly 180° out of phase with each other and 90° out of phase with the line current.

g. Decreasing R lowers the parallel impedance thereby increasing the line current.

h. At frequencies above resonance, the circuit draws a leading current which exceeds the lagging current, therefore, the line current leads the voltage applied.

i. At frequencies below resonance, the circuit draws a lagging current which exceeds the leading current, therefore, the line current lags the voltage applied.

j. If the frequency is above or below the resonant frequency, the leading and lagging currents are unbalanced, therefore, the line current will increase indicating a decrease in the impedance of the circuit.

IMPEDANCE (Numerical Magnitude)

R E S I S T O R S

$Z=R$

$\theta=0^{\circ}$

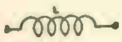
$Z=R_1+R_2+R_3$

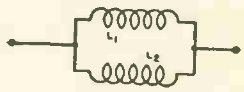
$\theta=0^{\circ}$

$$Z=\frac{R1 \times R2}{R1+R2} \quad \text{or} \quad \frac{1}{\frac{1}{R1}+\frac{1}{R2}}$$

$\theta=0^{\circ}$

C O I L S





$Z=XL$

$\theta=+90^{\circ}$

$Z=XL1 + XL2 + XL3$

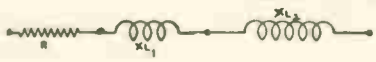
$\theta=+90^{\circ}$

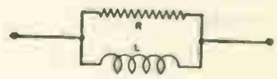
$$Z=2\pi f\left(\frac{L1 \times L2}{L_1+L2}\right) \quad \text{or} \quad \frac{XL1 \times XL2}{XL1+XL2} \quad \text{or}$$

$$\frac{1}{\frac{1}{XL1}+\frac{1}{XL2}}$$

$\theta=+90^{\circ}$

R E S I S T O R S & C O I L S



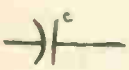


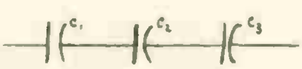
$Z=\sqrt{R^2 + XL^2}$

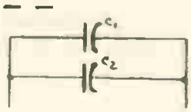
$Z=\sqrt{R^2 + (XL1 + XL2)^2}$

$$Z=\frac{RXL}{\sqrt{R^2 + XL^2}} \quad \text{or} \quad \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2+\left(\frac{1}{XL}\right)^2}}$$

C A P A C I T O R S







$Z=Xc$

0=-90°

$Z= Xc1 + Xc2 + Xc3$

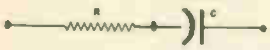
$\theta=-90^{\circ}$

$$Z=\frac{1}{2\pi f\ (C1+C2)} \quad \text{or} \quad \frac{1}{\frac{1}{Xc1}+\frac{1}{Xc2}}$$

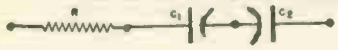
0=-90°

IMPEDANCE (cont'd)

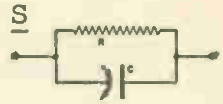
CAPACITORS & RESISTORS



$Z = \sqrt{R^2 + Xc^2}$

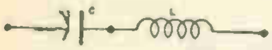


$Z = \sqrt{R^2 + (Xc1 + Xc2)^2}$

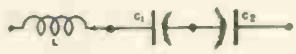


$Z = \frac{RXc}{\sqrt{R^2 + Xc^2}}$ or $\frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{Xc}\right)^2}}$

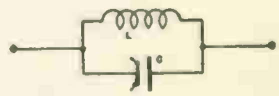
CAPACITORS & COILS



$Z = XL - Xc$



$X = XL - (Xc1 + Xc2)$

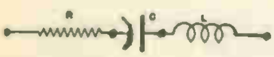


$Z = \frac{XL \times Xc}{XL - Xc}$

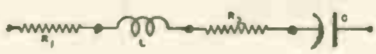
$\theta = -90^\circ$ when $XL < Xc$
$\theta = 0^\circ$ when $XL = Xc$
$\theta = +90^\circ$ when $XL > Xc$

$\theta = 0^\circ$ when total Xc and total XL are of equal value.

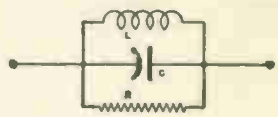
RESISTORS, COILS, and CAPACITORS



$Z = \sqrt{R^2 + (XL - Xc)^2}$



$Z = \sqrt{(R1 + R_2)^2 + (XL - Xc)^2}$



$Z = \frac{R \times XL \times Xc}{\sqrt{XL^2 \; Xc^2 + R^2(XL - Xc)^2}}$ or

$\frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{XL} - \frac{1}{Xc}\right)^2}}$

. Summary Questions:

1. What would be the impedance of a series circuit containing an inductance of 4 ohms and a resistance of 3 ohms?

2. What is the symbol for impedance? Capacity reactance? Inductive reactance?

3. What is the unit of measurement for impedance, capacity reactance. Inductive reactance?

4. State the formula for determining total "Z" when resistance, capacity reactance, and inductive reactance are known and in series? In Parallel?

5. State conditions necessary for resonance.

6. Is current high in any part of a parallel resonant circuit? If so in what part?

7. What factor must be true in both parallel and series resonance circuits?

8. At resonance, what is the power factor angle of the circuit?

9. When is Z equal to $\frac{E}{I}$?

10. Draw the circuit type which best fits the following formula:

FORMULA	CIRCUIT
$Z = \sqrt{R^2 + Xc^2}$	
$Z = \sqrt{R^2 + X_L{}^2}$	
$Z = \sqrt{R^2 + (X_L - X_C)^2}$	
$Z = \frac{R\ Xc}{\sqrt{R^2 + Xc^2}}$	
$Z = \frac{R\ X_L}{\sqrt{R^2 + X_L{}^2}}$	
$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{Xc} - \frac{1}{XL}\right)^2}}$	

STAR AND DELTA CONNECTIONS FOR THREE PHASE APPARATUS

Objective

To become familiar with star and delta winding connections and the factors which determine the connection to be used according to winding information, job requirements, etc.

References

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Lesson Content

A. General

In reviewing the factors which make up a three phase winding, we come to the following conclusions:

1. There are three distinct and separate windings (phases).
2. These windings are displaced 120 electrical degrees, which is to say that the starts are displaced by the same number of degrees as are the finishes.
3. Six leads are brought out to the outside of the stator when all of the phase groups are connected.
4. Star connections, Fig. 1A, may be formed by connecting the three finish leads together and bringing out the starts of these phases as line leads.
5. Delta connections, Fig. 1B, may be made with those same six leads, by connecting the finish of A phase to the start of B phase and connecting that junction to B line; finish of B to the start of C, which should be connected to line C; the finish of phase C to the start of A, which in turn is then connected to line A.
6. The VA or KVA rating will be the same for a given unit whether connected for star or delta.
7. For a visual comparison of the various forms of star and delta, observe the Fig. 1 and notice the various forms of the same connection.

B. Star Connection

The star (wye or Y) connection is made by connecting three like phase ends (usually the finish leads of the phases) together. The line wires are connected to the remaining loose ends of the phases. The phases are identified by the start lead connections of the various phase groups. This means that the start lead of phase A is brought out as A line, the start of phase B is brought out as B line, and the start of phase C is brought out as C line. See Fig. 1A.

1. Voltage

The voltages between lines in a balanced-Y system are equal and differ in phase by an angle of 120 electrical degrees. Each line voltage, however, differs from its phase voltage by an angle of only 30°. Therefore, the three line voltage are each equal in magnitude to the square root of three (3) or 1.732, times the phase voltage.

$$\text{Line Voltage} = \text{Phase Voltage} \times 1.732$$

$$\text{Phase Voltage} = \text{Line Voltage} \times \frac{1}{1.732}$$

or

Phase Voltage= Line Voltage x .5774 (two decimal places gives us the value of .58)

3. Power

In a balanced three phase system, at unity power factor, the line power is equal to the square root of three times the product of line voltage and line current

VA = (Phase voltage x 1.732) x Line or phase current x 1.732
$VA = E_{phase} \times I_{phase} \times 3$
$VA = E_{line} \times I_{line} \times 1.732$ (most used)

C. Delta Connection

A closed delta (△) or mesh connection is formed when the outside of one coil is connected to the inside of the next coil. More frequently, we speak of it as starts and finishes. For example, we can connect the finish of coil A to the start of coil B, then, that lead or junction point would connect to the line as line B or phase B. For a clarification of this statement, see Fig. 1B.

1. Voltage

The voltage between lines of a delta connected balanced three-phase system is the same as phase voltage. At first appearance the lines seem to be shorted upon themselves, further investigation will prove otherwise. Accordingly, the sum of the three voltages is zero according to the application of Kirchhoff's voltage law.

Line Voltage = Phase Voltage

2. Current

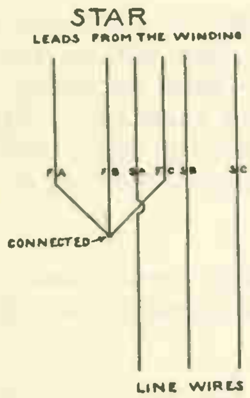
The current in a balanced delta system connected to three-phase lines may be found by multiplying Phase current by the square root of three (1.732), times phase current. It would seem, at first observation, that phase current and line current may be the same. With further study, however, it becomes apparent that for any given set of line wires, one phase is in parallel with two in series, hence, a difference in line and phase current.

Line Current = Phase Current x 1.732
Phase Current = Line Current ÷ 1.732
$\text{Phase Current} = \text{Line Current} \times \frac{1}{1.732}$

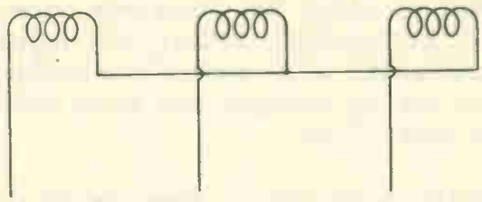
3. Power

At unity power factor in a balanced three phase system the line power is equal to the square root of three times the product of line voltage and current.

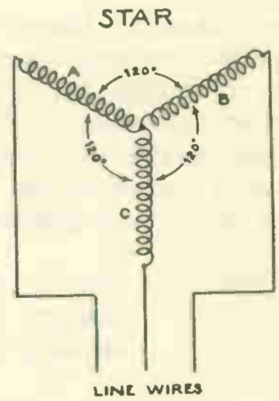
$VA = \text{Phase or Line Voltage} \times (I_{phase} \times 1.732) \times 1.732$
$VA = E_{phase} \times I_{phase} \times 3$
$VA = E_{line} \times I_{line} \times 1.732$ (most used)



A. Three phase line

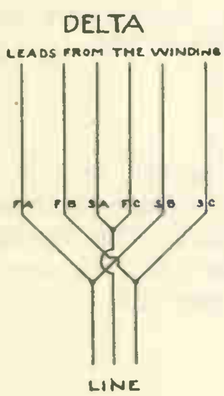


B. Three phase line

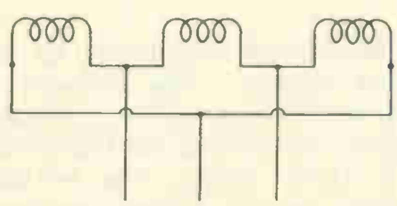


C. Three phase line

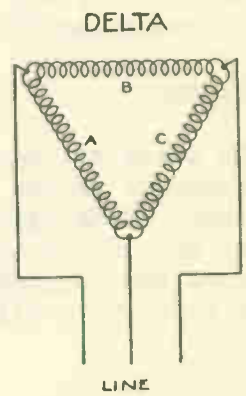
Fig. 1-A The above sketches show methodical connections for star or wye connections with a-c windings. Note mechanical connections at "a" for a three phase three wire star connection; at "b" we see the proper method for connecting 3 coil groups-star; at "c" we note the actual phase displacement of the three main phases (A, B, & C).



A. Three phase line



B. Three phase line



C. Three phase line

Fig. 1-B Sketches for methodical connection for delta connections with a-c windings. Note mechanical connections (a) for three phase 3 wire delta connections; at "b" the coil groups are shown for delta; "c" shows manner of making delta connections to the leads of a machine winding. Compare these windings with those in Fig. 1-A.

D. Open Delta

If one of the windings of a three phase delta connected alternator became defective, it is possible to disconnect the faulty winding and operate the unit at reduced load, (approximately 58% of the closed delta full load). This will result in decrease in alternator power factor.

It is not, however, common practice to use an alternator that has a faulty winding or phase, on open delta; unless in the most unusual circumstances.

Three phase to three phase transformation requires the transformers be similiar in construction and characteristics. The impedance characteristics need not be the same, although it is preferable, since the time may come when the bank capacity must be increased. Then, it is imperative that the impedances are identical. Since in open delta the transformer units will transform satisfactorily only about 86% of their rated value, let us see by example how much change is made by adding a third unit to a proper open delta line.

EXAMPLE: Two 100 kva units connected in open delta transforming three phase energy, 2300 volts to 3 phase 115/230 volts the bank capacity would be only 200 kva x 86% or about 172 kva.

An open delta connection is often used, as a temporary expedient, pending a contemplated increase of load by such concerns as utilities and REA. By following the above example and adding another 100 kva unti the bank's capacity will be increased from 172 kva to about 300 kva.

The voltage regulation of an open delta bank is not as good as a closed delta bank. The drop across the open delta is greater than across each of the separate transformers.

1. Connections

The open delta connection can be constructed by using two transformers of equal kva capacity and connecting the finish of A to the start of B. Bring out the two remaining line connections and the junction of AB as the third line. Fig. 2.

2. Voltage

The phase voltages in open delta are displaced by 120°, which is the same displacement as the closed delta system. The comparative voltage values with a closed delta system changed to an open delta system are the same. The vectorial sum of the three voltages, according to Kirchhoff's voltage law, is zero. Since the applied voltage is three phase, the voltages across any combination of line wires will be the same as any other combination.

$$E_{line} = E_{phase}$$

3. Current

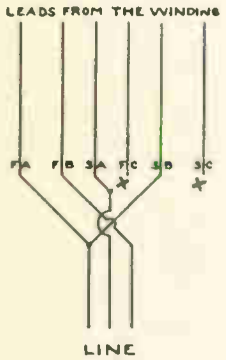
The current in a balanced three phase open delta system is the same for line current as for phase current. This is because there will never be an alternate parallel path for current in this V connection.

$$I_{line} = I_{phase}$$

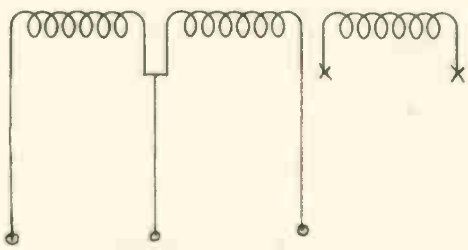
4. Power

Since the V connection is usually used on transformer banks with a possible expansion program in mind, it might be well to state that the addition of the third transformer would increase the transformer bank's capacity nearly 75% with an increased investment of only approximately 50%.

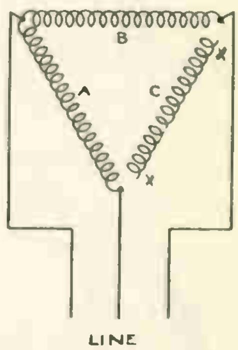
VA_3 phase V = E_{phase} x I_{phase} x 1.732
VA_3 phase V = E_{line} x I_{line} x 1.732
VA_2 in V = 5773 of VA if three in closed delta



A. Three phase line



B. Three phase line



C. Three phase line

Fig. 2 The above sketches show methodical connections for the open delta connections for a-c windings. Note in all three sketches, it is assumed that "C" phase has become defective in the delta connection shown in Fig. 1-B. This then is how the resultant unit could be operated at reduced load without danger to windings of transformers.

E. Utility Factor

The utility factor of a system is actually the ratio of a system's maximum demand to the capacity of the system (rated capacity).

EXAMPLE: Suppose we had two 1000 VA transformers which have a secondary E_{phase} of 100 volts, and I_{phase} of 10 amps.

$$\text{Utility Factor} = \frac{E_{ph} \times I_{ph} \times 1.732}{\text{Sum of Individual trans. Ratings}} = \frac{100 \times 10 \times 1.732}{2000} = \frac{1732}{2000} = .866$$

therefore

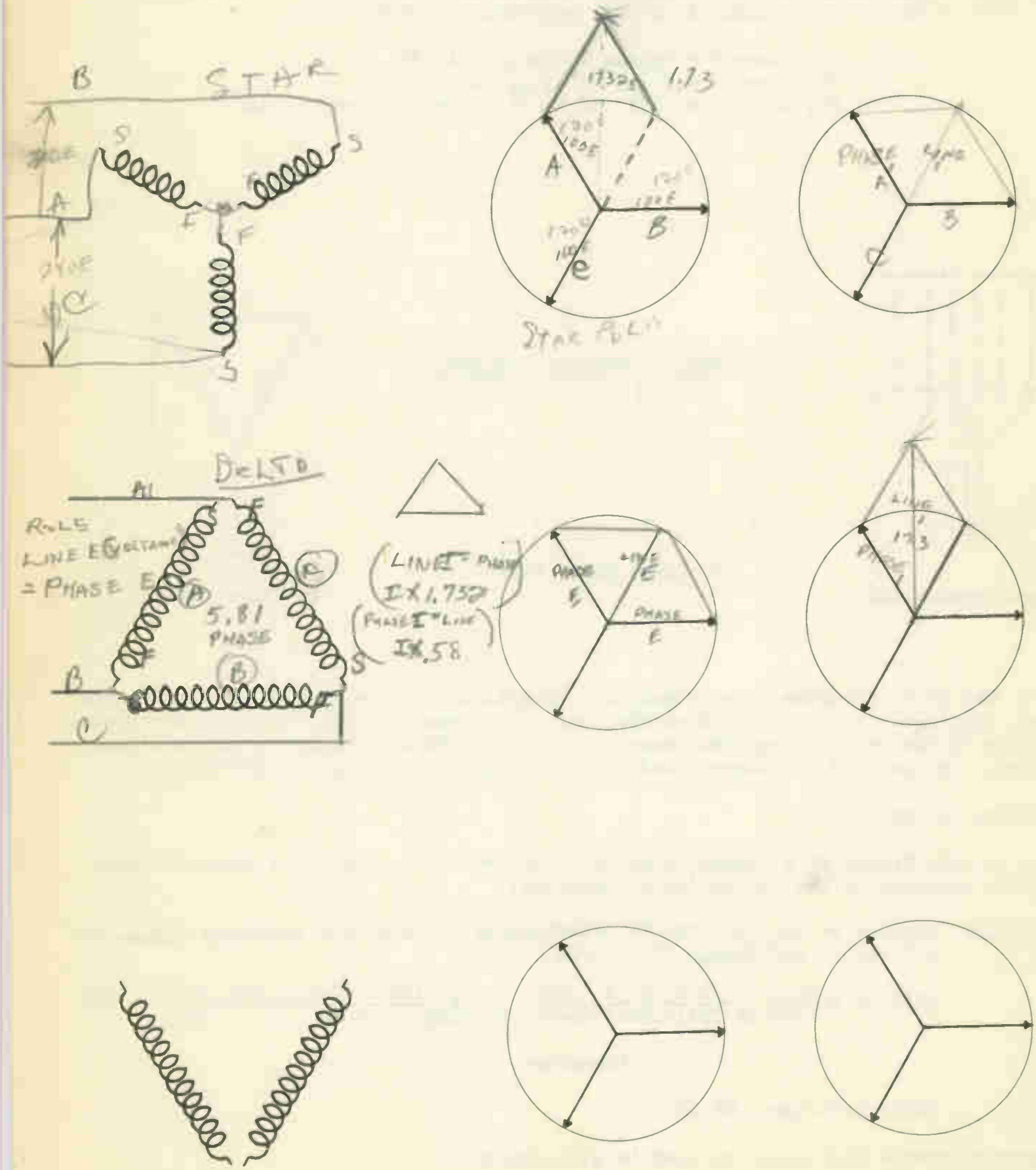
Utility Factor = 86.6%

Another formula that could be used is given below:

$$\text{Utility Factor} = \frac{\text{Load carried by 2 in V}}{\text{Sum capacity of 2 in V}}$$

F. Summary

For a comparison of the three windings or connections discussed in this chapter, we have on this page diagrams with all windings open. It may be finished in lecture.



Review Questions

1. How would you name the six leads that come out of a stator?

2. How would you connect those six leads for a three wire star connections?

3. Explain what is meant by a 4 wire star connection, and state its uses.

4. Are there 3 distinct windings in a three phase stator, or is it only one winding made into sections?

5. What is the phase displacement between phases of a three winding stator.

6. State the current, voltage, and power formulae for line and phase for a wye connection; for a delta connection.

7. What difference, if any, is there in VA rating for a given unit when connected Star or Delta? Explain.

8. What is meant by a mesh connection and how is it formed (using the six stator lead type-question 1)?

9. What is an open delta connection? Where is it used? What are the voltage, current, and power formulae for line and phase? How is the connection made?

10. Explain utility factor.

REVOLVING MAGNETIC FIELDS IN A THREE PHASE STATOR

Objective

To learn what constitutes a revolving magnetic field for three phase stators, its purpose, action, and application of the Fleming Rules for determination of poles.

References

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Lesson Content

A. General

Before discussing and applying information on a three phase revolving field, it would be well for the student to review the basic principles involved, which were discussed in the Wiring and Repair Department. Since the discussions and explanations were for single phase revolving magnetic fields, we now will discuss the basic differences in fields actions as applied to a three phase unit.

B. Three Phase Revolving Magnetic Fields.

Three phase and other polyphase motors depend upon a revolving magnetic field to produce a motion of the rotor. Since the windings are displaced 120 electrical degrees from each other, it follows that when currents applied are displaced by the same angle, the movement of the magnetic field is due to the continual variation of the currents applied, and can be illustrated in detail by tracing the circuits at frequent intervals. Care should be exercised to respect the instantaneous polarity and magnitude of each of the three phase currents. An interval of 30° has been selected for the diagram shown in Fig. 1-A. This is because each slot or bar is equal to 30° Electrical. A single layer winding is being used for reasons of simplicity

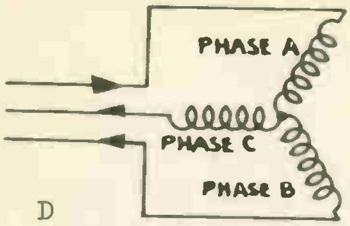
For instance, we see in Fig. 1, a set of diagrams and the motor stator schematic (Fig. 1-D) as well as a three phase current sine wave diagram (Fig. 1-C), which shows seven instants which will be discussed and traced in class. Note the setting up of polarities in the diagram, Fig. 1-A, when the currents have been traced according to the instant shown in Fig. 1-C. Fig. 1-B shows a representative form of a stator with all leads and field coils shown. The concentric circles in the center of this diagram are so shown, that you may indicate the direction of current through the coil that pertains to that particular instant.

The large diagram in the center of the page, should also be filled in so as to ascertain pole positions; this operation being done immediately after each instant is traced in Fig. 1-B.

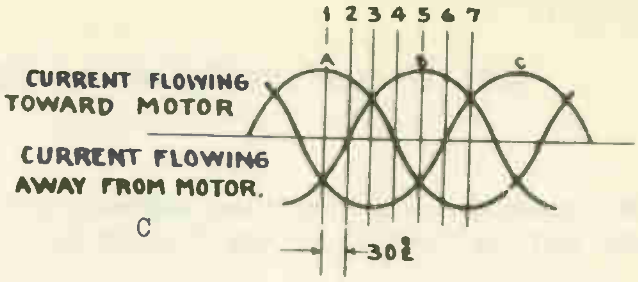
C. Diagram Tracing

The detailed diagrams are shown on successive pages. It is recommended that you do not attempt to trace the remaining diagrams until the instructor on the lecture platform makes an assignment.

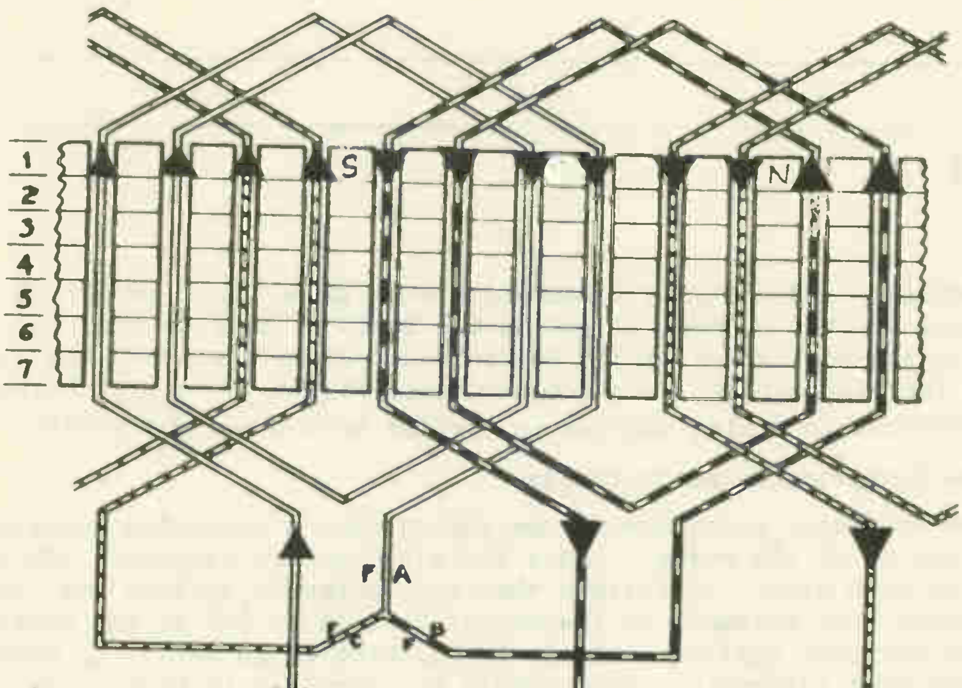
Check over the diagrams so as to determine what classification the connections would fall under, i.e. star or delta. Now ascertain for your own satisfaction why a certain connection or combination of connections makes for a connection of wye or delta. Perhaps it might be well to review the previous chapter which discusses the star and delta connections in detail.


PHASE A
PHASE C
PHASE B

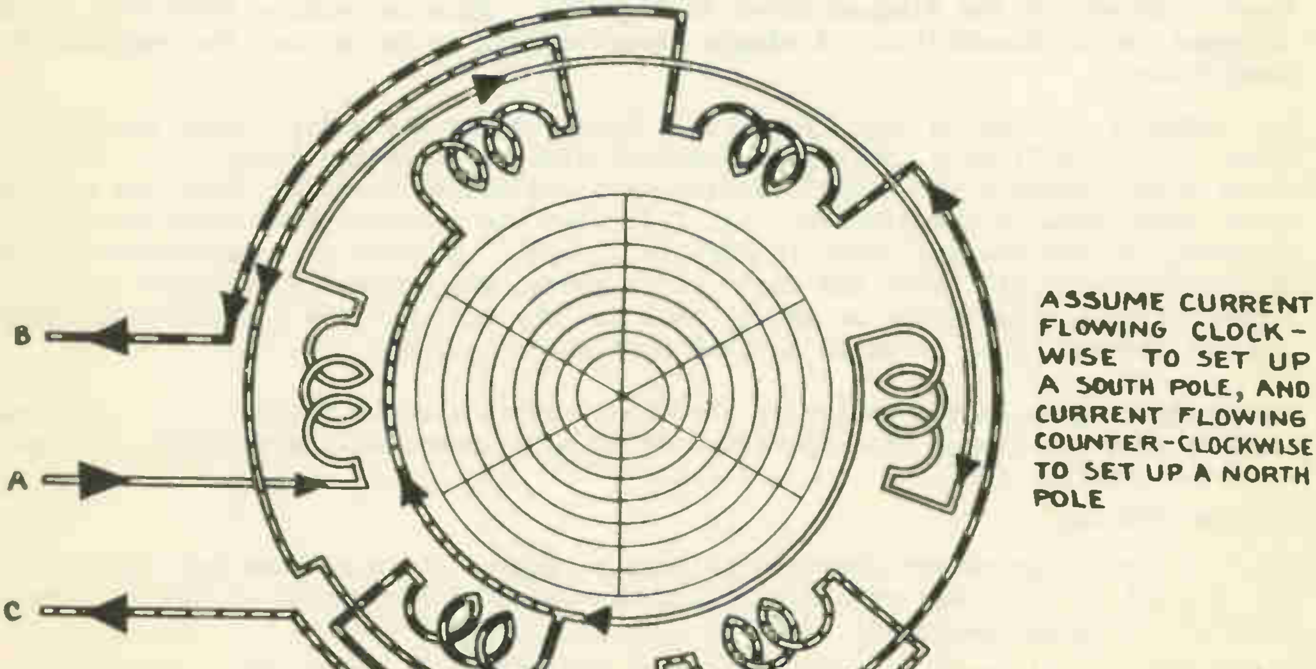
D


1 2 3 4 5 6 7
CURRENT FLOWING TOWARD MOTOR
CURRENT FLOWING AWAY FROM MOTOR.

C


1
2
3
4
5
6
7
S
N
F A
S A
S B
S C

A


B
A
C
ASSUME CURRENT FLOWING CLOCK-WISE TO SET UP A SOUTH POLE, AND CURRENT FLOWING COUNTER-CLOCKWISE TO SET UP A NORTH POLE

B
Fig. 1

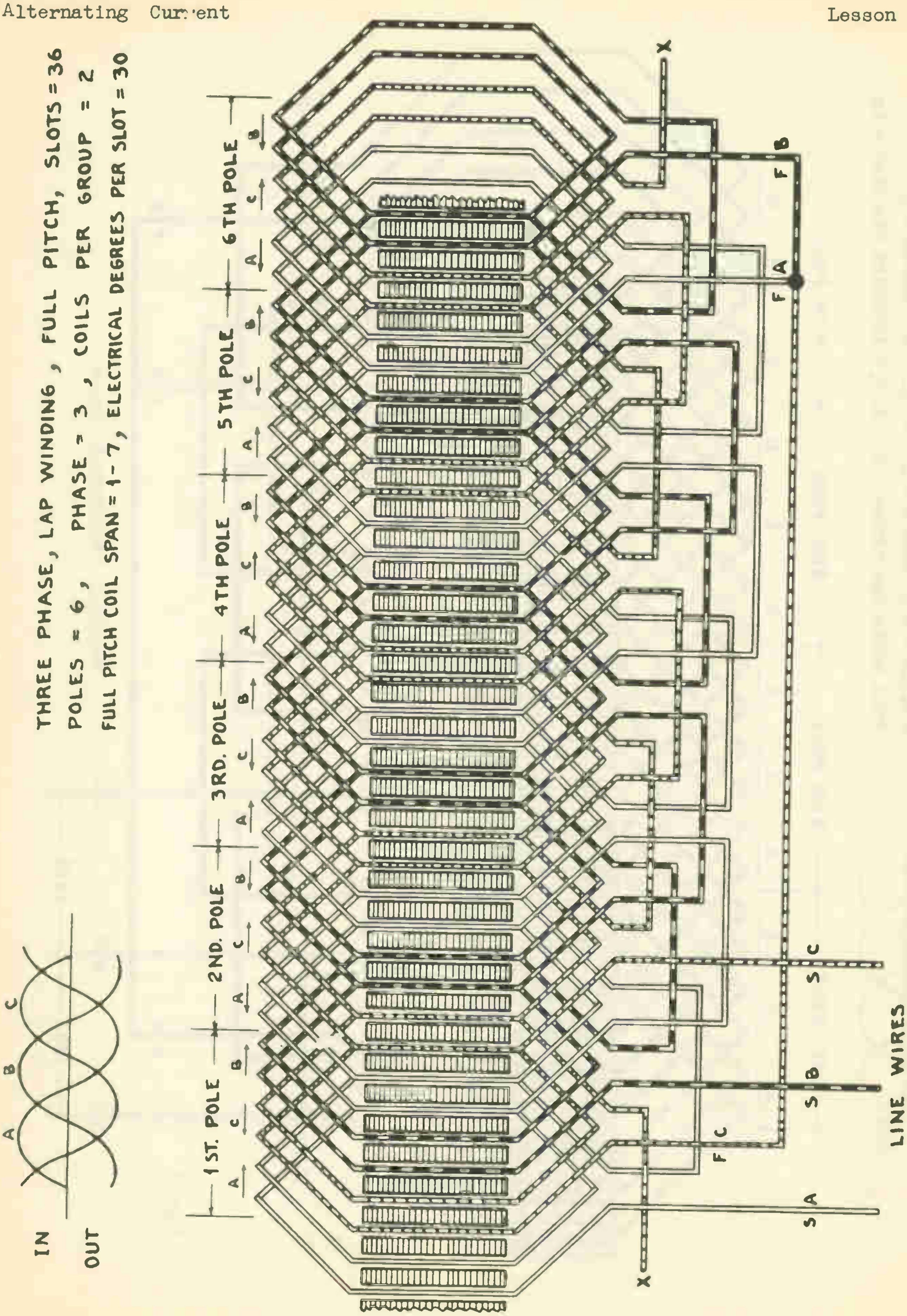

THREE PHASE, LAP WINDING, FULL PITCH, SLOTS = 36
POLES = 6, PHASE = 3, COILS PER GROUP = 2
FULL PITCH COIL SPAN = 1-7, ELECTRICAL DEGREES PER SLOT = 30
IN
OUT
A
B
C
1 ST. POLE
2ND. POLE
3RD. POLE
4TH POLE
5TH POLE
6TH POLE
X
F B
F A
S C
S B
F C
S A
LINE WIRES

Fig. 2

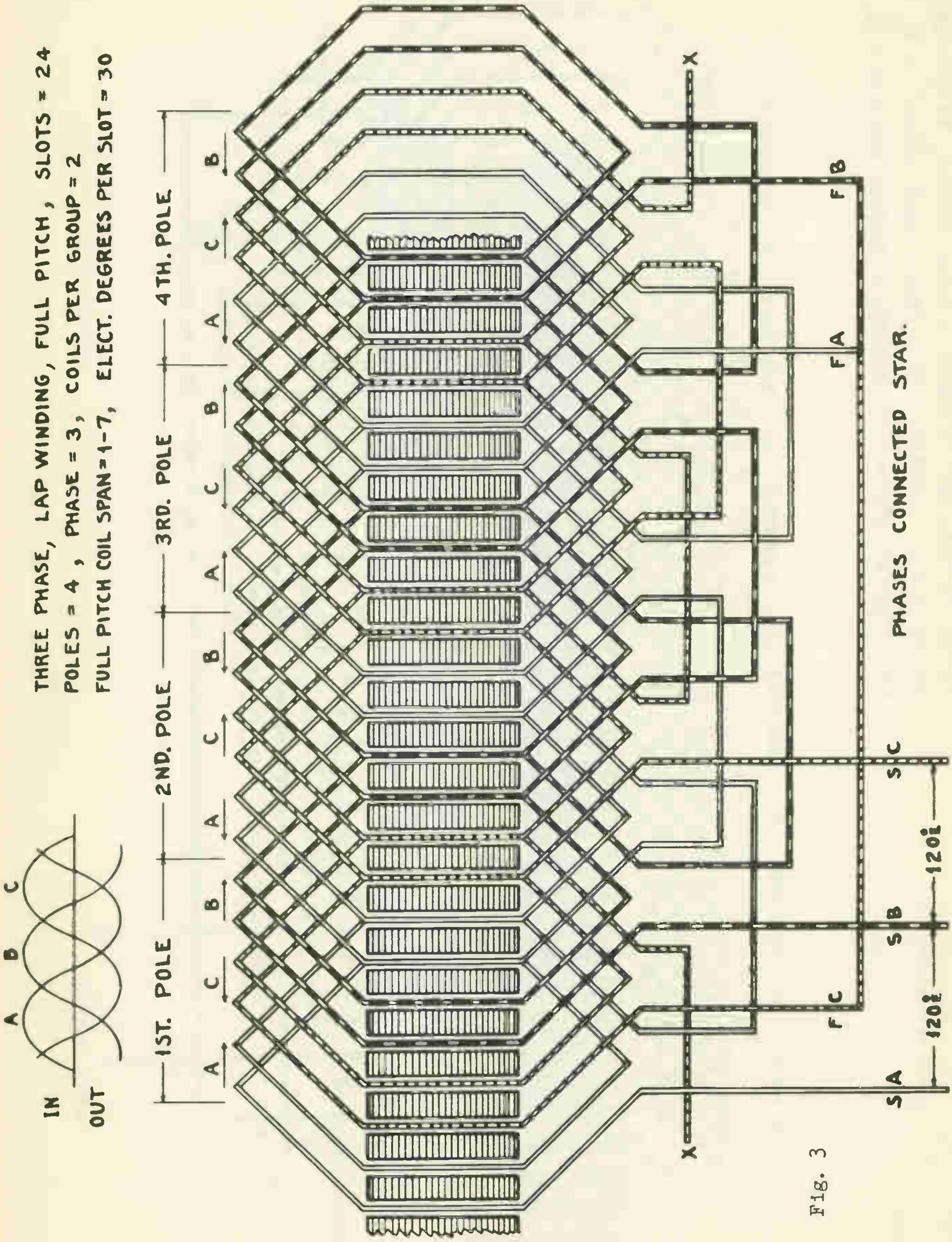

THREE PHASE, LAP WINDING, FULL PITCH, SLOTS = 24
POLES = 4, PHASE = 3, COILS PER GROUP = 2
FULL PITCH COIL SPAN = 1-7, ELECT. DEGREES PER SLOT = 30
IN
OUT
A
B
C
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
A
C
B
X
X
F B
F A
F C
S C
S B
S A
120°
120°
PHASES CONNECTED STAR.

Fig. 3

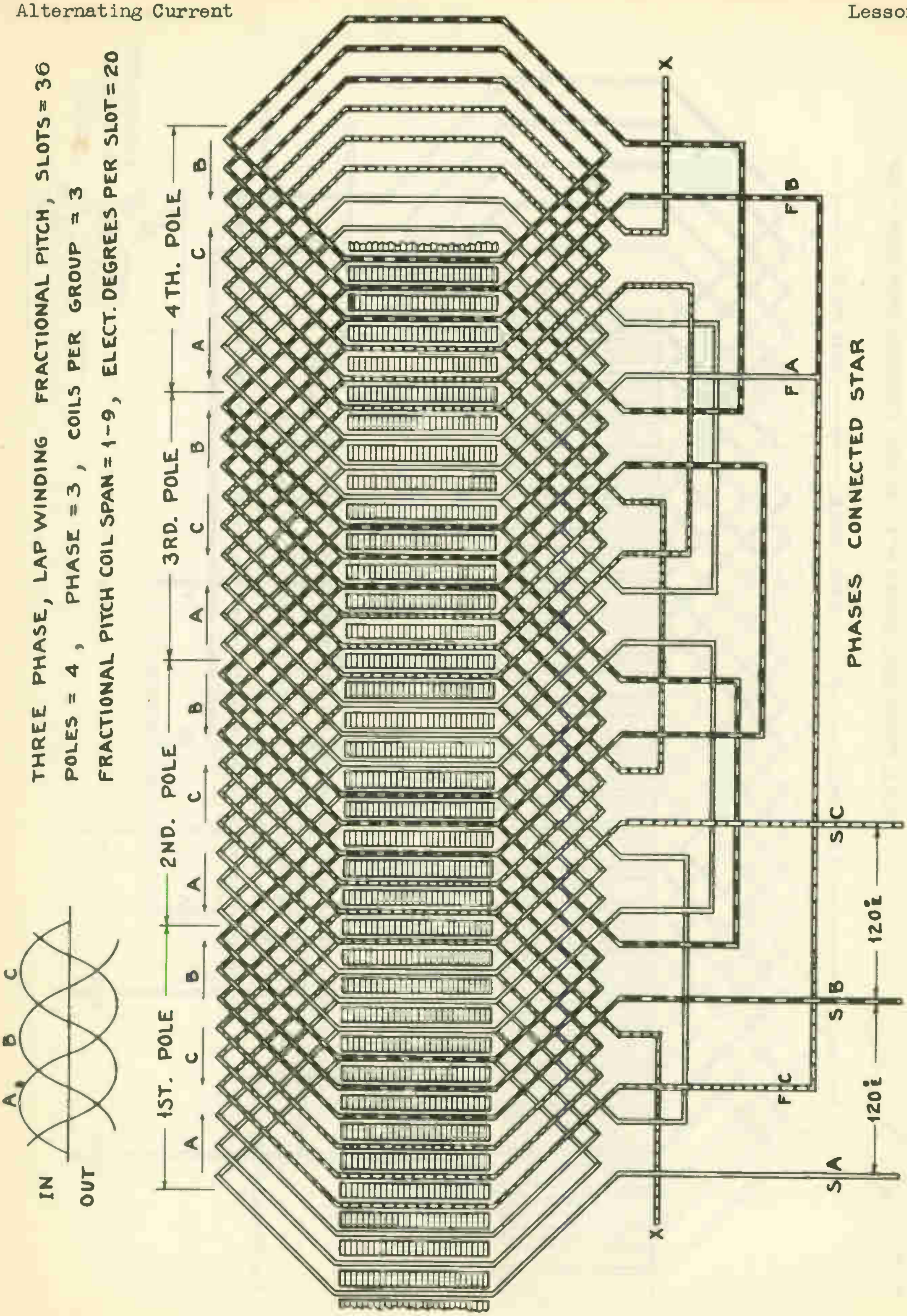

THREE PHASE, LAP WINDING FRACTIONAL PITCH, SLOTS = 36
POLES = 4, PHASE = 3, COILS PER GROUP = 3
FRACTIONAL PITCH COIL SPAN = 1-9, ELECT. DEGREES PER SLOT = 20
IN
OUT
A
B
C
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
X
F B
F A
F C
S A
S B
S C
120°
120°
PHASES CONNECTED STAR

Fig. 4

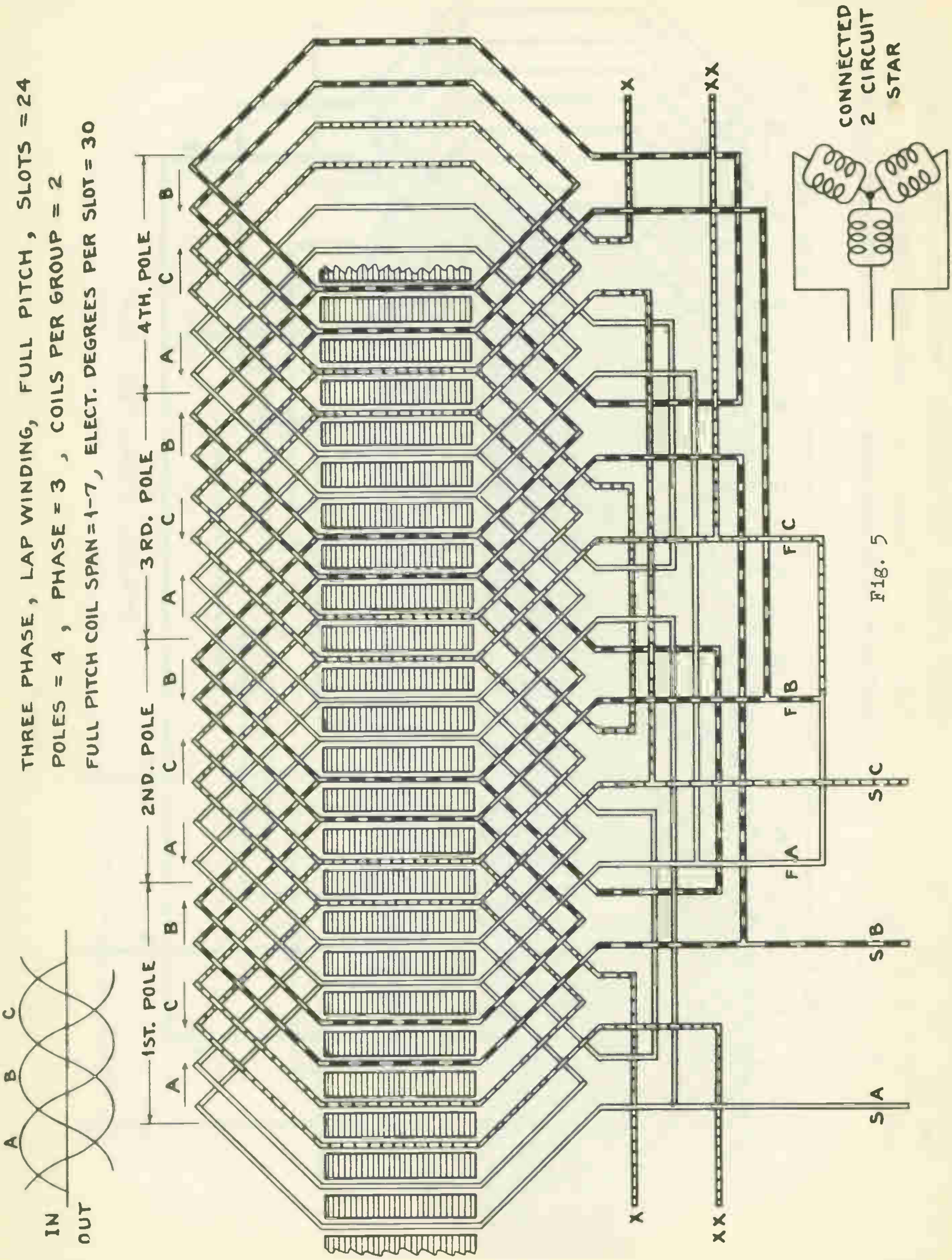

THREE PHASE, LAP WINDING, FULL PITCH, SLOTS = 24
POLES = 4, PHASE = 3, COILS PER GROUP = 2
FULL PITCH COIL SPAN = 1-7, ELECT. DEGREES PER SLOT = 30
IN
OUT
A
B
C
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
X
XX
S A
S B
S C
F A
F B
F C
CONNECTED 2 CIRCUIT STAR

Fig. 5

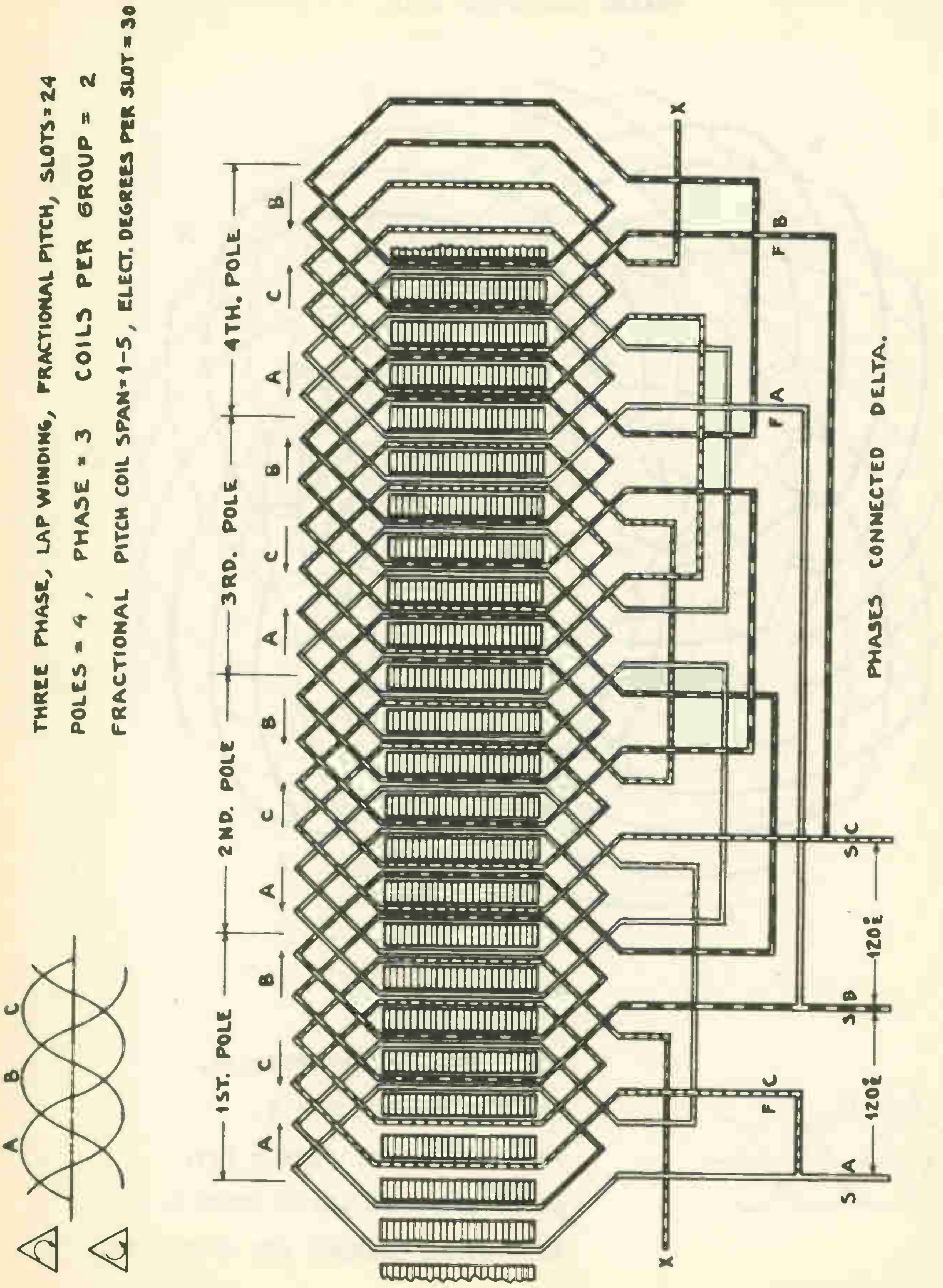
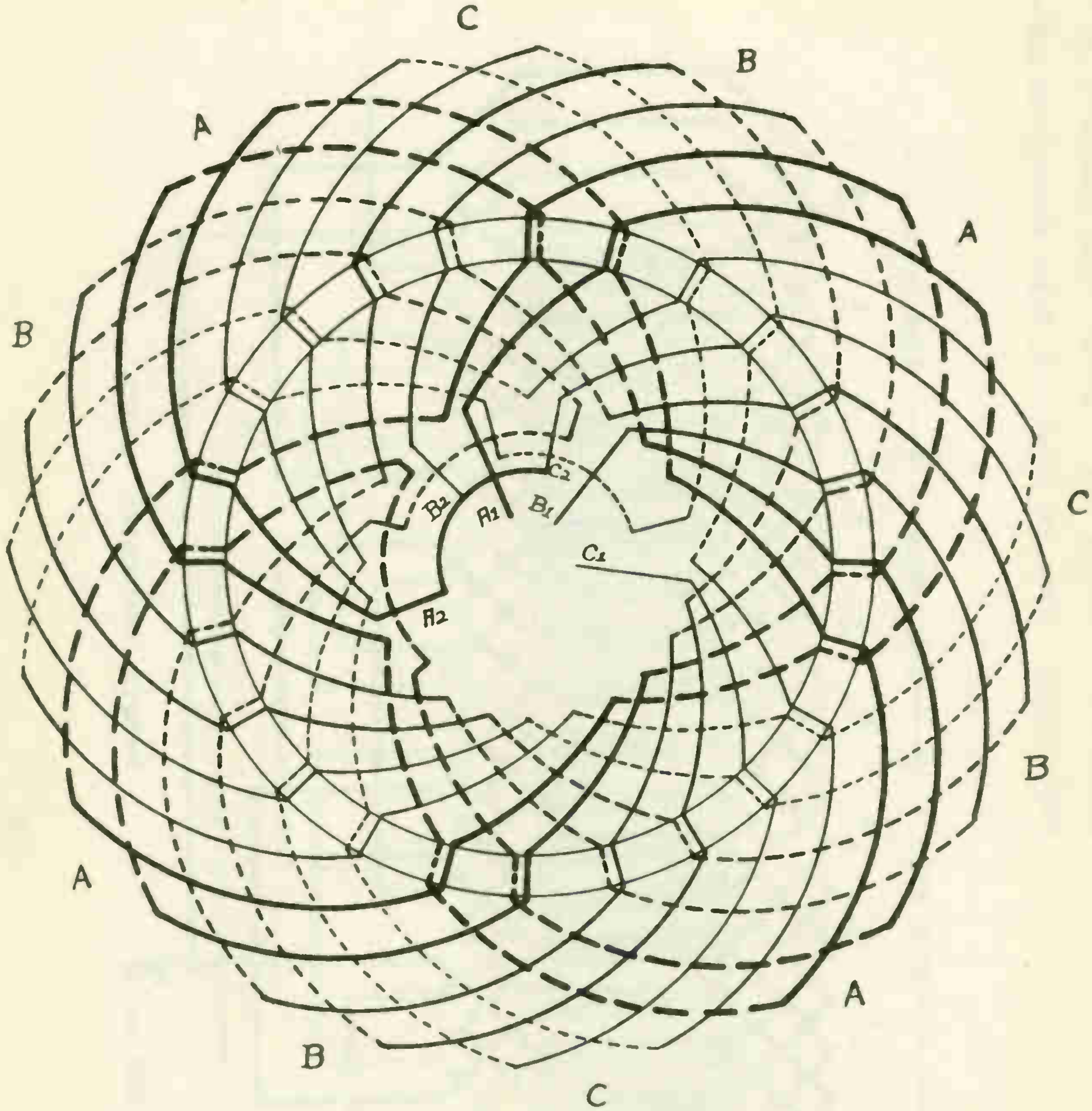
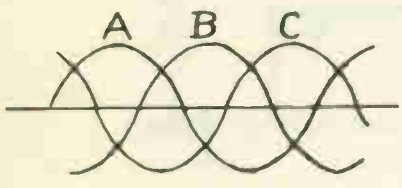

THREE PHASE, LAP WINDING, FRACTIONAL PITCH, SLOTS = 24
POLES = 4 , PHASE = 3 COILS PER GROUP = 2
FRACTIONAL PITCH COIL SPAN = 1-5, ELECT. DEGREES PER SLOT = 30
A
B
C
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
X
F B
F A
F C
S A
S B
S C
120°
120°
PHASES CONNECTED DELTA.

Fig. 6

PHASES CONNECTED STAR.





THREE PHASE, WAVE WINDING.

SLOTS = 24, POLES = 4.

FULL PITCH COIL SPAN = 1:7.

COILS PER POLE PHASE GROUP = 2.

ELECTRICAL DEGREES PER SLOT = 30.

Fig. 7

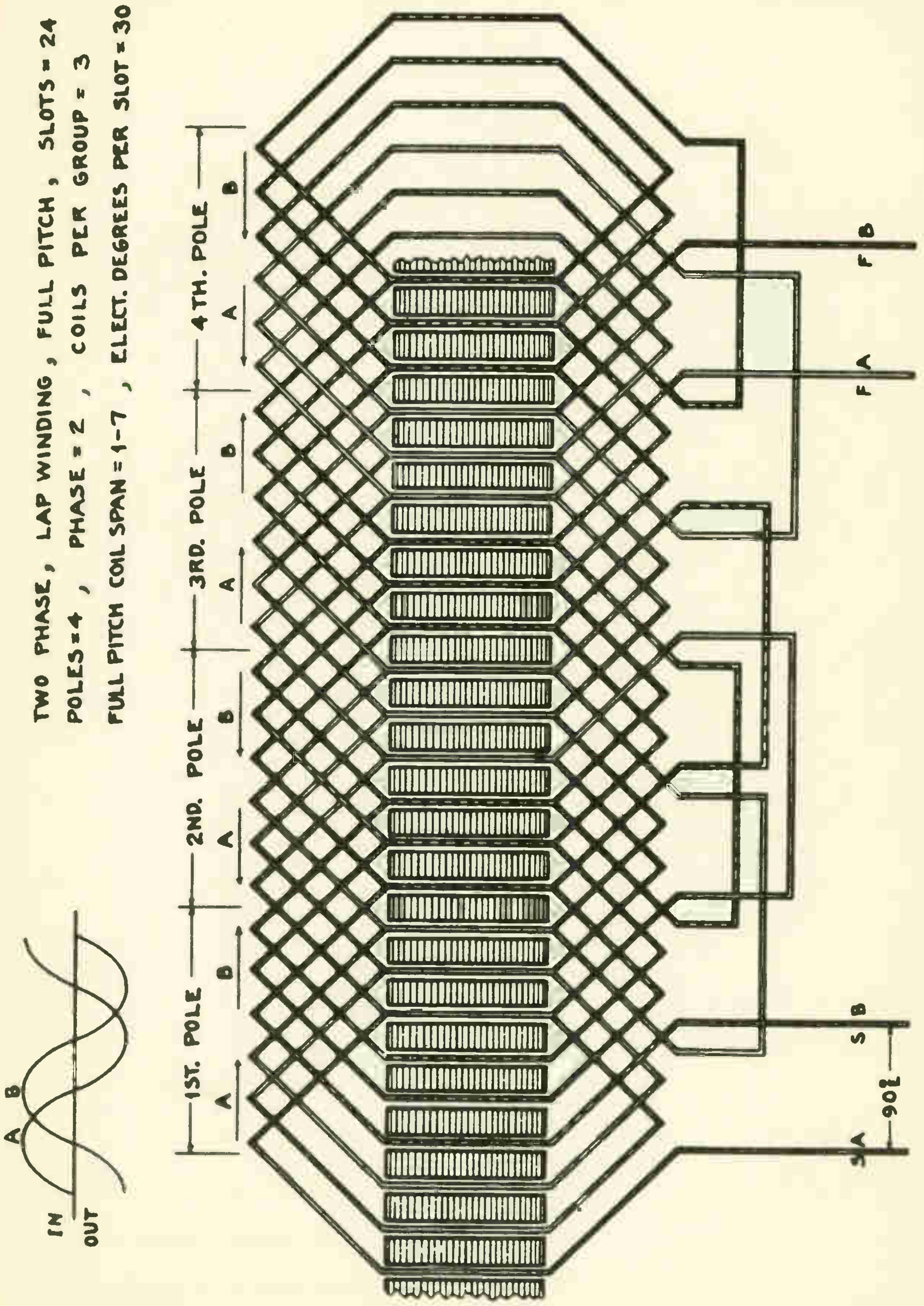

TWO PHASE, LAP WINDING, FULL PITCH, SLOTS = 24
POLES = 4, PHASE = 2, COILS PER GROUP = 3
FULL PITCH COIL SPAN = 1-7, ELECT. DEGREES PER SLOT = 30
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
A
B
IN
OUT
SA
SB
FA
FB
90°

Fig. 8

RECONNECTING A THREE PHASE STATOR

Objectives

1. To learn the development of a three-phase connection diagram.

2. How to reconnect the stator for different voltages.

References

____

____

Lesson Content

A. Review

1. Every third coil-group MUST be connected in the same phase.

   NOTE: The above statement does not say if the coil-groups are to be connected in series or parallel. Either type of connection may be used.

B. Development of Connecting Diagram

1. In lesson number 1, you were instructed on the procedure for winding and connecting a three-phase stator. It was connected series-star. The diagram which was used to enable the winder to connect the coil-groups properly to form the phases was drawn like the Fig. 1.

   Notice that the coil-groups are numbered. You can call any coil-group number one and continue clockwise or counter-clockwise and number the remaining groups. This diagram can be simplified as in Fig. 2.

2. Each heavy line is one coil-group. Let us call the left hand side of coil-group #1 the "top" lead of that coil-group. The top leads on all the coil-groups would correspond.

   The next step is to draw in the arrows on the coil-groups, indicating the direction of current in the coil-groups. Notice that the arrows, on adjacent coil-groups, alternate in direction. If d-c were sent through one phase the adjacent coil-groups in the phase must set up different polarities. By applying the d-c potential in such a manner that all the start leads of the phases are positive, the polarities of the different coil groups would be as indicated by the direction of the arrows in the diagram. Visualizing the development of the stator diagram in the above manner will enable one to quickly place the arrows on the coil-groups.

____

____

3. In actually winding the stator, we choose any top lead from any coil-group and call it the start lead of the first phase. We also call the coil-group, so selected, number "one".

4. We may now complete the diagram by showing the jumper connections. There are two common methods of "connecting the coil-groups in series to form the phases".

   a. The "top-to-top" connection, also called the "short jumper" connection.

   b. The "top-to-bottom" connection, also called the "long jumper" connection.

   When using the top-to-top (T-T), for a straight series star or delta connection, adjacent coil-groups of the same phase are connected in series. When using the top-to-bottom connection, allthe coil-groups of one phase which are south poles are connected in series first and then all coil groups representing noeth poles are connected. The diagram is Fig. 3, when completed is for a top-to-top connection.

   The diagram in Fig. 4, when completed is for a top-to-bottom connection for one phase. The other phases would be connected in the same manner.

   Notice that a short jumper was used between groups 13 and 16 in the diagram in Fig. 4.

C. Changing Operating Voltage of Three-phase Machines

1. General

   a. Very often the maintenance man is confronted with the problem of changing the operating voltage of induction motors. This will permit them to be operated on a different line voltage. This condition may arise when the motors are moved to a different locality where the original voltage is not economically obtainable.

   b. The voltage of any individual motor winding varies directly with the number of turns it has connected in series. Remembering the above simple rule will help solve many problems when making voltage changes on equipment. There are certain practical limits beyond which a change of voltage should not be carried. For example: A winding operating at 220 volts could be changed, possibly to operate on 2300 volts; however, the insulation could not withstand the higher voltage. It is almost always permissible to reconnect a winding to operate on a lower voltage than that for which it was originally designed. When reconnecting a machine to increase its operating voltage, its insulation must always be checked. The usual ground test for the insulation of such equipment is to apply an a-c voltage of twice the machine's rated voltage, plus one-thousand volts. This voltage should be applied from the winding to the frame for approximately one minute.

   c. When a winding is changed for a different voltage it should be arranged so that the voltage on each coil-group will remain unchanged. Complete Fig. 6A and 6B.

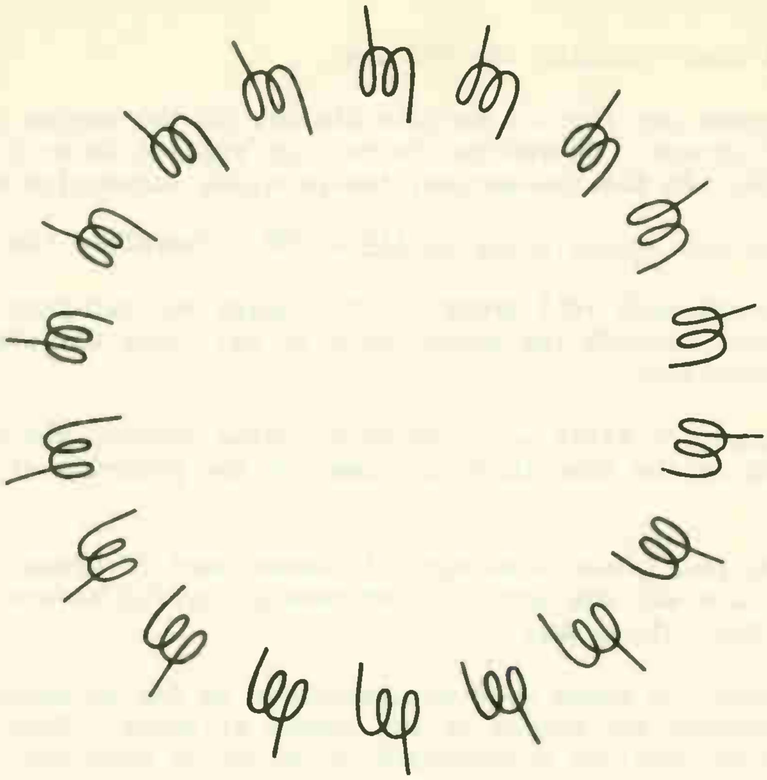


Fig. 1

Fig. 2

2. Effect on current when changing the voltage.

a. The above diagrams are for a four-pole stator. In the series connection we have four coil-groups. Therefore the voltage applied to each coil-group will equal $\frac{220}{4}$ = 55V. In the two-series, two-parallel connection the voltage applied to each coil-group would be $\frac{110}{2}$ = 55V. Therefore the same current would flow through each coil-group. Since there are two parallel paths, the total current through the phase would be two times the current through the series connection.

b. The rotating magnetic field will not be affected because the current through each coil-group is the same in both cases and the polarity of the coil-groups is the same.

c. When connecting poly-phase windings all phases must be connected for the same number of circuits and one should be extremely careful to avoid incorrect polarities on the coil-groups.

d. It is common practice among most manufacturers to design machines that can readily be connected for either of two common voltages. This is accomplished by a series or parallel arrangement which can be more easily understood by comparing figures 7 and 8 after completion. The diagrams are for a three-phase four-pole winding.

D Diagram 7 shows a connection diagram using the TT connection (short jumper). NOTE: Each loop in the simplified diagram of 7 represents one coil-group. Now check diagram 8. Notice that Fig. 7 has twice as many coil groups in series, between the terminal leads, as there are in the connection in Fig. 8. This means that the diagram of Figure 7 can withstand twice the voltage of diagram 8.

e. If any motor the horse-power depends on the number of watts which are developed in its circuit. The watts will vary as the product of the current and the voltage. To maintain the same horsepower of a motor, at one-half its normal voltage, it will have to carry twice as many amperes. By comparing Fig. 7 and 8 we can see that this extra current can be carried by the windings in Fig. 8, Because there are two parallel paths. This means there is twice the cross sectional area of copper in Fig. 8 as there is in Fig. 7.

f. If the number of poles in a machine is evenly divisible by "four" as, for example 4, 8, 12 etc., the winding may be connected in four parallel paths as can be shown in Fig. 9.

By comparing Fig. 9 with the connections in Fig. 7 we can see there are only one-fourth the coil-groups in series as there were originally. Therefore the safe voltage to apply to the winding in 9 would be one-fourth the voltage applied to the series connection.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Fig. 3


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Fig. 4

Fig. 5.

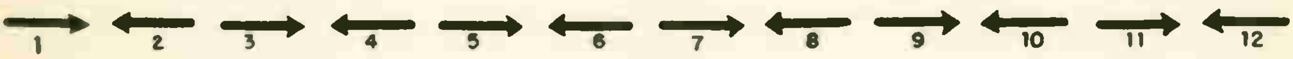


Fig. 6A

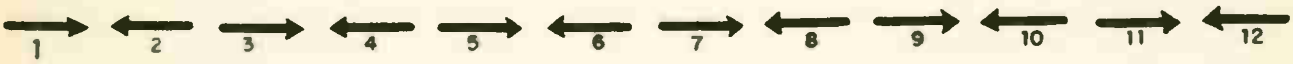


Fig. 6B

Fig. 7

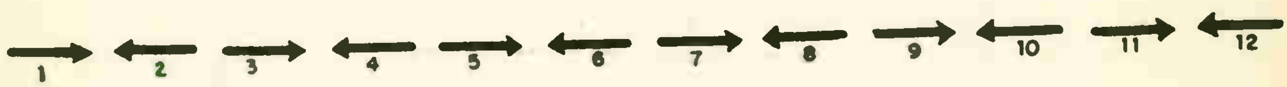


Fig. 8

Before attempting to make such changes in connections, a check should be made to see if the winding can be connected for the desired number of circuits. The rule: "The total number of poles must be evenly divisible by the number of circuits desired".

There are some motors that have a sufficient number of leads coming from them that may be reconnected without disassembling the motor. These will be covered in a later lesson.

Fig. 9

D. Questions

1. Should every third coil-group or every fourth coil-group be connected in the same phase?

2. In developing a connection diagram of a stator, why are the arrows placed on the coil-groups?

3. What are the two standard methods of connecting the coil-groups to form phases?

4. Is it practical to reconnect a winding for a different operating voltage?

5. Does the voltage of a winding vary directly with the number of turns, or the cross-sectional area of the copper?

STATOR VOLTAGE CHANGES

Objective

To learn a procedure of reconnecting for different voltage.

References

____

____

Lesson Content

In a previous lesson, we discussed stator connections for a different voltage. In this lesson we will outline further steps to take when considering practically all possibilities of voltage changes.

A Checking the Insulation

If changing from a high voltage to a lower voltage the insulation check is not too important. As previously explained, however, insulation resistance tests should be made on most apparatus.

When changing to a higher voltage, the insulation must be given careful consideration. Low voltage motors will usually withstand voltages up to 600v.

B. Checking Star and Delta Connections.

A change from a star connection to a delta connection may give the required number of turns, in series, for the new voltage.

Rules:

a. A change from star to delta will decrease the original voltage to 58%.
b. A change from delta to star will increase the original voltage 1.73 times.

The above relationships should be used when figuring any star-delta change, or vice-versa.

For example:

Can we change a 2300 v series star connection to a 440v motor?

$$2300 \times .58 = 1332 \text{ v (Voltage per phase).}$$

A two-parallel connection = $\frac{1332}{2} = 666\text{v}$

A three-parallel connection = $\frac{1332}{3}$ = 444 v

Therefore we may reconnect the motor to a three-parallel delta and use it on a 440v supply.

To be able to change the phases from series to three-parallel, the original motor would have to be designed for a number of poles which is a multiple of three, i.e., six or twelve poles etc.

If a motor is connected star it is possible to reconnect it delta and operate it on one-half original voltage. This should be done only in case of necessity and should be corrected as soon as possible. The starting and maximum torque will be decreased approximately 25%, therefore caution must be exercised when loading the motor.

1. Voltage per coil

   When reconnecting a machine for different voltage conditions, keep the voltage per coil the same value as originally.

2. Stub connections.

   Never parallel the coils in a "coil-group".

   Circulating currents would exist and in a very short time, hot coils would result.

3. Number of parallel paths possible =

   $$\frac{\text{poles}}{\text{paths wanted}} = \text{a whole number}$$

   Also, the whole number obtained from the above ratio will indicate the number of coil-groups which must be connected in series.

   Also, the new voltage will equal the original voltage divided by new number of parallel paths.

4. Checking Chord Factor (fc)

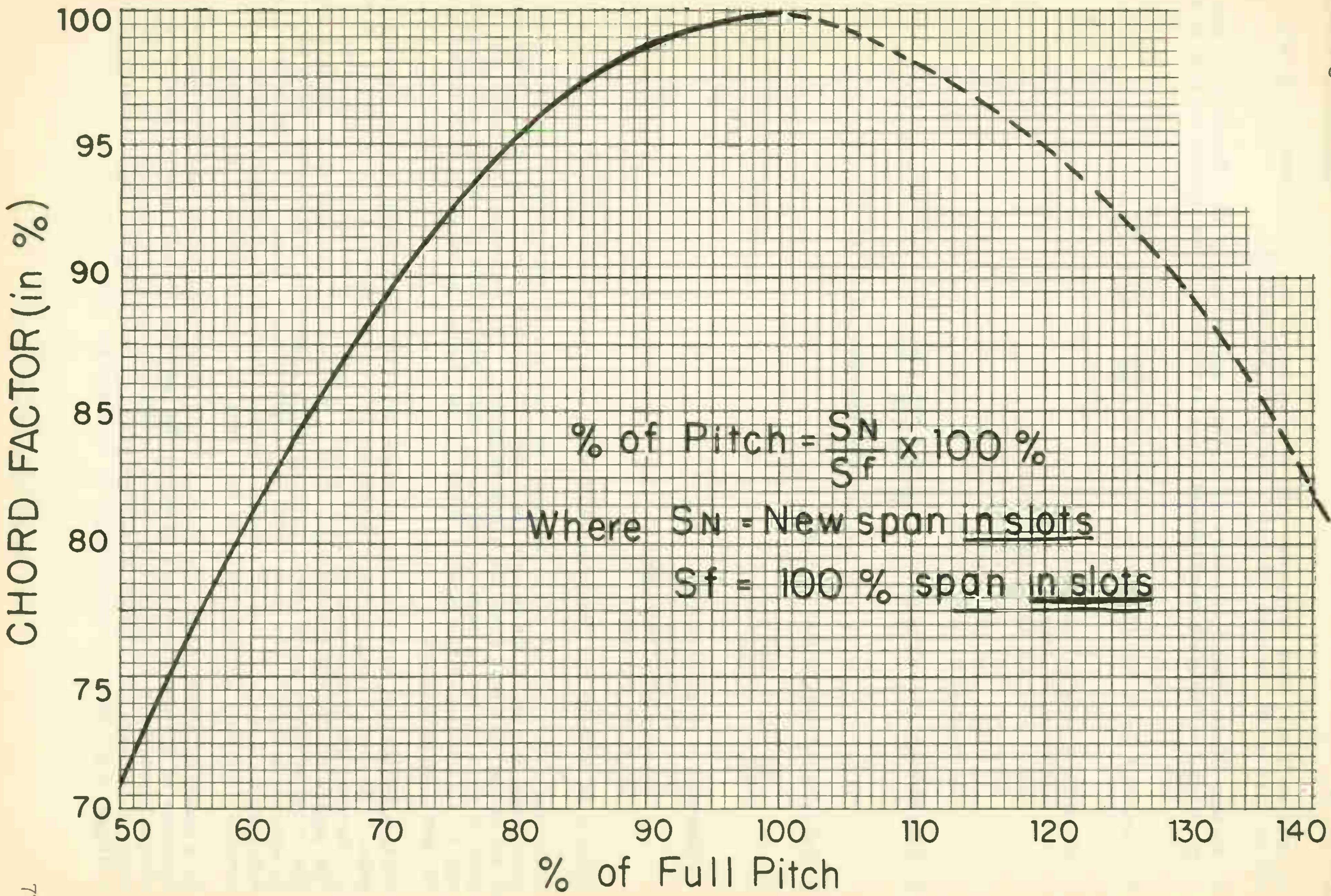
   fc=sin of "½ the angle spanned by the coil"

   $$fc = \left(\frac{Sn}{So} \times 100\%\right) \times 90^\circ$$

5. See curve on the following page.

   A so $\frac{Eo}{En} = \frac{fco}{fcn}$

   Where Eo = original voltage
   En = new voltage
   fco = original chord factor
   fcn = new chord factor.


100
95
90
85
80
75
70
CHORD FACTOR (in %)
50
60
70
80
90
100
110
120
130
140
% of Full Pitch
% of Pitch = SN/Sf x 100 %
Where SN = New span in slots
Sf = 100 % span in slots

In most machines, best operation will be obtained if the pitch does not go below 2/3 of full pitch, however the pitch may go to 50% or 150%.

6. Voltage Limitations - May vary the voltage approximately 5% - Practically all machines are designed to withstand a variation in applied maximum voltage of not over 10%.

7. Turns and Cross-Sectional Area Relations - $\frac{Eo}{En} = \frac{No}{Nn} = \frac{An}{Ao}$

where Eo = original voltage
En = new voltage
No = original turns in series
Nn = new turns in series
An = new area of copper
Ao = original area of copper

8. Considering over-voltages - a. $\frac{\%\text{ slip new}}{\%\text{ slip old}} = \frac{Eo}{En}$

b. pf will decrease slightly

9. Relation of torque and voltage

$$\frac{To}{Tn} = \frac{Eo^2}{En^2}$$

where To = original torque
Tn = new torque
Eo = original voltage
En = new voltage

C. Effects of voltage and frequency variations.

Induction motors are at times operated on circuits of voltage or frequency other than those for which the motors are rated. Under such conditions, the performance of the motor will vary from the standard rating. The following is a brief statement of some operating results caused by small variations of voltage and frequency, and is indicative of the general character of changes produced by such variations in operating conditions.

Voltage variations of 1-per cent on power circuits are allowed in most commission rules. However, changing the voltage applied to an induction motor has the effect of changing its proper rating as to power factor and efficiency in proportion to the square of the applied voltage. Thus a 5 hp motor, operated at 10 percent above the rated voltage, would have characteristics proper for a 6hp motor (6.05 hp to be exact); and at 10 per cent below the rated voltage, those of a 4 hp motor (more exactly, 4.05 hp). It is, of course, obvious that if the rating of a motor were greatly increased in this way, the safe heating would frequently be exceeded.

In a motor of normal characteristics at full rated horsepower load a 10 percent increase of voltage above that given on the name plate would usually result in a slight improvement in efficiency and a decided lowering in power factor. A 10 percent decrease of voltage below that given on the nameplate would usually give a slight decrease of efficiency and an increase in power factor.

The locked-rotor and pull-out torque will be proportional to the square of the voltage applied. With a 10 percent increase or decrease in voltage from that given on the nameplate, the heating at rated horsepower load will not exceed safe limits when operating in ambient temperatures of 40C or less, although the usual guaranteed rise may be exceeded.

An increase of 10 percent in voltage will result in a decrease in slip of about 17 percent, while a reduction of 10 percent will increase the slip about 21 percent. Thus if the slip at rated voltage were 5 percent, it would be increased to 6.05 percent, if the voltage were reduced 10 percent.

A frequency higher than the rated frequency usually improves the power factor, but decreases locked-rotor torque, and increases the speed, friction, and windage. At a frequency lower than the rated frequency, the speed is, decreased; locked-rotor torque is increased; and power factor slightly decreased. For certain kinds of motor load, such as in textile mills, close frequency regulation is essential.

If variations in both voltage and frequency occur simultaneously, the effects will be super-imposed. Thus if the voltage be high and the frequency low, the starting torque will be very greatly increased, but the power factor will be decreased and the temperature rise increased with normal load.

The foregoing facts apply particularly to general-purpose motors. They may not be true in connection with special motors, built for a particular purpose, or as applied to very small motors.

D. Summary Questions

1. How would you check the insulation in preparation for a voltage change?
2. What is the average maximum voltage that may be used on low voltage motors?
3. The phases of a three phase, 440v motor are connected delta. If they are changed to a star connection the new voltage rating should be ____? Is this a standard voltage?
4. What conditions are developed if "voltage per coil"., is kept constant when making voltage changes?
5. Should the coils in a coil group be connected in parallel? Explain.
6. Can a series connected six-pole three-phase motor be changed to a four-circuit machine? Explain.
7. What is "Chord factor"?
8. Is it possible to "chord" more than 2/3 pitch?
9. Should the cross-sectional area of the copper vary directly with the voltage when making voltage changes?
10. What are the torque variations when varying voltage?

RECONNECTING THREE PHASE STATORS

Objective

To learn the factors which must be considered when making changes in rpm, frequency, horsepower, phases, or poles.

References

Lesson Content

A. Frequency Changes.

Since speed = $\frac{\text{frequency} \times 120}{\text{poles}}$, an increase in frequency would result in an increase in speed, Expressed another way $\frac{fo}{fn} = \frac{So}{Sn}$

where fo = original frequency
fn = new frequency
So = original speed
Sn = new speed

Check the drive, i.e., couplings, gearing, etc. See lesson on motor installation for tables on proper belt and gear speeds.

Check the peripheral speed - peripheral speed = $\frac{\pi DS}{12}$

Peripheral speed should not be greater than about 7500-8000 ft. per minute.

If the voltage applied to the machine is varied directly as the speed is varied, the current density will remain the same and consequently the torque will remain the same.

$$\frac{Eo}{En} = \frac{So}{Sn}$$

where Eo = original voltage
En = new voltage
So = original speed
Sn = new speed

Since the horse power = $\frac{\text{torque} \times \text{speed}}{5252}$

the $\frac{HPo}{HPn} = \frac{So}{Sn}$

where Hp = horse power and the subscripts have the same meaning as above.

It is possible that the increase in ventilation, due to increased speed, will not offset the increase in heat developed in the iron. Therefore the heat developed by a converted motor should be checked carefully on a test run.

B. Horsepower Changes.

$$HP = \frac{T \times S}{5252}$$

where HP = horsepower
T = torque
S = speed in rpm

therefore the torque or speed may be varied to obtain a change in horsepower.

If torque is varied

$$\frac{To}{Tn} = \frac{Hpo}{Hpn}$$

where To = original torque
Tn = new torque
HPo = original horsepower
HPn - new horsepower

$$\text{Then } Tn = \frac{To \times HPn}{HPo}$$

Since the torque varies as the square of the applied voltage,

$$\frac{To}{Tn} = \frac{Eo^2}{En^2}$$

From this expression you may find the new voltage. If a voltage change is then necessary - see lesson 9.

C. Speed Changes.

$$\text{Since speed} = \frac{\text{frequency} \times 120}{\text{poles}} =$$

$S = \frac{f \times 120}{p}$, we would have to change either the frequency or the number of poles.

D. Phase Changes.

The best method to use when attempting to change a two-phase motor to three-phase, or vice versa, is to reconnect by regrouping. This involves checking the layout of the original motor and taking complete data, determining the voltage per coil on the original motor, laying out the new winding (different number of phases), and determining the voltage per coil on the new phase which will develop the same torque. The resulting voltage will not be, usually, a standard voltage and to make the proper voltage change, refer to lesson No. 9.

A two-phase motor has approximately 125% the number of turns in series as a series star, three-phase motor of the same characteristics. It is possible, when changing from two-phase, to cutout 20-25% of turns. This results in a decrease in horsepower, and final results are not too satisfactory.

E. Torque Changes.

The torque varies as the square of the applied voltage.

$$\frac{To}{Tn} = \frac{Eo^2}{En^2}$$

which leads us directly to considering voltage changes which were given in lesson No. 9.

F. Summary Questions

1. Does the synchronous speed of a three phase motor vary directly with the number of poles?

2. What is the safe peripheral speed of the average motor?

3. How may peripheral speed be determined?

4. Is the synchronous speed of a three phase machine equal to $\frac{\text{frequency x 120}}{\text{poles}}$?

5. Does a three-phase, series star connected motor have the same number of turns as a two-phase motor of the same characteristics?

6. What must be considered when changing motors if the torque is to remain the same?

RECONNECTING A STATOR FOR A DIFFERENT NUMBER OF POLES

Objective

To reconnect a stator to obtain a different speed.

References:

Lesson Content

A. Procedure and Factors to be Checked

1. General

a. The primary purpose of any motor is to produce torque. When torque overcomes the inertia of the rotor a speed, measured in RPM, is developed. Consequently work is done. The rate at which the work is done is called power, (horsepower).

b. When reconnecting a motor for voltage changes, the current through the coil-groups, is not changed. The flux density in the air gap does not change, therefore performance does not vary from one voltage connection to another

c. Torque is developed due to a current through a conductor that is surrounded by a magnetic field. Therefore the maximum torque of any motor is limited by the capacity of the conductors to carry current and the capacity of the iron to carry flux, without exceeding a safe value of temperature. The mechanical and electrical properties of copper and iron are available for the designer, allowing him to develop a motor to a point of maximum efficiency, to give most satisfactory performance.

d. It is advisable that when making changes in an induction motor, the changes should be made in such a manner that the current density and flux density will remain approximately the same. Consequently the torque will remain the same. Therefore the horsepower will vary with any change in speed, because

$$HP = \frac{T \times speed}{5252}$$

2. Chording the winding

a. To find the full pitch coil span in an a-c machine, we should divide the slots by the poles and add one, i.e.

$$\text{Full pitch coil span} = \frac{\text{slots}}{\text{poles}} + 1$$

If the above equation is used on a certain problem and the result is the number "ten" this would mean that one side of the coil would lie in slot "one" and the other side would lie in slot "ten" or the equivalent (4 to 13) or 7 to 16).

b. It is possible that the finished coils might be too small. In this case the coils would be placed in slots which would represent a span less than full pitch. This would be called "fractional pitch". It is also possible, on a hurry-up job, that you might have to use coils a little too large to be placed in slots equivalent to full pitch, and they would span a greater number of slots than full-pitch span. When windings are placed in a machine in either manner mentioned above, they are called "chorded windings".

c. The chord factor is the percentage of voltage generated in the coils as compared with 100% pitch. It is equal to the sine of one-half the angle, in electrical degrees, spanned by the coil.

Chord factor = sine (P x 90°)
where P = % of pitch and the % of pitch is found

by $\frac{\text{new span in slots}}{\text{full span in slots}} \times 100\% = \frac{Sn}{Sf} \times 100\%$

NOTE: Span in slots for 100% coil span = $\frac{\text{slots}}{\text{poles}}$.

To enable the student to determine the effect of a chorded winding on the voltage of a machine, a curve has been plotted, Fig. 1. This will save time and will be found a simple procedure.

Example: A three-phase, thirty-six slot stator is to be wound for six-poles.

100% span = $\frac{\text{slots}}{\text{poles}} + 1 = \frac{36}{6} + 1 = 7$

Let us imagine that the coils are too small and would not cover such a span properly and it is necessary to "drop them back" two slots. What is the effect on voltage?

% of pitch = $\frac{Sn}{Sf} \times 100\% = \frac{4}{6} \times 100\% = 66.6\%$

Refer to the chart and find 66.6% on "% of pitch side" and trace to curve. By referring to the other side of chart you can find the value of 87%. This means that the winding is good for only 87% of voltage that it would be good for if it was full pitch.

Using the same stator and the same poles with a pitch from slot "one" to slot "six".

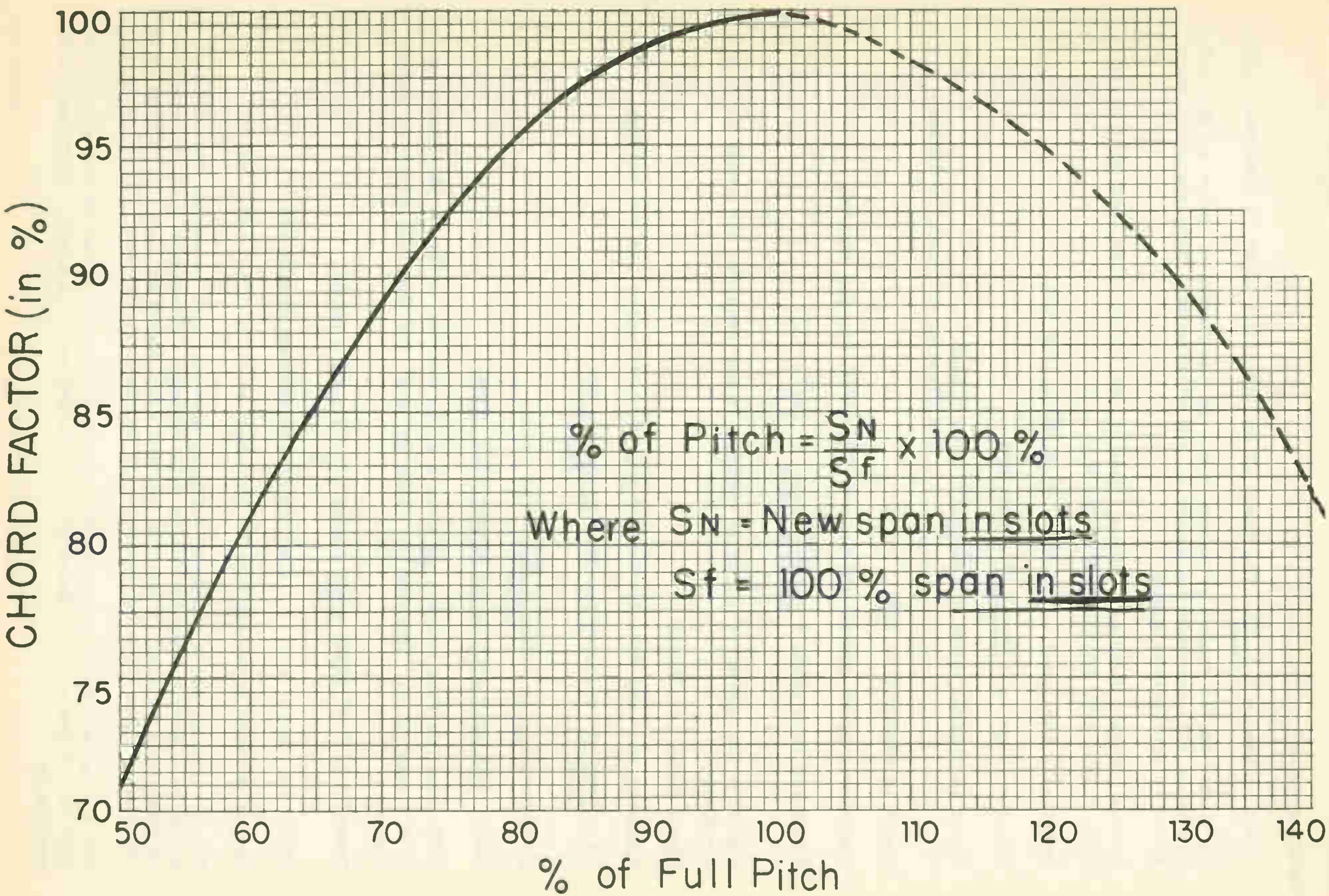
$\frac{5}{6} \times 100\% = 83.3\%$ (see chart)

% of E generated = 96.5%

e. There are several advantages to be gained by the use of chorded windings.

Less copper,	Shorter coils
Improved winding performance	Improvement of operating conditions on Several types of machines.

The above list represents some of the advantages. You can use a fractional pitch down to 50% or a pitch greater than full pitch up to 150%, however, the overall efficiency of operation will be best if the pitch is 66.6% (two thirds) or more.


CHORD FACTOR (in %)
100
95
90
85
80
75
70
50
60
70
80
90
100
110
120
130
140
% of Full Pitch
% of Pitch = SN / Sf x 100 %
Where SN = New span in slots
Sf = 100 % span in slots

3. Changing poles

a. Since - speed = $\frac{f \times 120}{poles}$, The speed of an induction motor is inversely proportional to the number of poles, i.e., if the number of poles is doubled, the speed will decrease to one-half, and vice-versa. This statement pertains to synchronous speed.

b. Let us change a 6-pole, 3-phase, 36-slot, 60 cycle, 3-HP, 440 volt stator Fig. 3 to a four pole stator, Fig. 4.

Originally the speed = $\frac{f \times 120}{P} = \frac{60 \times 120}{6}$ = 1200 RPM

Speed at 4-poles = $\frac{60 \times 120}{4}$ = 1800 RPM

Check peripheral speed = $\frac{\pi\ D\ speed}{12}$ π = 3.1416
D = diameter of rotor in inches

Speed is measured in RPM

Peripheral speed should not be over 7500-8000 ft. per minute.

Coils per coil-group = $\frac{slots}{poles \times phase} = \frac{36}{4 \times 3} = 3$

Any time the number of poles is changed in any machine, the coils have to be re-grouped.

Check phase insulation.

Assuming the same flux in the air gap, we will solve for new voltage.

$\frac{En}{Eo} = \frac{Speed\ n}{Speed\ o}$ transposing, En = $\frac{Speed\ n \times Eo}{Speed\ o}$

Substituting: En = $\frac{1800 \times 440}{1200}$ = 660 volts.

NOTE: <u>the coil span is no longer 100% pitch.</u>

100% span for four poles = $\frac{36}{4}$ plus 1 = 10. but the coils in the stator only have a span of 7. The span in slots is "six" and for 100% pitch it should be "nine".

Therefore, % of pitch = $\frac{Sn}{Sf}$ x 100% = $\frac{6}{9}$ x 100% = 66.6%

Check the chart, Fig. 1. The percent of voltage equals 87%.

Proper voltage to be applied to the motor = .87 x 660 = 574.2 volts.

574.2 volts is not a standard voltage, however, let us assume that we do have a tap on a transformer to obtain this voltage. The motor will now operate at same flux density in the air gap and will therefore develop approximately the same torque. The horsepower will be greater, because HP = $\frac{T \times speed}{5252}$

The torque value has not changed, but, the value of speed in the above equation has increased and therefore, the horsepower increases. Expressed mathematically -

Fig. 2

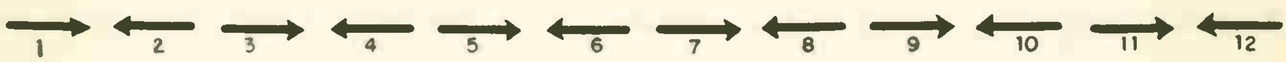


Fig. 3

$$\frac{HP_1}{HP_2} = \frac{Speed_1}{Speed_2} \quad \text{transposing} \quad HP_2 = \frac{HP_1 \times Speed_2}{Speed_1}$$

$$HP_2 = \frac{3 \times 1800}{1200} = 4.5 \text{ horsepower}$$

It would be advisable to change the chord of the winding so the motor could operate properly on 550 volts, which is a standard voltage. If this was not possible, you could vary the number of turns in series, in the motor, for the voltage change necessary.

It is not advisable to change most motors from a high number of poles to a lower number, due to increase in flux density in the stator yoke, however, it is usually permissable to change to a higher number of poles.

B. Troubles.

1. Wrong connection when regrouping coils.

2. Too high peripheral speed.

3. Mistakes in calculations

4. Machine operates hot due to too high flux density in the stator yoke.

5. Watch insulation on any voltage changes from a low value to a higher value.

C. Testing and Repair

1. After completing the winding, follow the same test procedure which was presented in lesson number 2.

2. Watch carefully when making the installation. Check the temperature rise under operating conditions.

3. The maintenance on a reconnected machine is the same as applied to any induction motor, lesson No. 2.

D Summary Questions

1. Does the synchronous speed of an induction motor vary directly with the frequency of the applied voltage?
2. If you regroup the coils in a motor, for a lower number of poles, the frequency increases. True or False.
3. If you regroup the coils in a motor for a higher number of poles, the speed will increase. True or False.
4. Would you be correct in saying "the torque is a result of horsepower", or would you be correct in saying "the horsepower is a result of torque?"
5. What causes a torque to be developed?
6. What is "chord factor"?
7. Will a decrease in chord factor, decrease the voltage rating of a machine?
8. What advantages are gained by the use of chorded windings?

POLYPHASE MOTOR PRINCIPLES AND CHARACTERISTICS

Objective

To become familiar with the three phase motor, its characteristics, and the principles of operation including slip, squirrel cages, torque, rotor - stator frequencies, etc.

References

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Lesson Content

A. General

In previous lessons, we learned that an AC motor stator produces a revolving magnetic field, the rpm of which is proportional to the frequency, and inversely proportional to the number of poles.

$$RPM = \frac{\text{frequency} \times 120}{\text{poles}}$$

In following discussions the various parts and characteristics will be discussed in detail.

B. The Rotor

The rotor or squirrel cage winding of induction motors has no electrical connections made to the supply lines. Energy reaches that winding by electromagnetic induction through the medium of the stator field. The transference of this energy is affected by the type of fields in stator and rotor and the air-gap between rotor and field. One cause of excessive vibration of a motor is worn bearings which make the air gap around the rotor unequal, thereby causing unequal transfer of energy.

1. Voltages induced in the rotor cause the circulation of currents in the squirrel cage. These currents establish magnetic fields which in turn produce rotor poles which are equal in number to the number of stator poles.
2. Reaction between stator and rotor poles develops a twisting effort called torque. The attraction and repulsion of rotor and stator poles is the cause of rotor rotation.

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C. Slip

Since rotor energy is transferred from stator by induction, the stator field must overspeed the rotor. (The rotor speed must be less than the stator field). The difference between stator field and rotor rpm is known as slip. The average full load slip for industrial motors varies from 2% to 8%. Slip is also a measure of the losses in the rotor windings, which in the following example is approximately 3.33% of the total power input which is lost in the heating of the rotor. This indicates a definite relationship between slip and the efficiency of the motor. Increased slip increases the rotor losses, and decreases the motor's efficiency.

EXAMPLE: Suppose we take an example of a 4 pole motor-60 cycle, where the name plate shows on RPM of 1740. Calculating speed by the formula $RPM = \frac{f \times 120}{poles}$ indicates a speed of 1800 RPM for the stator field. The slip is 1800 - 1740 or 60 RPM.

$$\% \text{ of Slip} = \frac{N - N2}{N} = \frac{1800 - 1740}{1800} = \frac{60}{1800} = .0333 \text{ or } 3.33\%.$$

Thus, we see 3.33% is the slip of the rotor at full load with respect to the stator field.

N = Stator Field RPM
N2= Rotor Field RPM

D. Rotor Frequency

The frequency of rotor currents depends upon slip. If the rotor of the motor is not rotating, and the stator is energized by 60 cycle energy, frequency of rotor currents is the same as the line frequency.

$$F2 = sf$$

where:
- f2 = rotor frequency
- s = slip in RPM
- f = stator frequency

At standstill, slip = 1 or 100%

$$f2 = sf = 1 \times 60 = 60 \text{ cycles per second}$$

By the same reasoning we deduce, f2 at $\frac{1}{2}$ of synchronous speed when s = .5

$$f2 = sf = .5 \times 60 = 30 \text{ cycle per second}$$

At full load slip, f2 = sf = .0333 x 60 or 1.998 cycles per second.

From the foregoing we have learned that rotor frequency (f2) depends upon slip, and will have an important bearing upon the operating characteristics of the induction motor.

Also that the value of induced rotor voltage depends upon slip. It is of maximum magnitude at rotor standstill (S=1) resulting in maximum magnitude of current circulating in the squirrel cage rotor winding. This causes the stator winding to draw excessive current from the supply line. As the rotor accelerates, the rate at which the stator field cuts the squirrel cage bars is reduced, and produces a

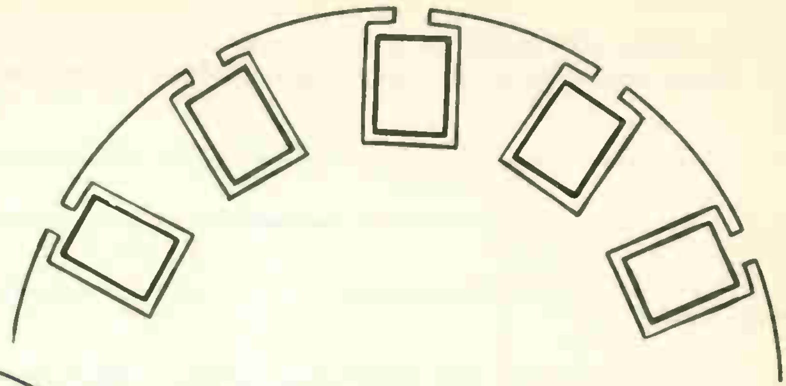

Fig. 1

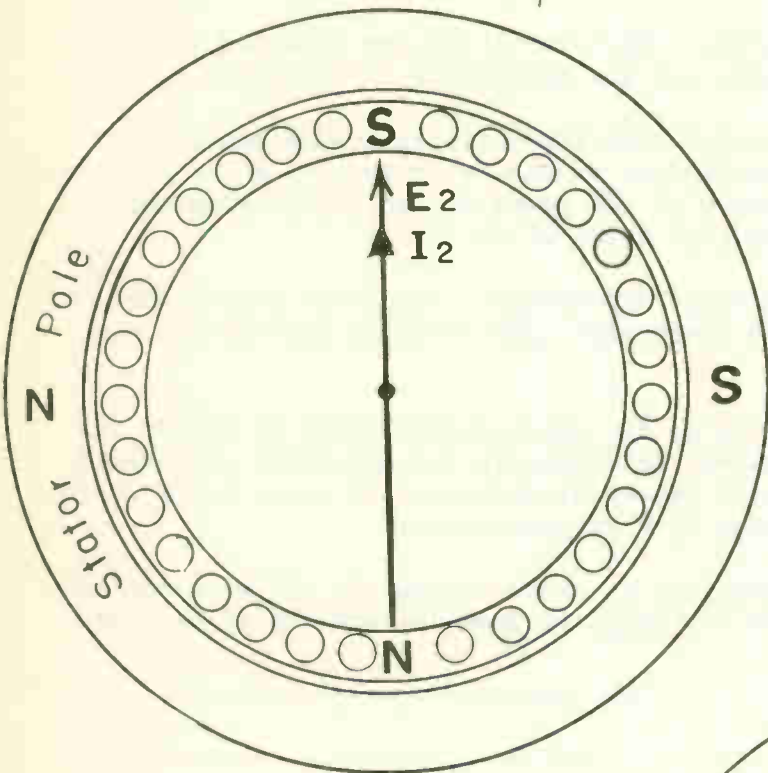

Fig. 2

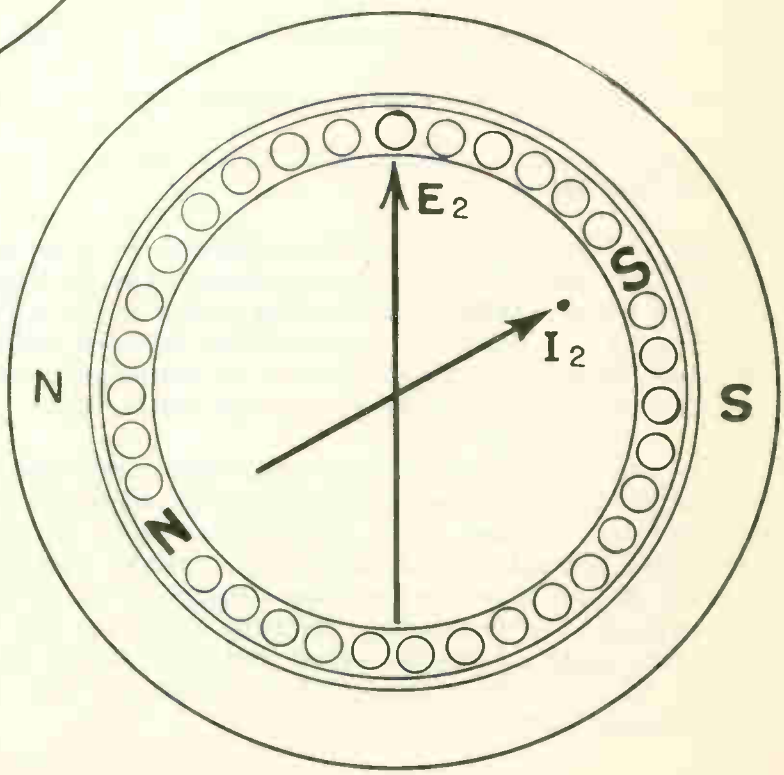

Fig. 3

corresponding decrease in rotor voltage. This of course, reduces the rotor to a value which will satisfy the existing operating condition.

E. Rotor Design

The starting torques and starting current characteristics are obtained by the different designs of rotor slots and bars, and the resistance of the rotor windings.

In Fig. 1, the rotor bars are constructed with low resistance windings and are placed close to the outer surface (periphery) of the rotor to give a low reactance and low slip at a rated load. Reactance of the rotor may be high during the starting periods, however, due to the high value of f2.

Starting torque may be $1\frac{1}{2}$ or 2 times full load torque, with about 5 to 7 times full load current. It is customary to start this type motor at reduced voltage to avoid an excessive current.

The starting torque is greatly affected by the space relationship of stator and rotor poles. Fig. 2 illustrates an ideal relationship not generally obtainable due to the reactance of the rotor which causes displacement of rotor E and I. In actuality, the current lags the voltage by a varying degree.

If stator and rotor poles have the position as shown in Fig. 2, all reaction between them will produce useful effort or torque to promote rotation of the rotor.

F. Rotor Reactance

Since the frequency of rotor currents is high during the starting period, the inductive reactance of the squirrel cage is high and causes the current to lag in the rotor, thus establishing rotor poles at a position such as illustrated in Fig. 3. A part of the reaction between stator and rotor poles is directed to the center of the shaft and is therefore, useless. It does not contribute to the useful torque developed by the motor.

It is now apparent that the starting characteristics of the induction motor will be determined by the relationship between the resistance and the inductance of the rotor winding, since resistance tends to cause "in phase" conditions and inductance tends to cause "out of phase" conditions of voltage and current. As the rotor accelerates, the frequency of rotor current is reduced to normal operating slip frequency, thereby reducing the reactance of the rotor winding and the angle of displacement between E2 and I2. Since the frequency of I2 will never be reduced to zero, I2 will thereby lag E2 by a small angle under normal operating conditions.

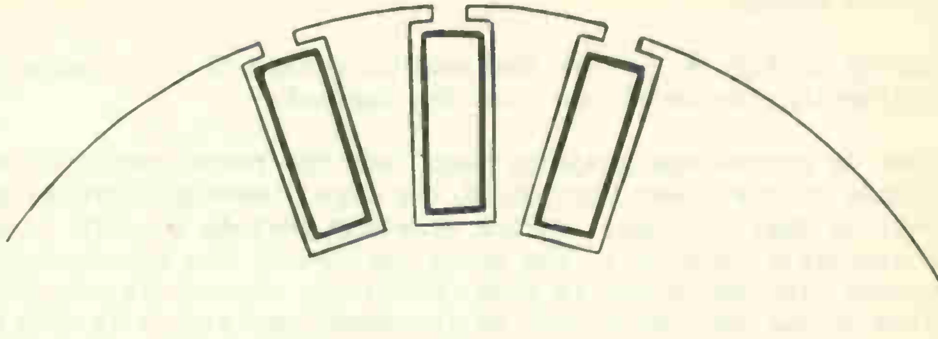

Fig. 4

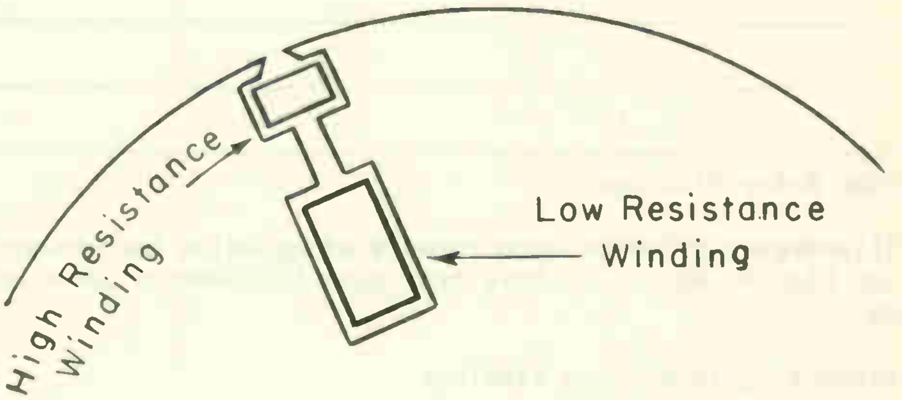

Fig 5

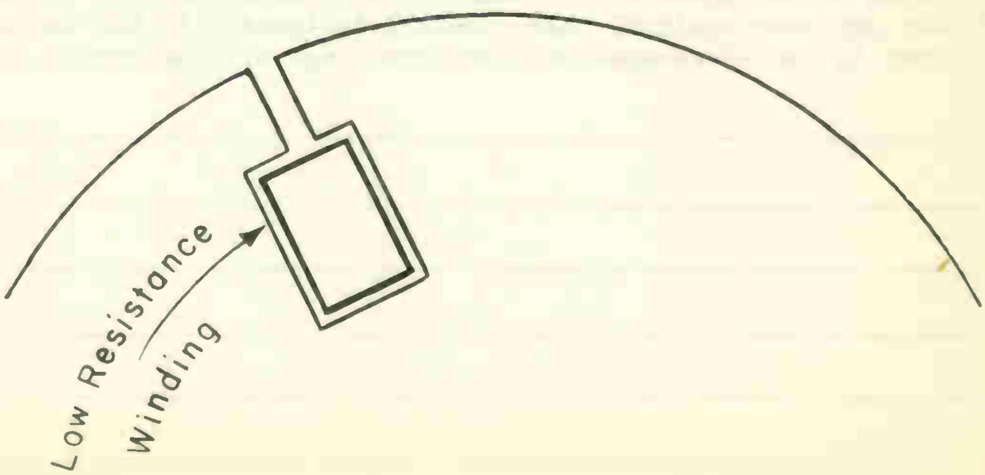

Fig. 6

G. Rotor Bar Design

Referring to Fig. 4, we see the general design of rotor bars required to produce high starting torque at low starting current.

The bar is narrow and projects deep into the rotor core. This results in a higher reactance in the lower portion of the bars, thereby increasing the impedance to current in that section. During starting periods when f2 is high, rotor currents will circulate largely in the upper portion of the bar where reactance is low; therefore, the impedance is less. Since the current is circulating through a small portion of the bar, an effect of increased resistance is obtained, which tends to decrease the angle of displacement between E2 and I2. This results in a more favorable space relationship between the stator and the rotor poles and produces greater useful starting torque, even at a low current. Starting torque is about 3 times full load torque, with about 3 to 4 times full load current. This type of motor can generally be started at full voltage. The slip at full load is relatively low resulting in good speed regulation and comparatively high efficiency. Current density is more or less uniform in the entire bar at normal full load slip frequency.

H. Double Cage Rotor Windings

Fig. 5 illustrates a double cage rotor winding which has characteristics similar to that of Fig. 4. Motors of this type used in elevator service are very quiet in operation.

I. Low resistance Squirrel Cage windings

Fig. 6 illustrates a low resistance winding placed to give high reactance during the starting period. It will develop low starting torque, but draws low starting currents. Slip is relatively low at full rated load. This design may be found in motors up to and including 40 horsepower, because of starting current requirements.

J. Summary Questions

1. Which of the squirrel cage designs will give greatest starting torque?
2. Why are some squirrel cage windings designed with two sections, Fig. 5?
3. What is the advantages of a squirrel cage winding over a phase wound rotor?

CONSEQUENT POLE MOTORS

Objective

To study the development of multi-speed winding diagrams, the operating characteristics of multi-speed motors, and to become familiar with standard terminal markings.

References

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Lesson Content

A. Application and Classification

1. Multi-speed motors are manufactured in two general types.

a. The single winding motor
b. The multi-winding motor (two or more windings)

The above motors will give from two to four different speeds. When the connections to the line are changed, to develop a different speed, the operating characteristics of the multi-speed motors will change.

NOTE: Fundamentals of consequent pole windings are shown in Fig. 1. These motors are in turn, sub-classified as:

1. Constant horse-power motors, (Fig. 2-C and Fig. 3)

With this motor, the horsepower ratings will be the same at all speeds, The principal uses for this motor are on machine tools such as lathes, boring machines and mills, planers and radial drills.

Connections

SERIES DELTA 4 POLE
T6 T4 T5 to lines 1 2 3 Respectively
T1 T2 T3 open

PARALLEL STAR 8 POLE
T1 T2 T3 to lines 1 2 3 Respectively
T4 T5 T6 together

This connection, Fig. 3, gives practically constant horsepower, that is, the maximum horsepower of both speeds is practically the same.

2. Constant Torque Motors (Fig. 2-B and Fig. 4)

With this type of motor, the horsepower ratings at each speed are directly proportional to the speed. For example, 20/10 Horsepower motor would have speed ratings of 1800/900 RPM.

The principal uses for this motor are conveyer, stoker, reciprocating compressor printing press, and other constant torque loads.

Connections

SERIES DELTA 8 POLE	PARALLEL STAR 4 Pole
T1 T2 T3 to Line	T6 T4 T5 to Line
T4 T5 T6 open	T1 T2 T3 together

Group connections in a constant torque motor differ from these of a constant Horsepower motor in that, half of each phase is reversed. When the constant torque type is connected parallel star, 4 poles are produced, giving a field speed of 1800 RPM. When connected series delta, 8 poles are produced and field speed is 900 RPM, Fig. 4.

3. Variable Torque Motors (Fig. 2A and Fig. 5). At each speed, the horsepower of this motor is proportional to the square of the speed, for instance, a motor rated at 20/5 Horsepower will have speed ratings of 1800/900 RPM. They are used on loads such as centrifugal pumps and fans where horsepower requirements decrease at least as rapidly as the square of the reduction in speed.

a. Connections

SERIES STAR 8 POLE	PARALLEL STAR 4 POLE
T1 T2 T3 to Line	T6 _T4 T5 to Line
T4 T5 T6 open	T1 T2 T3 together

b. Applications

Fans and blowers require an increase in both torque and horsepower when the speed is increased.

A parallel star connection on this motor doubles the voltage per turn or per coil, the current drawn on torque developed will be about two times as great, resulting in about 4 times the horsepower output with respect to the lower speed, Fig. 5.

4. Multispeed motors (Figs. 6 and 7)

Multispeed Motors of the constant torque or variable torque types are usually given a standard horsepower rating at the top speed, but may have odd horsepower ratings at the lower speeds, since the later are fixed by speed ratios.

a. The single winding motor is most common and it develops a "two to one" speed ratio.

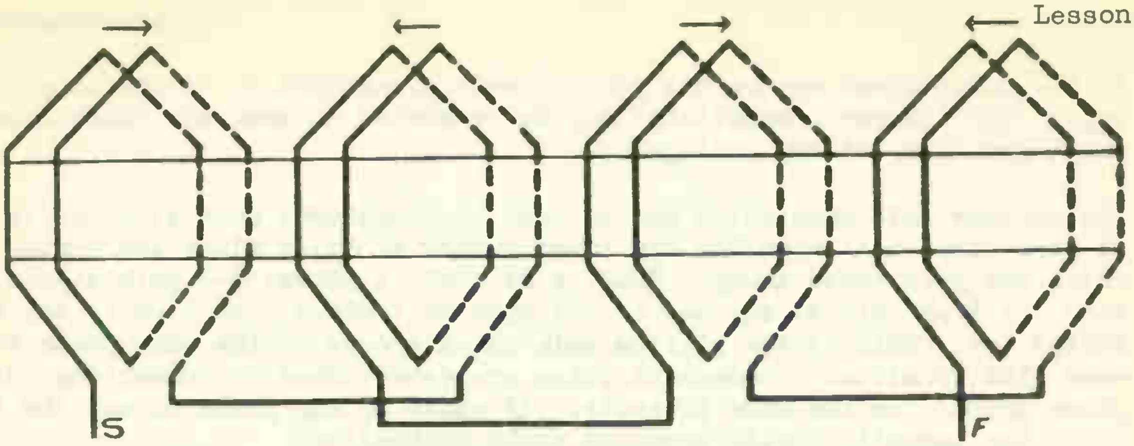
b. Variable torque motors are many times used to replace a slip ring motor which will be discussed in detail in a later chapter.

B Construction and Operation

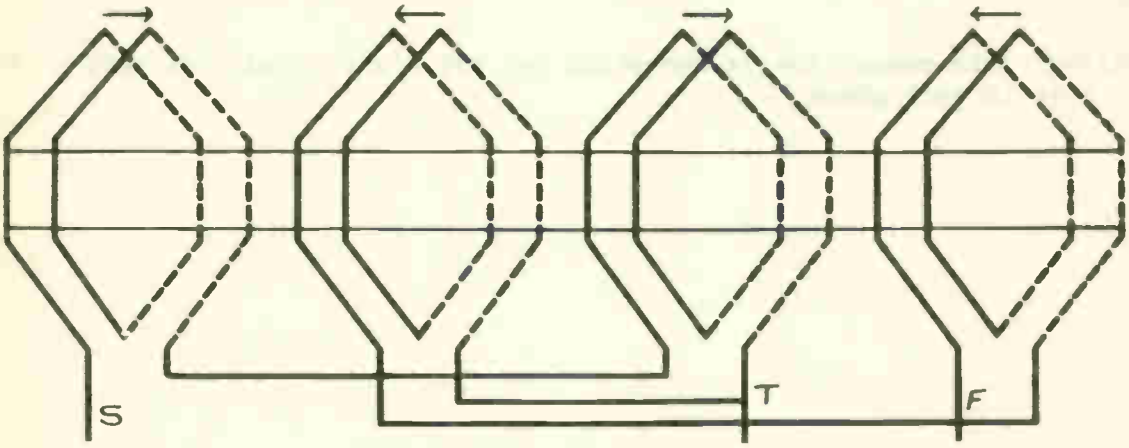
1. The single winding multi-speed motor.

Most single-winding multi-speed motors have six leads. The manner in which the leads are connected to the line will determine the speed of the motor.

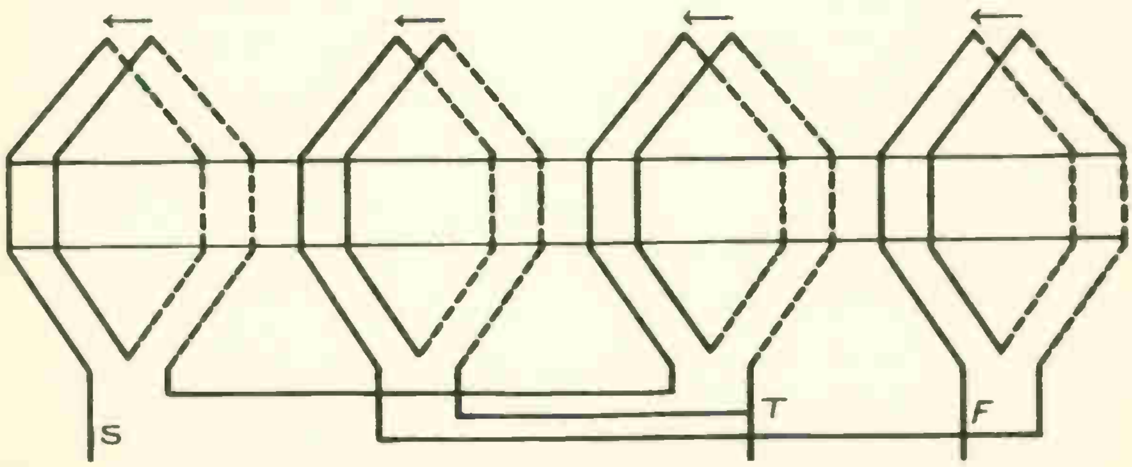
2. In developing a diagram of this kind, or in actually placing the winding in the stator, there are a few rules that must be observed.



Slots = 24, Poles = 4, Fractional Pitch Coil Span = 1 to 5.
"A" Phase only of a 3 phase winding illustrating common method of short jumpers. (Top to Top, Bottom to Bottom) Trace the circuit and mark the polarities in the proper position. This type of jumper connection is not suitable for consequent pole windings.



"A" Phase only of 3 phase winding illustrating long jumper method of connection. (Top to Bottom, Bottom to Top) Trace the circuit for 4 poles disregarding the center tap, and mark the polarities in the proper position. Note that the poles are established in the same position as for the common method of connection.



Same connection as shown above. Trace the circuit from the center tap. This places the 2 sections of the phase winding in parallel, reversing the current in ½ of the coil groups, producing 4 regular & 4 consequent poles. Note that phase rotation is reversed and it will be necessary to reverse 2 leads on this connection to obtain the same rotor rotation.

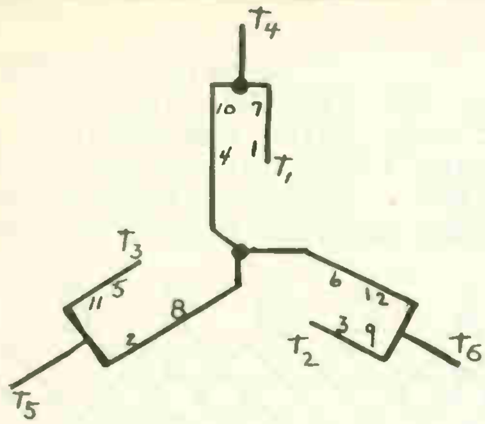
a. In all multi-speed motors the jumper connections must be of the long-jumper type. The "jumper connections" may be construed to mean the connections which are made between coil-groups.

b. The maximum coil span which may be used in consequent pole windings is equal to full pitch coil span for the lower number of poles minus the number of coils per pole phase group. Thus, a 24 slot, 3 phase, 4-8 pole stator, coil span 1:7 (full pitch) may use a coil span of 7 minus 2 or 5 or it may be stated 1:5. This avoids placing pole phase groups of the same phase in the same slot or slots. Consequent poles are established by connecting pole phase groups for the same polarity. If coils or any phase occupy the same slot, the magnetic fields produced would neutralize.

3. Definitions

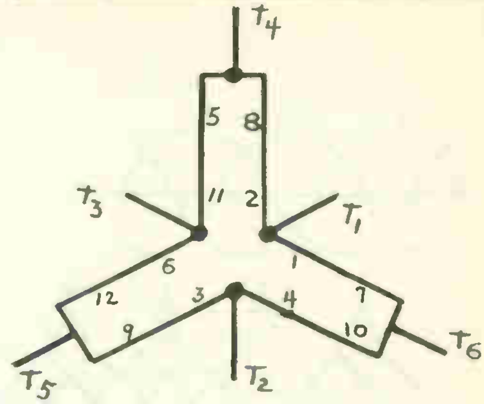
a. A consequent pole connection is one wherein one coil-group forms two magnetic poles, thereby, developing twice as many poles as there are coil-groups per phase.

b. A salient pole connection is one which has one magnetizing "coil-group" for each pole in each phase.



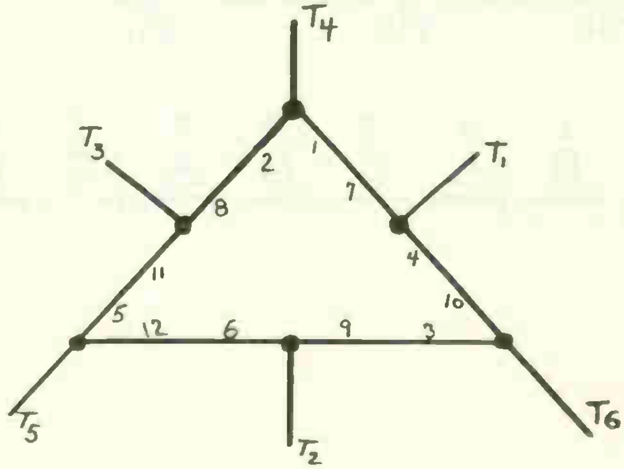
Speed	L1	L2	L3	Open	TIE TOGETHER
Low					
High					

Fig. 2A



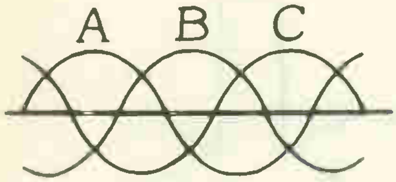
Speed	L1	L2	L3	Open	TIE TOGETHER
Low					
High					

Fig. 2B



Speed	L1	L2	L3	Open	Tie Together
Low					
High					

Fig. 2C



CONSTANT HORSEPOWER.
3 PHASE, LAP WINDING, SLOTS= 24.
POLES = 4-8, COILS PER GROUP = 2.
FRACTIONAL PITCH COIL SPAN = 1 TO 5.
COIL PITCH = 66.6% OF FULL PITCH.
ELECTRICAL DEGREES PER SLOT = 30-60.

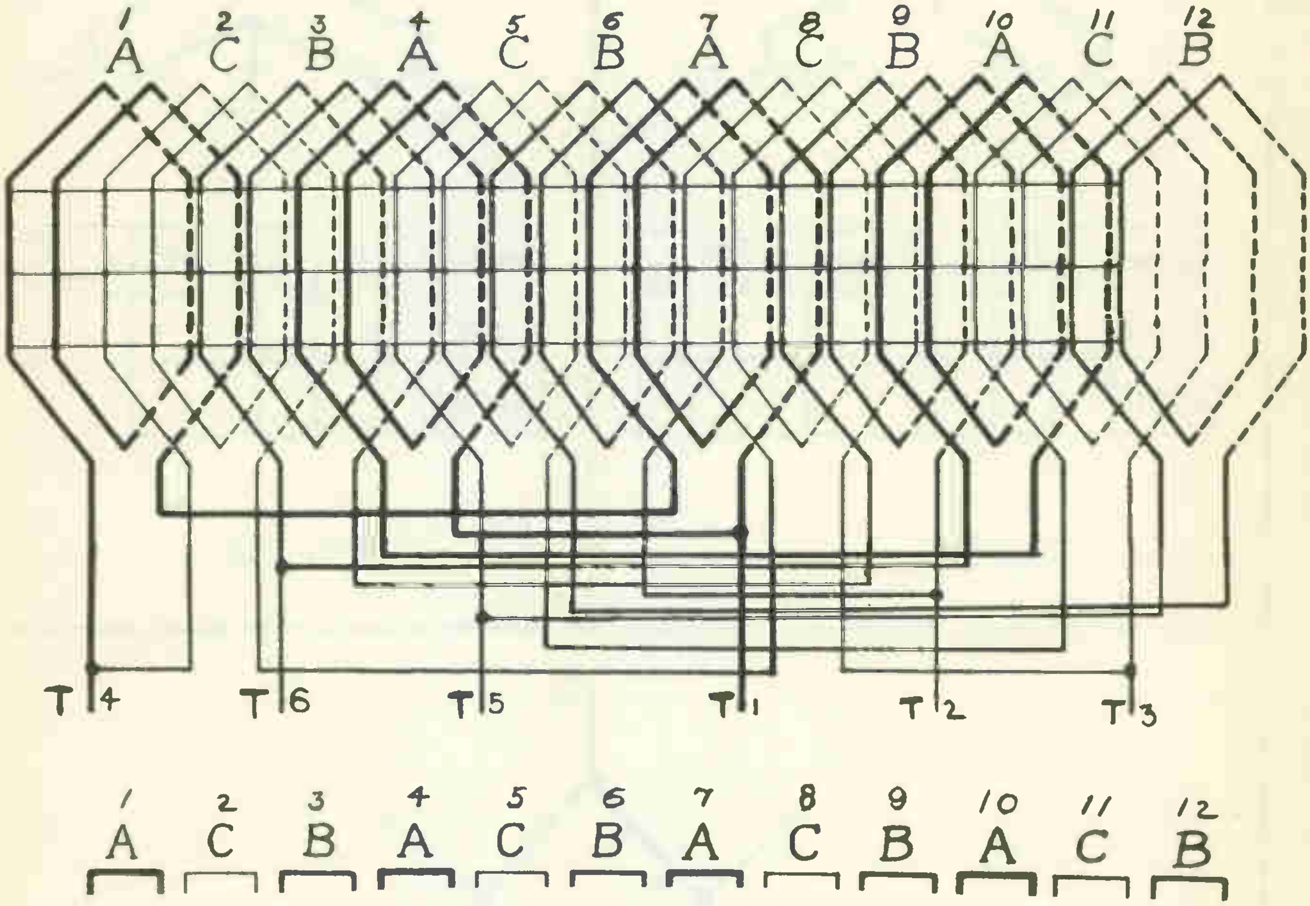
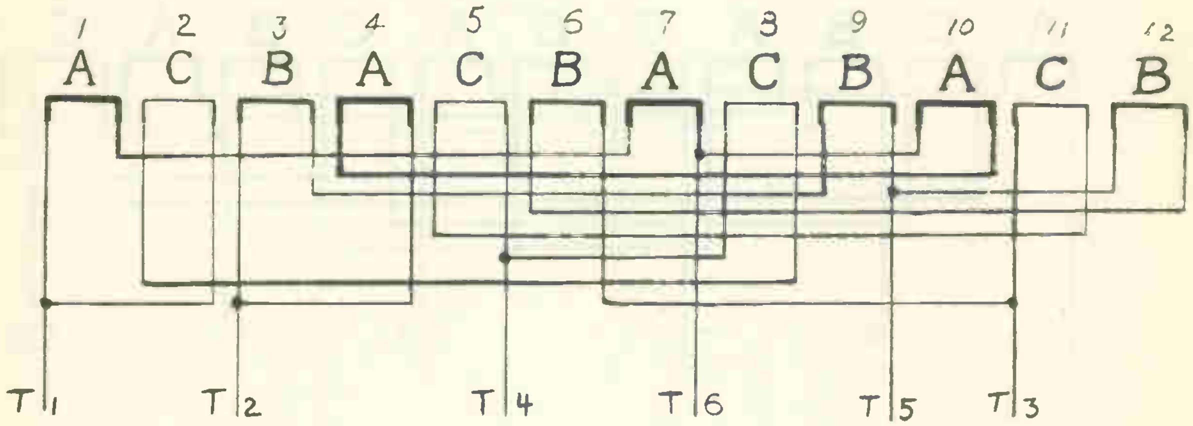


Fig. 3


1 2 3 4 5 6 7 8 9 10 11 12
A C B A C B A C B A C B
T1
T2
T4
T6
T5
T3

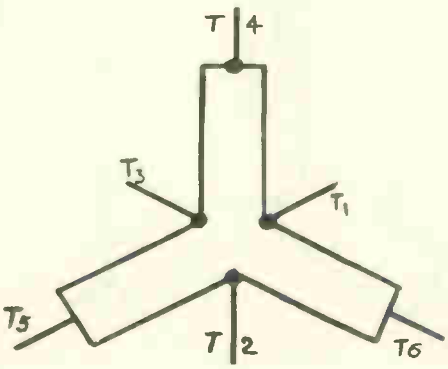
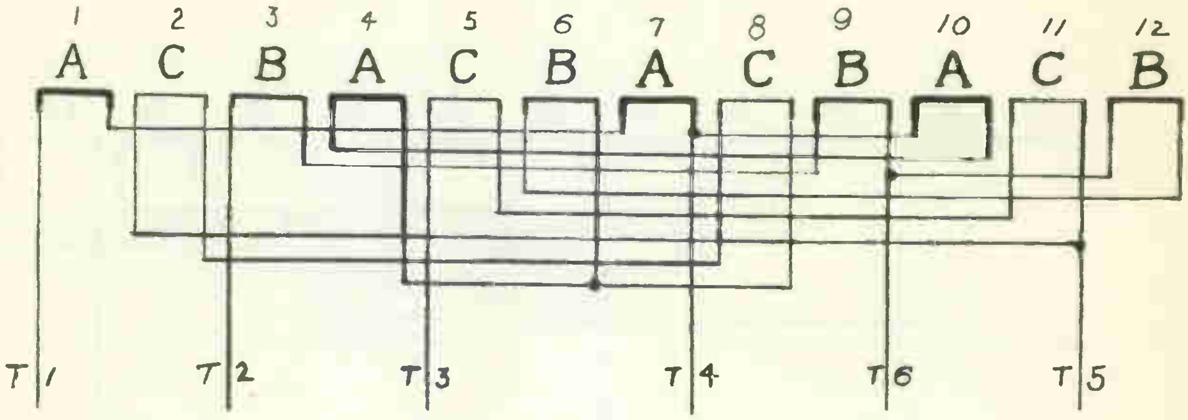

T4
T3
T1
T5
T2
T6

Fig. 4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A
C
B
T 1
T 2
T 3
T 4
T 6
T 5

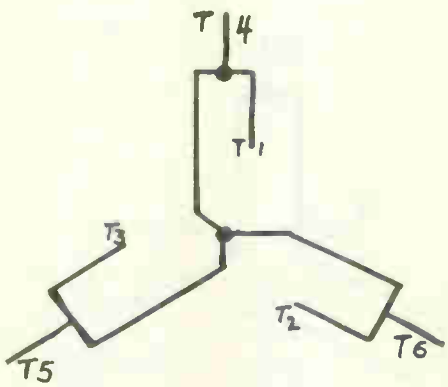
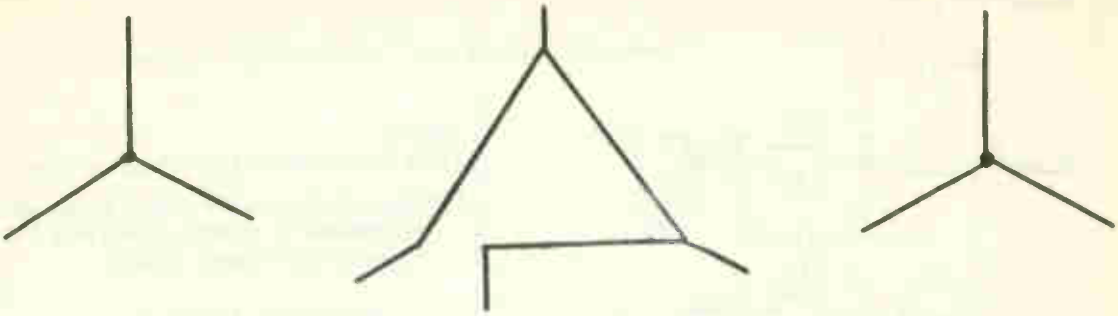
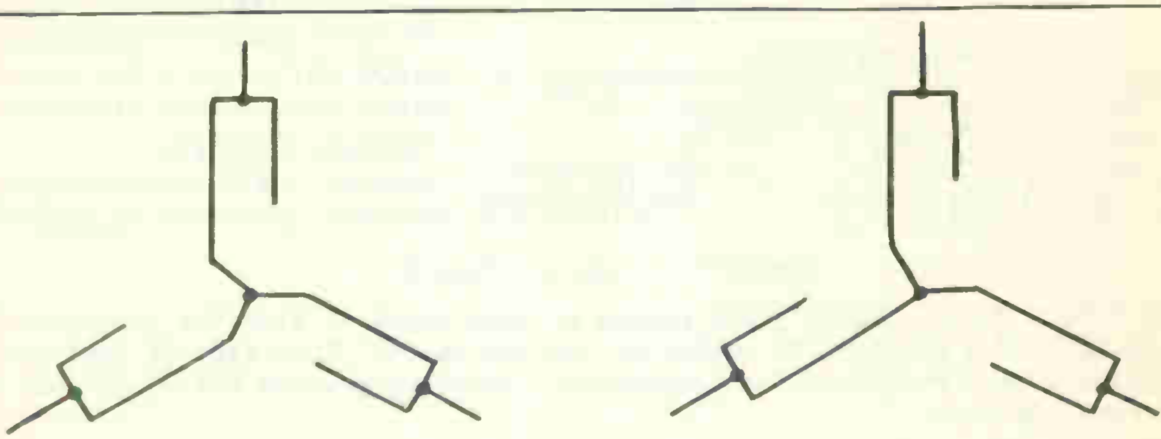

T 4
T1
T3
T2
T5
T6

Fig. 5



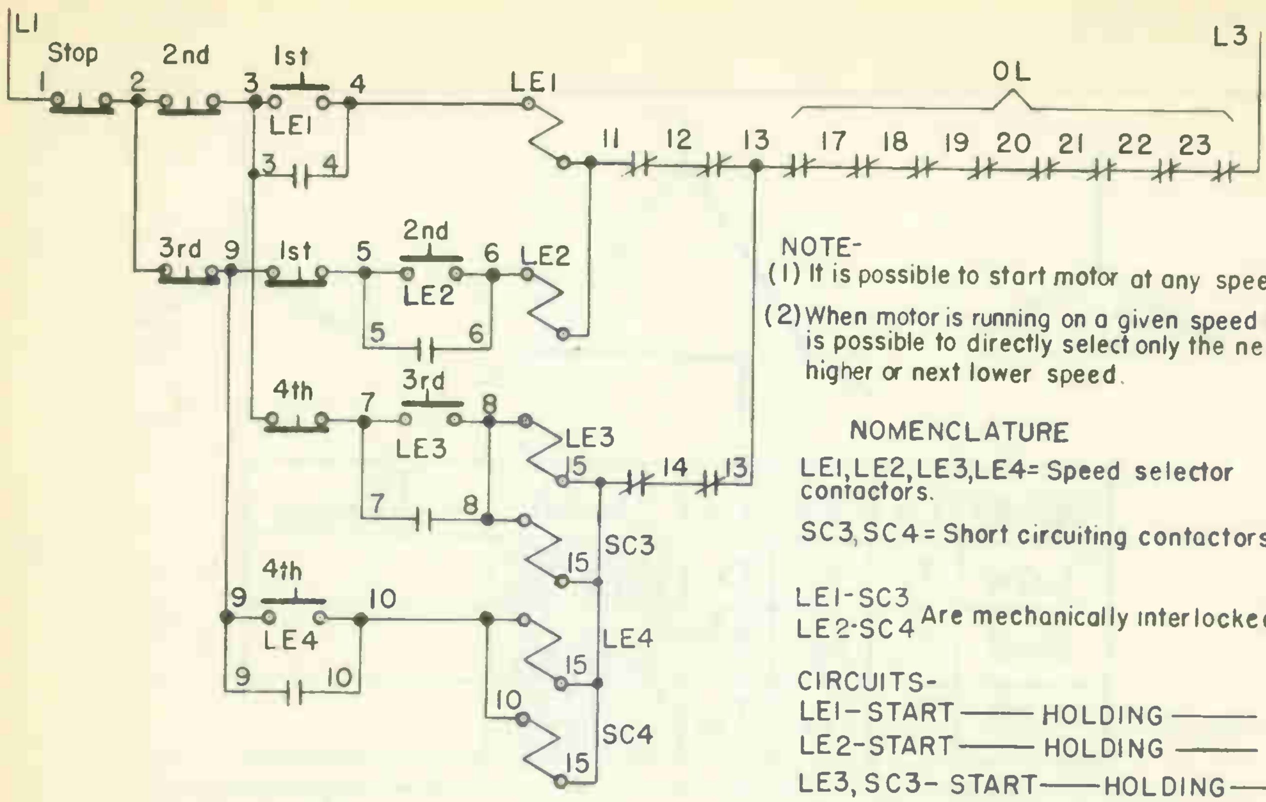
Speed	L_1	L_2	L_3	Open	Tie Together
Low	T_1	T_2	T_3	T_{11}, T_{12}, T_{13} T_{17} T_{21} T_{22} T_{23}	
2nd	T_{11}	T_{12}	T_{13} T_{17}	T_1, T_2, T_3, T_{21}, T_{22}, T_{23}	
High	T_{21}	T_{22}	T_{23}	T_1, T_2, T_3, T_{11}, T_{12}, T_{13}, T_{17}	

Fig. 6



Speed	L_1	L_2	L_3	Open	Tie Together
Low					
2 nd.					
3rd.					
High					

Fig. 7



NOTE-
(1) It is possible to start motor at any speed
(2) When motor is running on a given speed it is possible to directly select only the next higher or next lower speed.

NOMENCLATURE

LE1, LE2, LE3, LE4 = Speed selector contactors.

SC3, SC4 = Short circuiting contactors.

LE1-SC3
LE2-SC4 Are mechanically interlocked.

CIRCUITS-
LE1-START ——— HOLDING ———
LE2-START ——— HOLDING ———
LE3, SC3- START ——— HOLDING ———
LE4, SC4- START ——— HOLDING ———
MOTOR- 1ST ——— 2ND ———
MOTOR-3RD ——— 4TH ———
REVERSING STARTER-
FORWARD- START ——— HOLDING ———
REVERSE- START ——— HOLDING ———

MOTOR CONNECTIONS

SPEED	L1	L2	L3	OPEN	TOGETHER
1ST	T1	T2	T3, T7	ALL OTHERS	
2ND	T11	T12	T13, T17	" "	
3RD	T6	T4	T5	" "	T1, T2, T3, T7
4TH	T16	T14	T15	" "	T11, T12, T13, T17

Simplified Control Circuit

CONSTANT TORQUE MOTOR: Horse power rating at each speed is directly proportional to the speed WITH a standard HP rating at the top speed. This type is used on conveyors, stokers, receprocating compressors, printing presses and other constant torque loads.

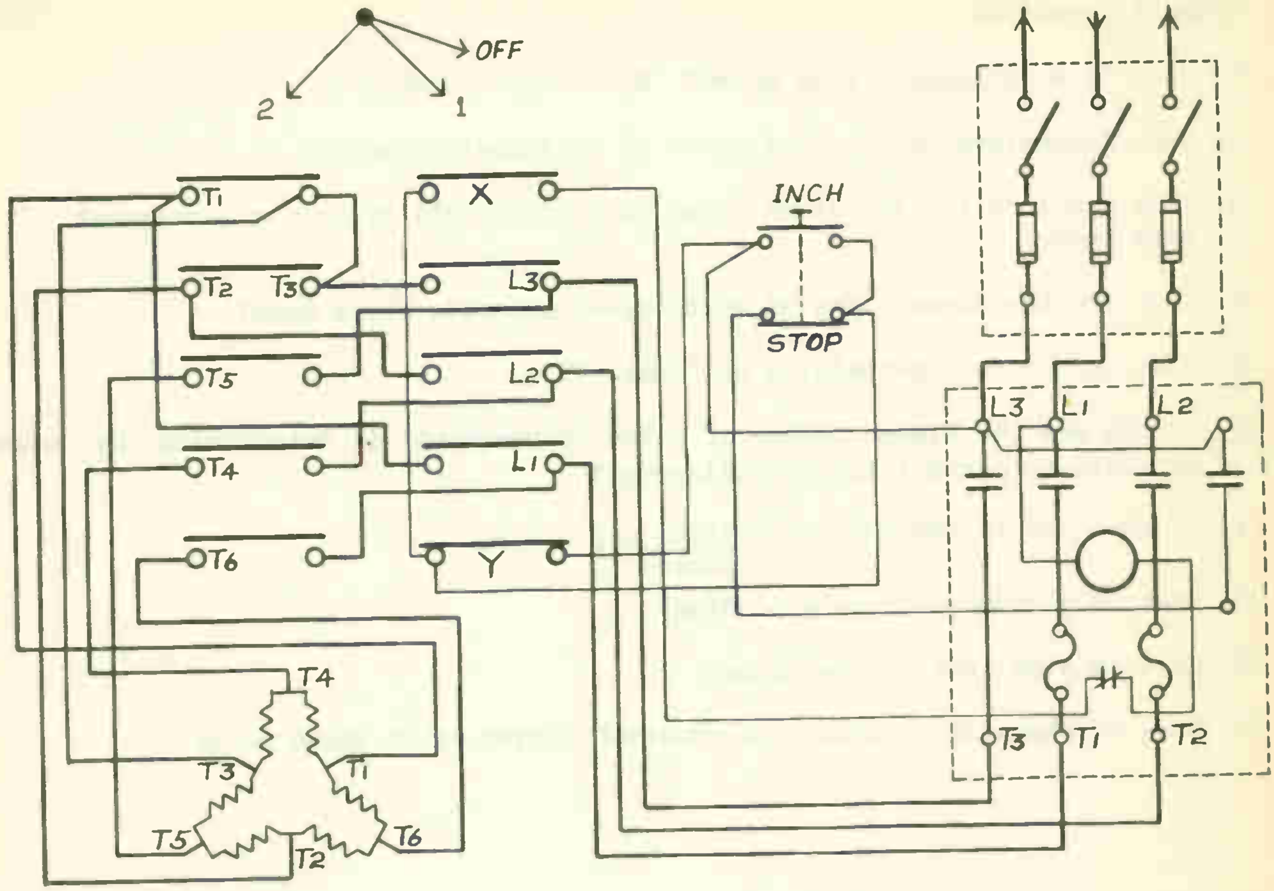
MOTOR OPERATION is as follows:

4th SPEED - The first motor winding is connected two circuit STAR for 4 poles regular, 1800 RPM stator field, 1725 RPM rotor speed; with T16 to L1, T14 to L2, T15 to L3 at contactors of LE4, and T11, T12, T13-T17 shorted at contactors of SC4. HP output will be 3, or maximum rating of the motor.

3rd SPEED - The second motor winding is connected two circuit STAR for 6 poles regular, 1200 RPM stator field, 1155 RPM rotor speed; with T6 to L1, T4 to L2, T5 to L3 at contactors of LE3, and T1, T2, T3-T7 shorted at contactors of SC3. HP output, is 2, or two thirds of maximum rating.

2nd SPEED - The first motor winding is connected single circuit DELTA for 8 poles consequent, 900 RPM stator field, 875 RPM rotor speed; with T11 to L1, T12 to L2, T13-T17 to L3 at contactors of LE2. HP output will be 1.5, or $\frac{1}{2}$ of the maximum rating of the motor.

1st SPEED - The second motor winding is connected single circuit DELTA for 12 poles consequent, 600 RPM stator field, 575 RPM rotor speed; with T1 to L1, T2 to L2, T3-T7 to L3 at contactors of LE1. Since the torque is constant, HP output varies as the speed and will be one third of 3 or 1 HP at one third of the top speed.



Two speed motor with drum control and inching control.

SEQUENCE OF OPERATION: The initial circuit for the magnet is completed through contacts X and Y as the control is moved to the 1st or slow speed position. Contact X closes before Y opens. A holding circuit is completed through Contact X, the STOP switch, and the holding contact in the line starter. Inching duty may be obtained with either slow or fast motor speed by opening the STOP switch and closing the normally open or inch switch, which completes the magnet circuit at the discretion of the operator. For continuous motor operation at either speed it will be necessary to move the control to the OFF position and repeat the starting sequence.

The motor is designed to operate at 2 speeds with 4 poles regular, 8 poles consequent pole connection. No. 1 control position connects T_1, T_2, T_3, to the 3 phase line for SINGLE DELTA, 8 poles consequent, 900 RPM stator field. T_4, T_5, T_6, are left open. No. 2 control position connects T_4, T_5, T_6, to the line, with T1, T_2, T_3, shorted, for DOUBLE STAR, 4 poles regular, 1800 RPM stator field. This machine is classified as a constant torque type.

The motor and control apparatus is suitable for the operation of printing presses or machine tools where 2 speeds can be employed and inching duty is required.

C. Summary Questions

1. What is a consequent pole motor? Multi-speed motor?

2. What determines the no-load speed of an induction motor?

3. What would be the effect of using full pitch coil span in a consequent pole motor?

4. What are the three types of multi-speed motors? Where used?

5. What is the rule pertaining to "jumper"?

6. Do you use the higher number of poles (consequent) in determining the number of coils to connect into a coil-group?

7. Of what use is the formula - $\frac{\text{slots}}{\text{poles}} + 1$?

8. What is a consequent pole winding?

9. What is a salient pole winding?

10. Draw a schematic diagram of a constant torque multi-speed motor.

ACROSS THE LINE MOTOR STARTERS

Objective

To learn the basic principles of across the line motor starters, overload equipment, and some of the limitations of this type starter.

References

Lesson Content

A. General

The motor starter discussed in this chapter is a switching arrangement which is operated electro-magnetically and it connects the motor directly to the line, applying full line voltage to the motor at the instant of starting. Certain motor starters which will be explained in a later chapter apply a reduced voltage at the instant of starting, and after a predetermined time, apply full line voltage. Such arrangements require a special type of transformer used for reduced voltage starting of these motors.

B. Across the Line Motor Starter

An across the line motor starter is a magnetically operated switch which connects the polyphase induction motor directly across the line and applies full line voltage at the instant of starting.

1. Line Terminals - points in the controller to which the polyphase line wires are terminated.
2. Remote controls - a push button control station which consists of a normally open circuit and a normally closed circuit switch.
3. Line Contactors - heavy contactors which are designed to make and break the motor to line circuit.
4. Holding Coil - a coil which is connected parallel with 2 of the lines and is so arranged to hold the line to motor contactors in place while the motor is in operation.
5. No voltage release - see holding coil.
6. Overload Protection - a bimetallic switching arrangement which has its contactors in series with the holding coil. This is the controller and motor overcurrent protection.
   Some concerns have developed a solder release type of overload protection, Fig. 4.
7. Motor Terminals - The terminals to which the motor leads are attached.

C. Limitations on Horsepower sizes

As a general rule, a squirrel cage of the low resistance type may be started satisfactorily across the line, in sizes up to 5 horsepower.

A high resistance type of squirrel cage motor is preferable for many jobs because in some instances, the sizes may be as large as 200 horsepower which may be directly started across the line.

If in doubt about the advisability of connecting a large motor across the line without reduced voltage starting - consult your public service company.

440E motors (50 to 200 hp.) are not protected by the regular type overload equipment.

D. Advantages of the Line Starter

1. Remote Control - the motor starter may be operated from one or more places which may not be at the controller. The National Electrical code suggests for maximum safety and efficiency that the number of wires between remote control units must be at least 3.

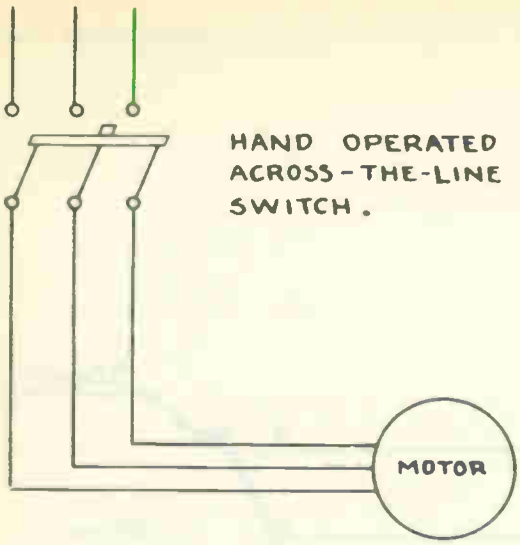
2. No Voltage Release - protection equipment within the motor starter to prevent a motor starter from operating unintentionally. In other words, when a line de-energizes the motor must be restarted. In some controls, serious damage to operators and equipment could result if this protection was not afforded.

3. Overload Protection - consisting of two types which are thermal (solder release and bimetallic) and magnetic. For maximum protection a minimum of two overload units will be used on a three phase 3 wire circuit. If the circuit is three phase four wire, three units must be used. This is to say that for full protection the number of overload units will be equal to line wires minus one.

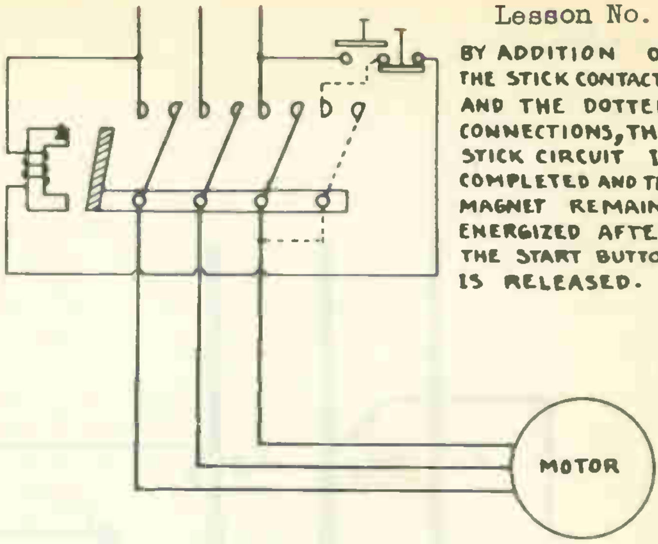
4. Simple in Design - Easy maintenance and easily inspected. Some of the most common troubles are caused from oxidized contacts or burned contactors.

5. A method of checking whether contacts are burned or oxidized is to use a millivolt meter and check to see if the voltage drop of closed contactors is 20 millivolts or over. If the voltage drop has reached this critical point, dress them down with 0000 sandpaper or a burnishing tool or some other appropriate material at hand.

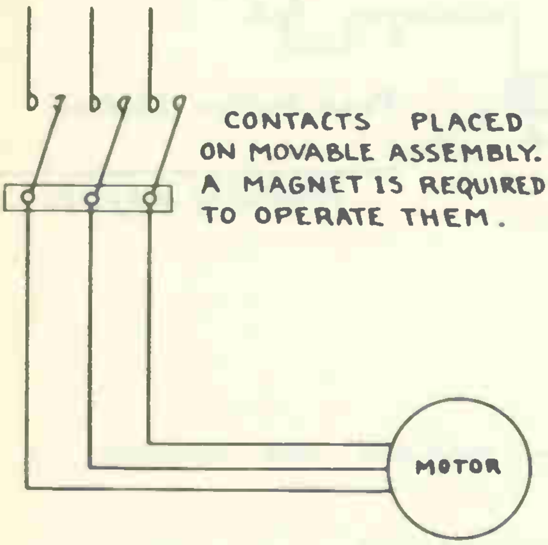
   If contactors need replacement, be sure to use approved replacement parts. For extra long life and a minimum of maintenance, silver alloy contactors should be used in preference to copper contactors. Silver, when oxidized becomes silver oxide which is nearly as good as the silver. Not so with the copper, which oxidized creates a high resistance point which causes more heating or the I^2R losses increase.



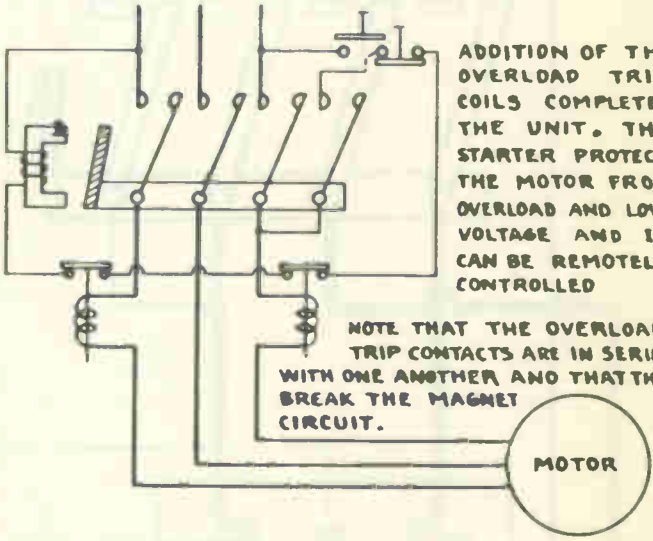
HAND OPERATED ACROSS-THE-LINE SWITCH.



BY ADDITION OF THE STICK CONTACTS AND THE DOTTED CONNECTIONS, THE STICK CIRCUIT IS COMPLETED AND THE MAGNET REMAINS ENERGIZED AFTER THE START BUTTON IS RELEASED.

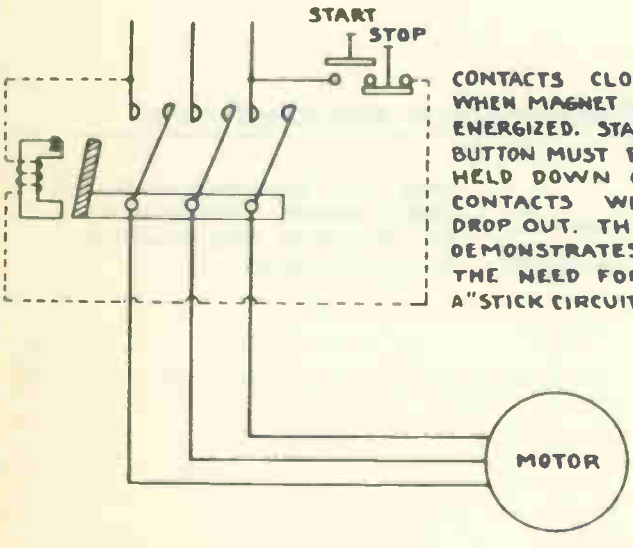


CONTACTS PLACED ON MOVABLE ASSEMBLY. A MAGNET IS REQUIRED TO OPERATE THEM.

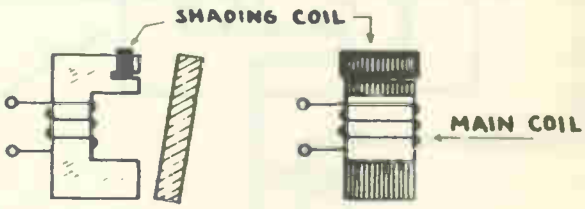


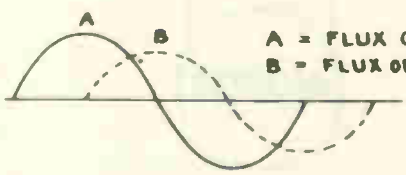
ADDITION OF THE OVERLOAD TRIP COILS COMPLETES THE UNIT. THIS STARTER PROTECTS THE MOTOR FROM OVERLOAD AND LOW VOLTAGE AND IT CAN BE REMOTELY CONTROLLED

NOTE THAT THE OVERLOAD TRIP CONTACTS ARE IN SERIES WITH ONE ANOTHER AND THAT THEY BREAK THE MAGNET CIRCUIT.



CONTACTS CLOSE WHEN MAGNET IS ENERGIZED. START BUTTON MUST BE HELD DOWN OR CONTACTS WILL DROP OUT. THIS DEMONSTRATES THE NEED FOR A "STICK CIRCUIT".





A = FLUX OF MAIN COIL
B = FLUX OF SHADING COIL

THE SHADING COIL IS USED TO PREVENT VIBRATION OF THE MAGNET ARMATURE, DUE TO PULSATIONS IN THE PULL CAUSED BY THE MAGNETIC FLUX FALLING TO ZERO TWICE PER CYCLE. AS SHOWN BY THE CURVES, THE SHADING COIL SETS UP A FLUX IN THE POLE FACE 90° OUT OF PHASE WITH THE FLUX OF THE MAIN COIL, THEREBY PRODUCING A PULL ON THE ARMATURE AT ALL TIMES.

DEVELOPMENT OF AN
ACROSS-THE-LINE STARTER

read this

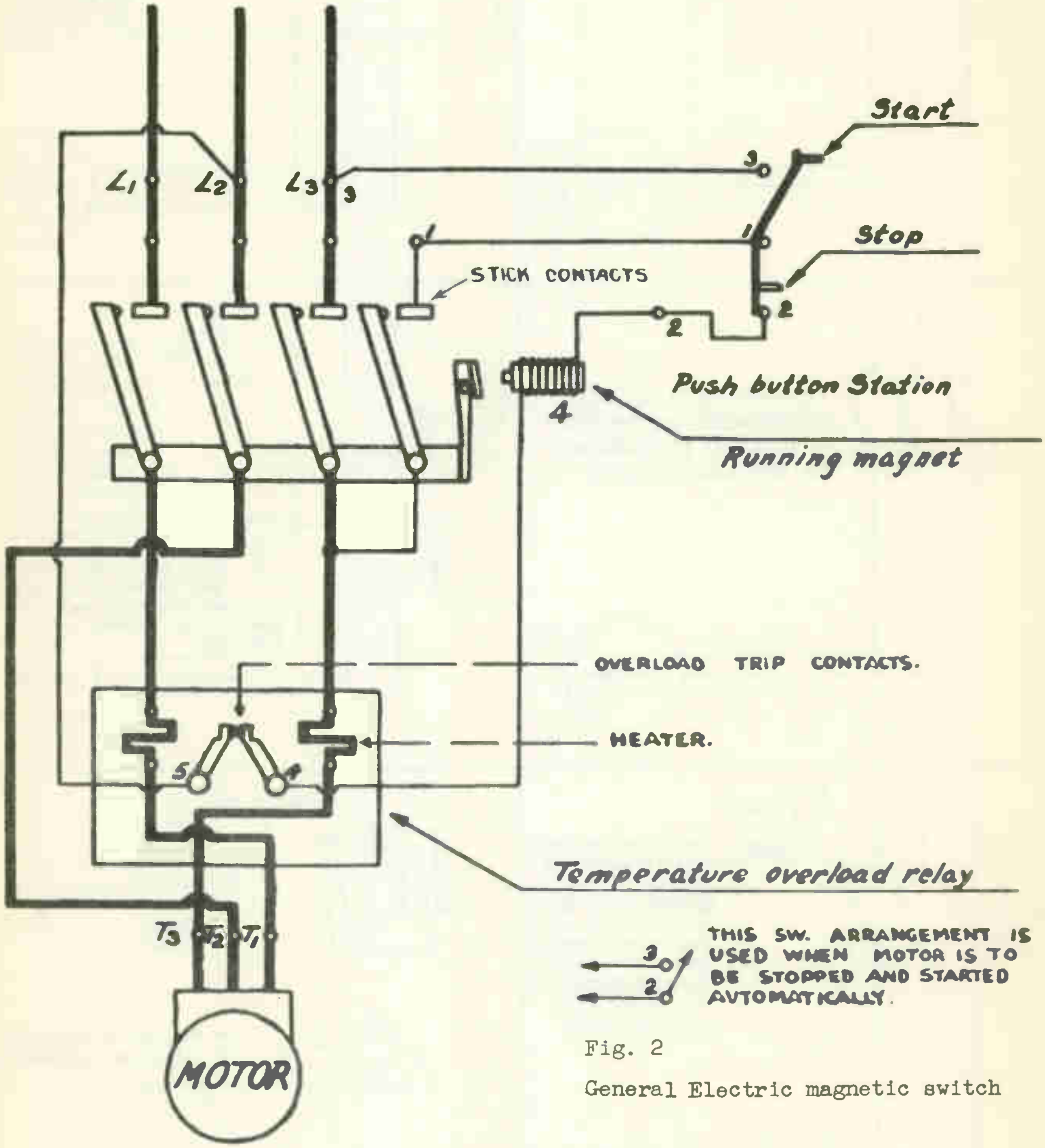


Fig. 2

General Electric magnetic switch

ACROSS THE LINE AUTOMATIC MOTOR STARTING SWITCH. TYPE "A".

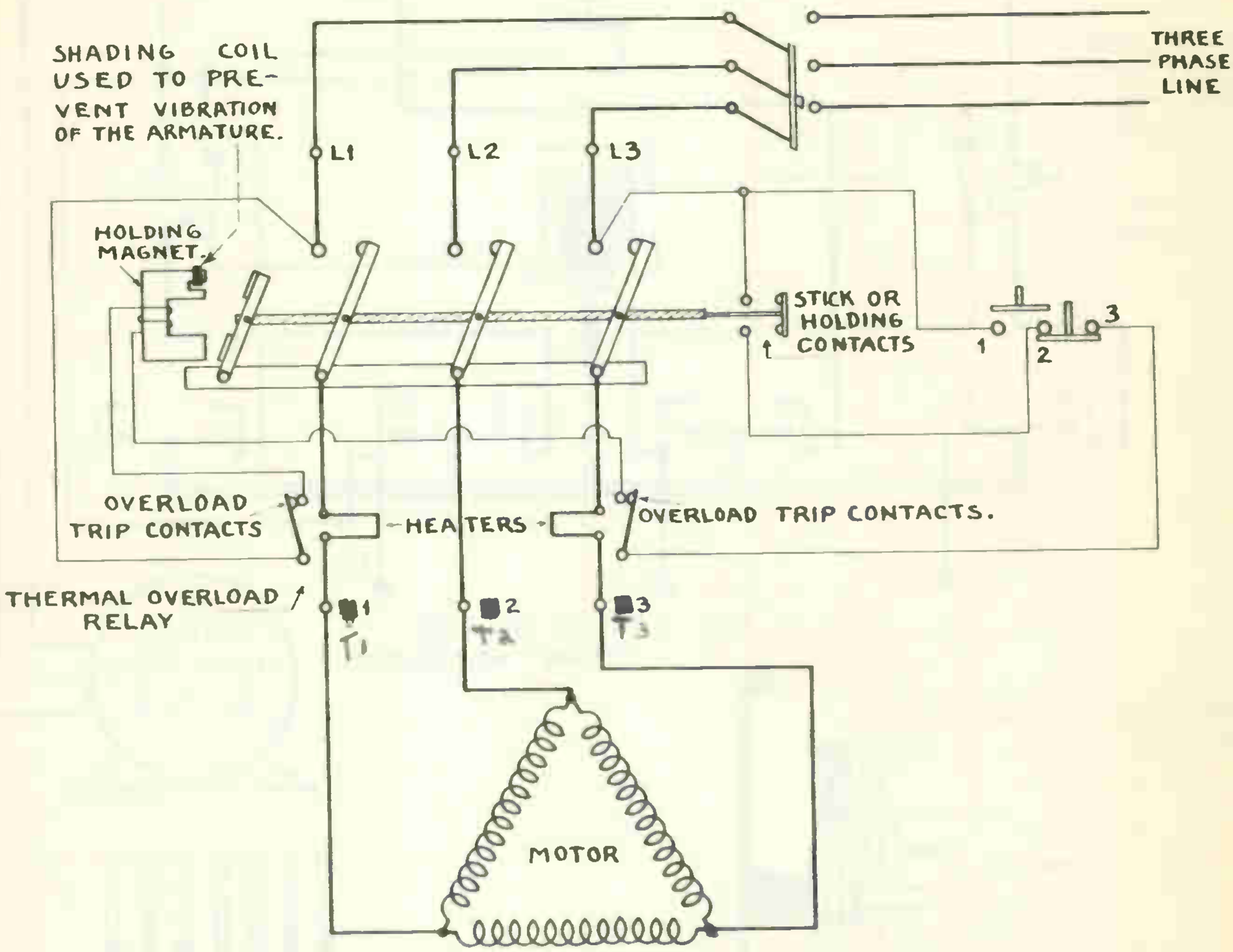


Fig. 3 Allen Bradley across the line starter.

WHEN AN OVERLOAD OCCURS THE HEATER MELTS THE SOLDER WHICH ALLOWS THE ARM "A" TO MOVE UPWARD OPENING OVERLOAD TRIP CONTACTS.

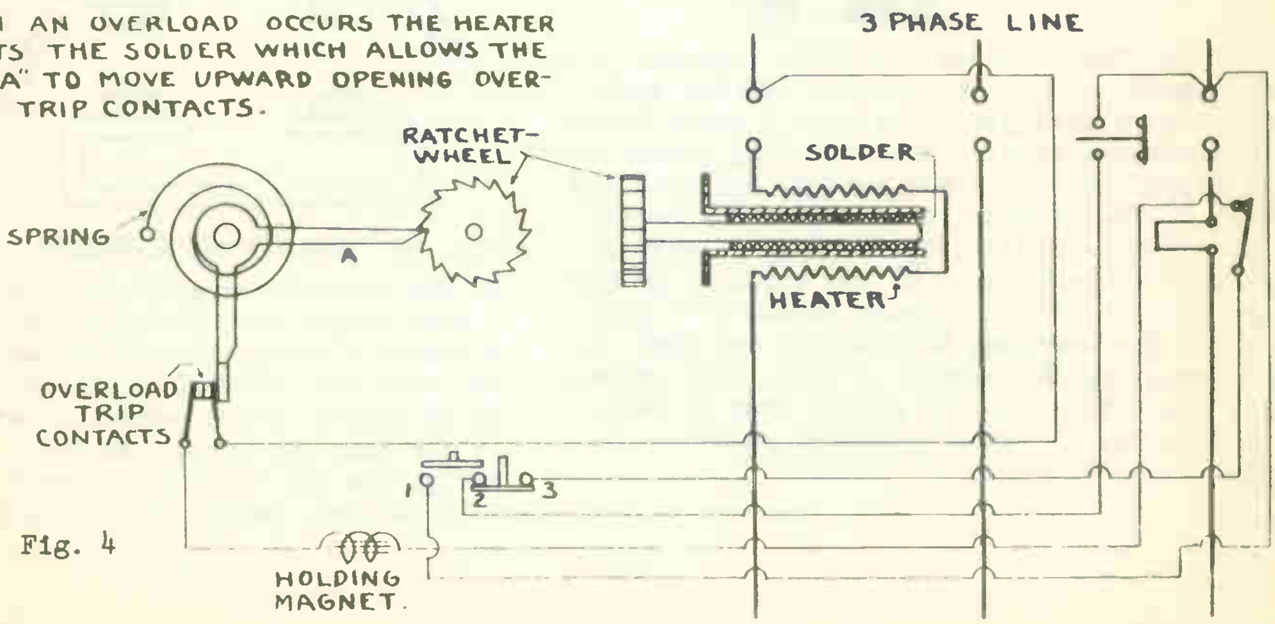


Fig. 4

DETAIL OF THERMAL OVERLOAD RELAY (SOLDER TYPE).

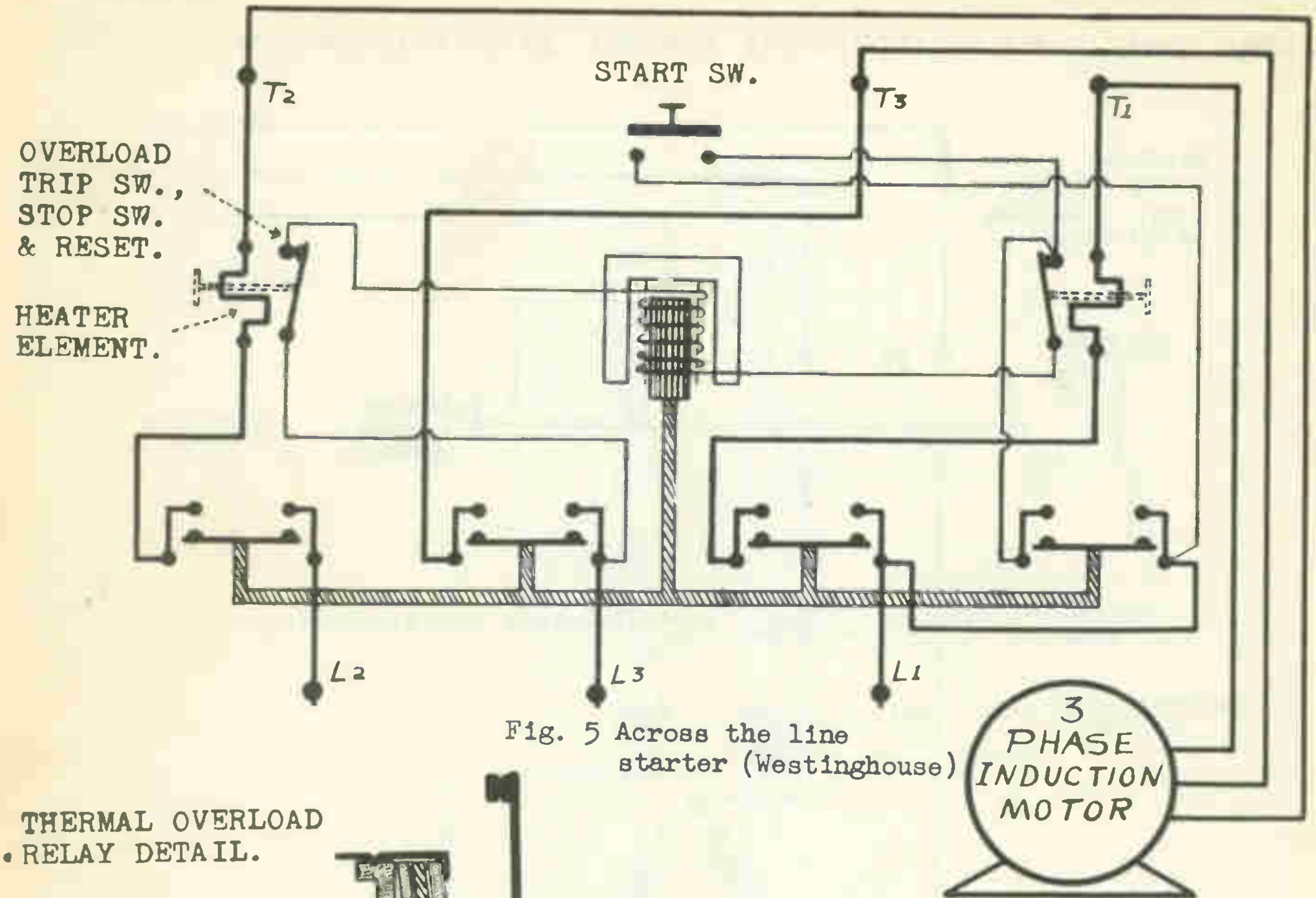


Fig. 5 Across the line starter (Westinghouse)

THERMAL OVERLOAD RELAY DETAIL.

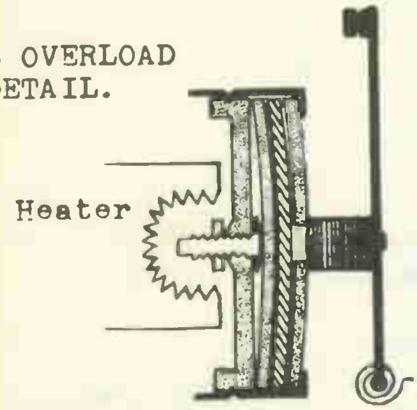


Fig. 6A The bi-metal diaphragm consists of a soft metal disc such as brass (shaded with diagonal lines) placed between 2 steel discs of diaphragm steel. The adjusting screw, which is supported by a steel bridge, conducts the heat to the bi-metal diaphragm. The brass expands more rapidly than the steel with a rise in temperature. If the screw is properly adjusted, the diaphragm center will move toward the overload trip switch and open it, interrupting the magnet circuit, thus releasing the motor from the supply when an overload occurs. Thermal overload releases usually require resetting by hand.

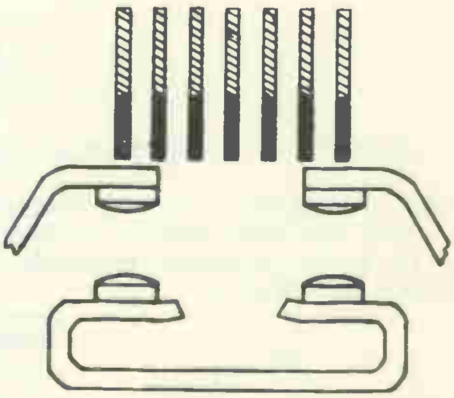


Fig. 6B "DE-ION" ARC QUENCHER.

As the contacts separate, the specially shaped moving contact gives a magnetic reaction that forces the arc into the "DE-ION" grids where it is sliced into a series of arcs. At the next zero point on the I cycle, the air adjacent to each grid is deionized, and the arc is put out.

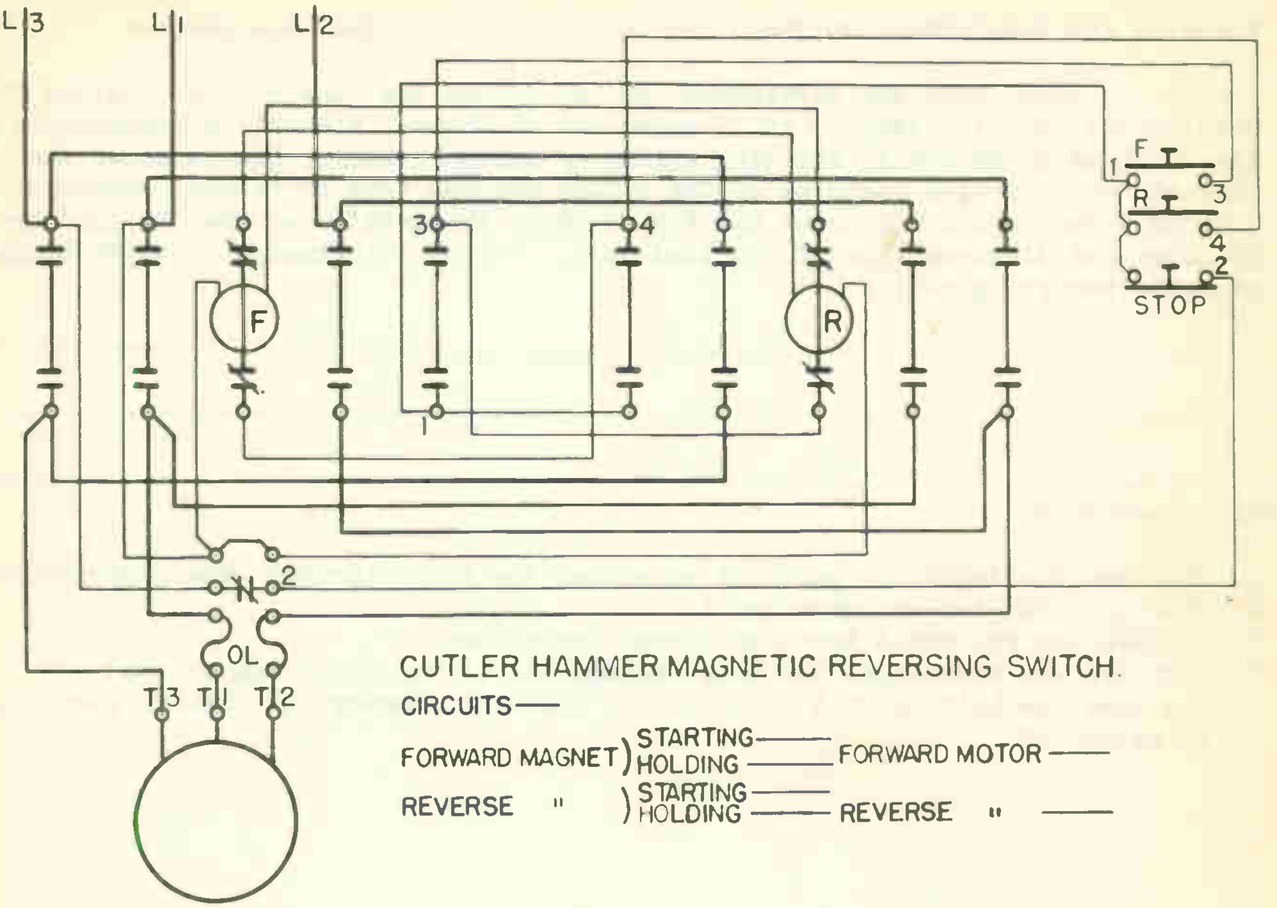


Fig. 7

E. Summary

Reversal of rotation of any three phase induction motor is merely a matter of interchanging any two of the three line leads connected to the stator. TI and T2 are reversed by the line starter shown above.

Although most motor driven machines are designed for one direction of rotation, there are many applications that demand periodic reversal; such motors are generally equipped with a remote controlled or push button operated control similar to this unit.

Motor starters or switches that have more than one set of contactors are usually designed so that both sets cannot be closed at the same time. Should this happen in the starter, the line wires would be short circuited. To prevent this, the sets of contactors are mechanically connected together in such a way as to force one set open when the other closes. When so arranged, the sets of contactors are said to be mechanically interlocked. In addition to this, many starters are also electrically interlocked. In the starter shown above a normally closed contactor is provided at both "F" and "R" magnets to prevent energizing the second magnet before de-energizing the first.

The remote control circuit is arranged to energize the "F" magnet by closing the open circuit switch "F" at the remote control station. Forward rotation of the motor is obtained by this operation. Reverse rotation of the motor will be obtained by first opening the "STOP" switch to de-energize the "F" magnet and allow the interlocking switch at "F" to reclose. Magnet "R" is energized by closing open switch "R" at the remote control station. Thus we see that selection of opposite motor rotation must be preceded by opening the "STOP" switch. This avoids instant reversal of motor rotation, which is generally not to be recommended for motors of integral H.P. sizes.

F. Examples and Development of the circuits for an Across the Line Starter

In Fig. 1, study over the development of the across the line starter. Notice the shading coil and its uses. Fig. 2 shows one of General Electric's Magnetic Switches. Fig. 2 shows an automatic starting switch by Allen Bradley. Fig. 4 shows the workings and construction features of the solder release type of thermal overload. Fig. 5 shows a Westinghouse Starter and Fig. 6 shows the details of the "De-ion" Arc Quencher and diaphram type of overload unit. Fig. 7 illustrates a Cutler Hammer magnetic reversing switch.

Summary Questions

1. What are the important parts of an across the line Starter? Their purposes?
2. What is a "de-ion arc quencher"?
3. Explain how you would test for burned contactors.
4. What are the advantages and disadvantages of silver alloy contactors?
5. Why does the holding coil of an across the line starter not chatter when properly adjusted?

AUTOTRANSFORMER PRINCIPLES

Objective

To learn about a single winding multitapped special type of transformer which is used to a great extent for reduced voltage motor starting.

References

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Lesson Content

A. General

When we think of transformers we usually think of the transformation of energy from one circuit to another by means of the magnetic coupling, between coils. The single winding transformer which is explained in Fig. 1 has some limitations but at the same time has many useful applications. A more complete discussion of transformers in general under power transformers.

B. Definition

An autotransformer is a transformer in which part of the winding is common to both the primary and the secondary circuits. ASA 15.20.015.

An autotransformer consists of a single winding placed on a laminated iron core. This winding serves as both primary and secondary. It is tapped to provide low voltages for starting of induction motors equipped with low resistance squirrel cages. If a motor does not have the desired starting torque, it might require a re-selection of tap, i.e., suppose the motor was attached to the 50% tap, it could be moved to the 65% tap without danger to the motor and this would increase the torque of the machine.

NOTE: Before any change of tap is brought about, the connected load and the supply voltage should be checked. The operating voltage may be low in the entire plant or the load that the motor is expected to operate may be too great for the horsepower rating.

Autotransformers are generally used in three phase motor starters, Fig. 1. If two are used, they are connected open-delta. If three are used they are invariably connected star. It is impractical to connect three auto transformers in closed delta because of possible difference in impedances, danger of heavy circulating currents, etc.

The National Electrical Code forbids the use of autotransformers for utility to customer distribution because of the flashover danger.

Before any autotransformer is installed on a motor circuit, it is recommended that all the electrical code rulings pretaining thereto, be carefully studied.

The rating of an auto transformer is usually classified in VA or KVA. The cost per KVA is approximately $25.00 (varying as to districts).

The efficiency of an autotransformer is approximately 80% depending upon design and load. It is impossible to obtain 100% efficiency because of the iron (core) and copper (windings) losses.

C. Power Ratings

An autotransformer is usually rated in VA or KVA and it follows, that the KVA of the primary and secondary would be exactly equal if there were no losses in the iron and copper of the unit. Compare then, the findings of secondary voltage and secondary current whose sum should be nearly equals to that of the primary.

The current in the primary circuit can be found by the VA in the primary divided by the voltage in the primary. If the current in the secondary or motor circuit is of a higher value than that of the line current, the additional current over the line current value will be attributed to secondary induced current.

D. Motor Currents

Motor currents will consist of two parts:

1. Conducted current through primary section which develops a magnetic field and generates a cemf, in the primary. At the same time it generates a secondary voltage.

2. Secondary voltage will supply the remaining motor current which is known as secondary or induced current. The power drawn from the line and the power existing in motor circuits would be equal if the transformer efficiency was 100%.

$$E_p \times I_p \text{ equals } E_s \times I_s$$

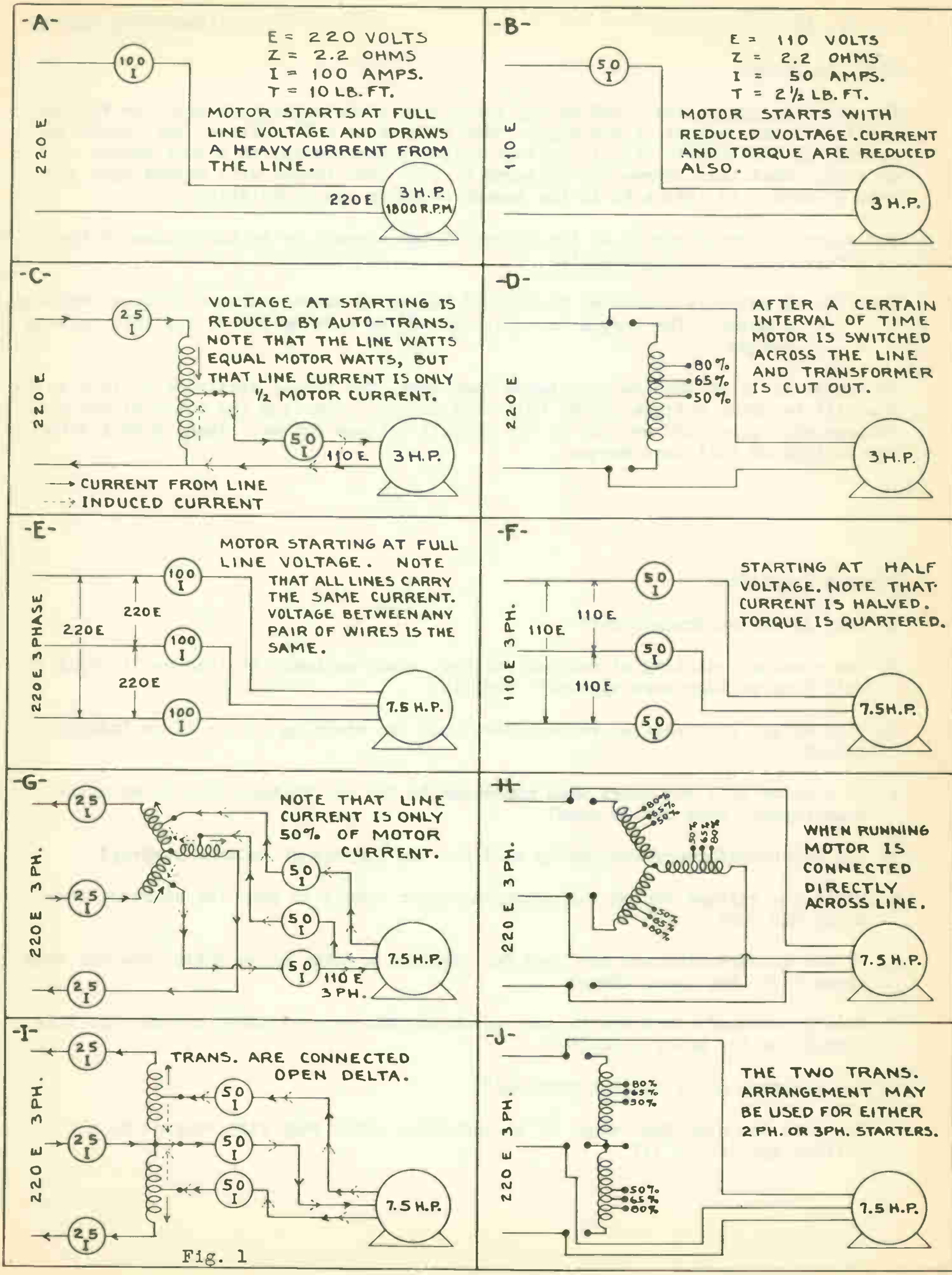

-A-
E = 220 VOLTS
Z = 2.2 OHMS
I = 100 AMPS.
T = 10 LB. FT.
MOTOR STARTS AT FULL LINE VOLTAGE AND DRAWS A HEAVY CURRENT FROM THE LINE.
220 E
100 I
220E
3 H.P. 1800 R.P.M.
-B-
E = 110 VOLTS
Z = 2.2 OHMS
I = 50 AMPS.
T = 2½ LB. FT.
MOTOR STARTS WITH REDUCED VOLTAGE. CURRENT AND TORQUE ARE REDUCED ALSO.
110 E
50 I
3 H.P.
-C-
VOLTAGE AT STARTING IS REDUCED BY AUTO-TRANS. NOTE THAT THE LINE WATTS EQUAL MOTOR WATTS, BUT THAT LINE CURRENT IS ONLY ½ MOTOR CURRENT.
220 E
25 I
50 I
110 E
3 H.P.
CURRENT FROM LINE
INDUCED CURRENT
-D-
AFTER A CERTAIN INTERVAL OF TIME MOTOR IS SWITCHED ACROSS THE LINE AND TRANSFORMER IS CUT OUT.
220 E
80%
65%
50%
3 H.P.
-E-
MOTOR STARTING AT FULL LINE VOLTAGE. NOTE THAT ALL LINES CARRY THE SAME CURRENT. VOLTAGE BETWEEN ANY PAIR OF WIRES IS THE SAME.
220 E 3 PHASE
220E
220E
220E
100 I
100 I
100 I
7.5 H.P.
-F-
STARTING AT HALF VOLTAGE. NOTE THAT CURRENT IS HALVED. TORQUE IS QUARTERED.
110 E 3 PH.
110E
110E
110E
50 I
50 I
50 I
7.5 H.P.
-G-
NOTE THAT LINE CURRENT IS ONLY 50% OF MOTOR CURRENT.
220 E 3 PH.
25 I
25 I
25 I
50 I
50 I
50 I
110 E 3 PH.
7.5 H.P.
-H-
WHEN RUNNING MOTOR IS CONNECTED DIRECTLY ACROSS LINE.
220 E 3 PH.
80%
65%
50%
7.5 H.P.
-I-
TRANS. ARE CONNECTED OPEN DELTA.
220 E 3 PH.
25 I
25 I
25 I
50 I
50 I
50 I
7.5 H.P.
-J-
THE TWO TRANS. ARRANGEMENT MAY BE USED FOR EITHER 2 PH. OR 3 PH. STARTERS.
220 E 3 PH.
80%
65%
50%
7.5 H.P.

Fig. 1

E. Starting Torque

The starting torque developed by any given type of motor depends upon the voltage applied at the instant of starting. When started at full voltage, the torque developed is referred to as full voltage torque, numerically, as a unit torque of 1 or 100%. What this represents in terms of full lead torque will depend upon the type of motor, as indicated in the lesson on motor characteristics.

The starting torque varies as the square of the current or as the square of the percentage of full voltage applied.

EXAMPLE: A motor is connected to the 80% tap in an autotransformer reduced voltage starter. The torque is equal to 0.8^2 or 0.64 or 64% of the full voltage torque.

If the motor is of the low resistance cage type, the torque developed at full voltage will be about 2 times (200%) full load torque. Starting the motor at 80% full voltage will give 0.8^2 or 0.64 or 64% of full voltage torque. Then .0.64 x 200% equals 128% of full load torque.

F. Summary Questions

1. What is an autotransformer?
2. Can a motor,,starting at reduced voltage, start as heavy at load as it could if full line voltage were applied? Explain.
3. What effect does reduced voltage have upon the starting torque of an induction motor?
4. If a motor will not start when connected to the low voltage taps on an autotransformer, what can be done?
5. Are autotransformers frequently used for the purpose of voltage step-up?
6. Which low voltage tap on the autotransformer should be used for starting the motor and why?
7. If two autotransformers are used for starting a three phase motor, how are they connected? How about three?
8. When autotransformers are in use, which circuit carries more current, the line circuit or the motor circuit?
9. How is extra motor current obtained?
10. How does the starting torque of an induction motor vary with respect to the voltage applied to it?

REDUCED VOLTAGE STARTERS

Objectives

To learn about the uses and necessities of a reduced voltage starter which may be subclassified as:

1. Manual - must be operated by hand and is a single place control.
2. Automatic - may be operated from a remote position and may also be multi-place operated.

References:

Lesson Content

A. General

Since reduced voltage starters depend upon various methods of reducing the voltage at the instant of starting the motor, it may be well to review a previous chapter on only one of the methods (autotransformers); since this is the most efficient and most economical method, requiring the smallest amount of attention and maintenance. Another method of reduced voltage starting of induction motors is the carbon pile (resistance) method. Cast grid and wire wound resistor methods are used to a small extent in some varied cases.

B. Reduced Voltage Motor Starter Parts

Some of the important parts of a reduced voltage motor starter are:

1. Line contactors - makes the line to starter connections.

2. Terminal Board - a small board containing terminals to which the line is connected along with motor connections and reduced voltage equipment terminals. This is also used as a convenient test terminal block.

3. Holding Magnet - A no voltage release coil which will hold the controller in the "run" position as long as the motor is operating normally and the line is continually energized.

4. Autotransformer - a multitapped single winding transformer - with an iron core which may be in one of two arrangements. If only two units are used they are connected open delta; if three units are used they are connected star. The tap precentages will vary from approx. 40% to 90%, but probably the most common tap arrangement for a classification of up to 25 hp is as follows: 50% - 65% - 80%.

   NOTE: If the autotransformer has only one tap in use and starts the motor with only one reduced voltage step, it may also be called a "compensator". This arrangement can be arranged for manual or automatic operation and the horsepower sizes will probably vary from 5 HP to 100 HP or larger.

5. Compensator Oil - a mineral oil which is used to squelch the arc at the contractors so as to reduce burning of contacts, when the circuit from the line is broken. The breaking of the circuit under or in oil reduces fire hazard.

6. Time Control - a timing device is usually added to an automatic reduced voltage starter to govern the time allocated for the motor to come up to full speed

before applying line voltage. The General Electric Company and Westinghouse Corporation both have a mechanical timer which is used on their controllers. Allen Bradley, Western Electric, and other concern may have oil dash pot arrangements which govern the time delay between starting and running positions of the line to motor contactors. The time delay may be from a very few seconds to several minutes and must be adjusted on the job according to application of the motors.

C. General Controller Rulings

Any motor controller shall be so arranged that, when the controller is in the off position there shall be no connections made to the motor. Thus, the National Electrical Code makes definite provisions for the proper connections to three phase motor controls to minimize the danger to persons and motor equipment.

A good rule to follow for maximum life of a motor controller is to make sure connections when operating a manual motor control. Never abuse a motor or controller. This abuse of controllers can be minimized by the use of automatic compensators or controllers with appropriate protection equipment already mounted, such as mechanical interlocks which prevents a motor from being started at full line voltage. Then too, in the automatic compensator classification, we encounter the electrical interlock which serves to disconnect the start button and the starting magnet from a possibility of being energized accidentally while the motor is running.

D. Manual Reduced Voltage Starters

In Fig. 1, we see a starter which gained prominence in recent years; put out by Western Electric Company, it is a three phase - 60 Cycle - type 1 - form k - 10 HP - with a voltage rating as follows: Primary 220 volts - Secondary 110 - 175 volts.

Since this controller will be tied to a three phase line, we could trace the circuit in several ways. Let us assume, current in on the bottom line and out on the top two. You should try to trace four different circuits on this diagram. They are:

1. Motor Starting or conducted current
2. Motor Starting or induced current
3. Motor Run circuit
4. No voltage release circuit.

2. In Fig. 2, we see an "auto starter" by Westinghouse. It is a three phase - 60 - cycle 5 to 15 HP - 220 Volts - style No. 185156 Motor Starter.

This controller, too, will be tied to a three phase line and is protected by two sets of overloads. This arrangement provides full protection for the circuit because the current carried by the third line must pass through at least one other line which is provided with overload protection. Try to trace four different circuits in this Figure:

1. Motor Starting Circuit (Conducted Current)
2. Motor Starting Circuit (Induced Current)
3. Motor Run Circuit
4. No Voltage Release Circuit

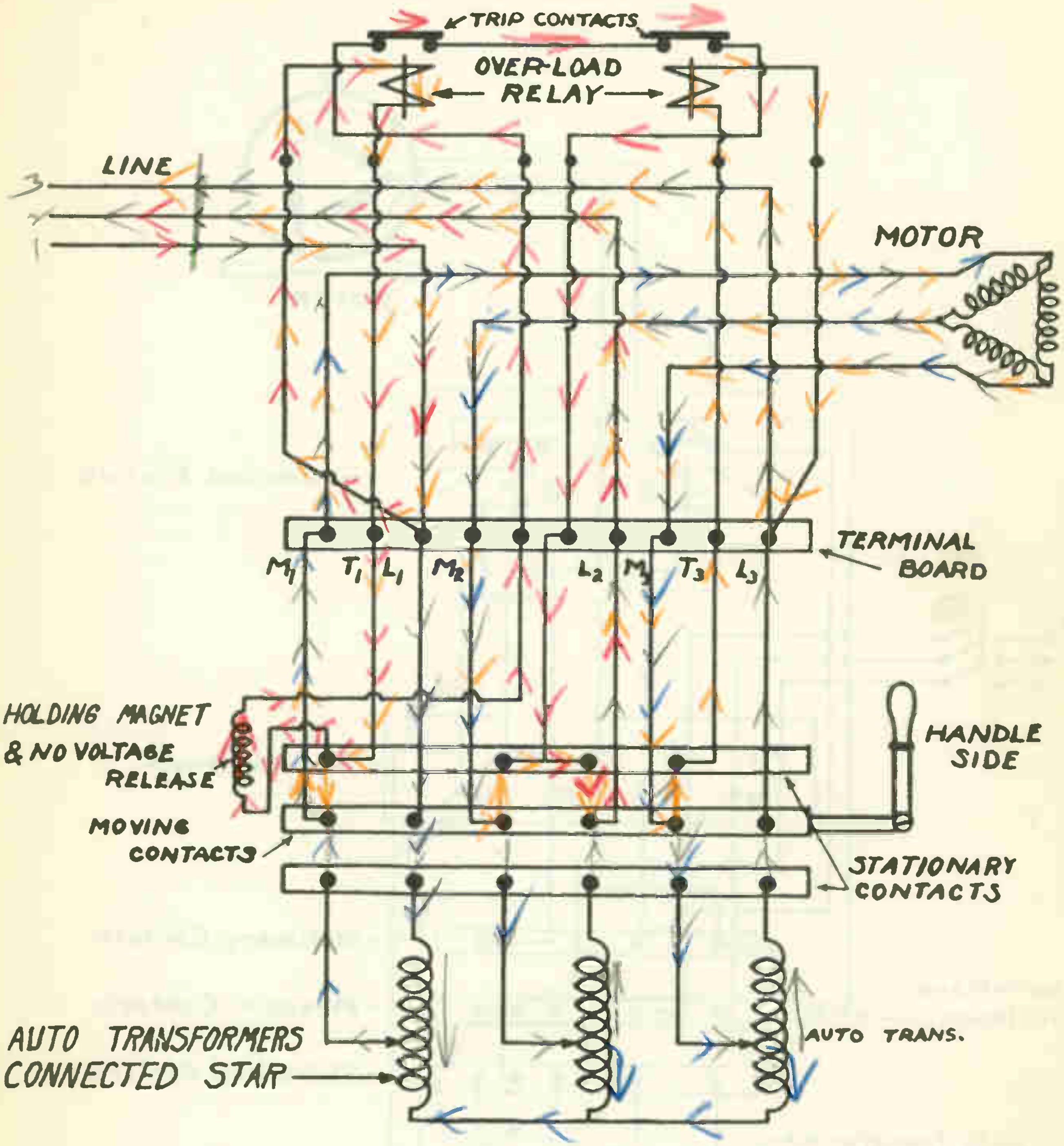


Fig. 1 Auto-starter (Western Electric)

Motor Start →
Auto transf ckt →
Motor ckt →
No Voltage Release Coil ckt →

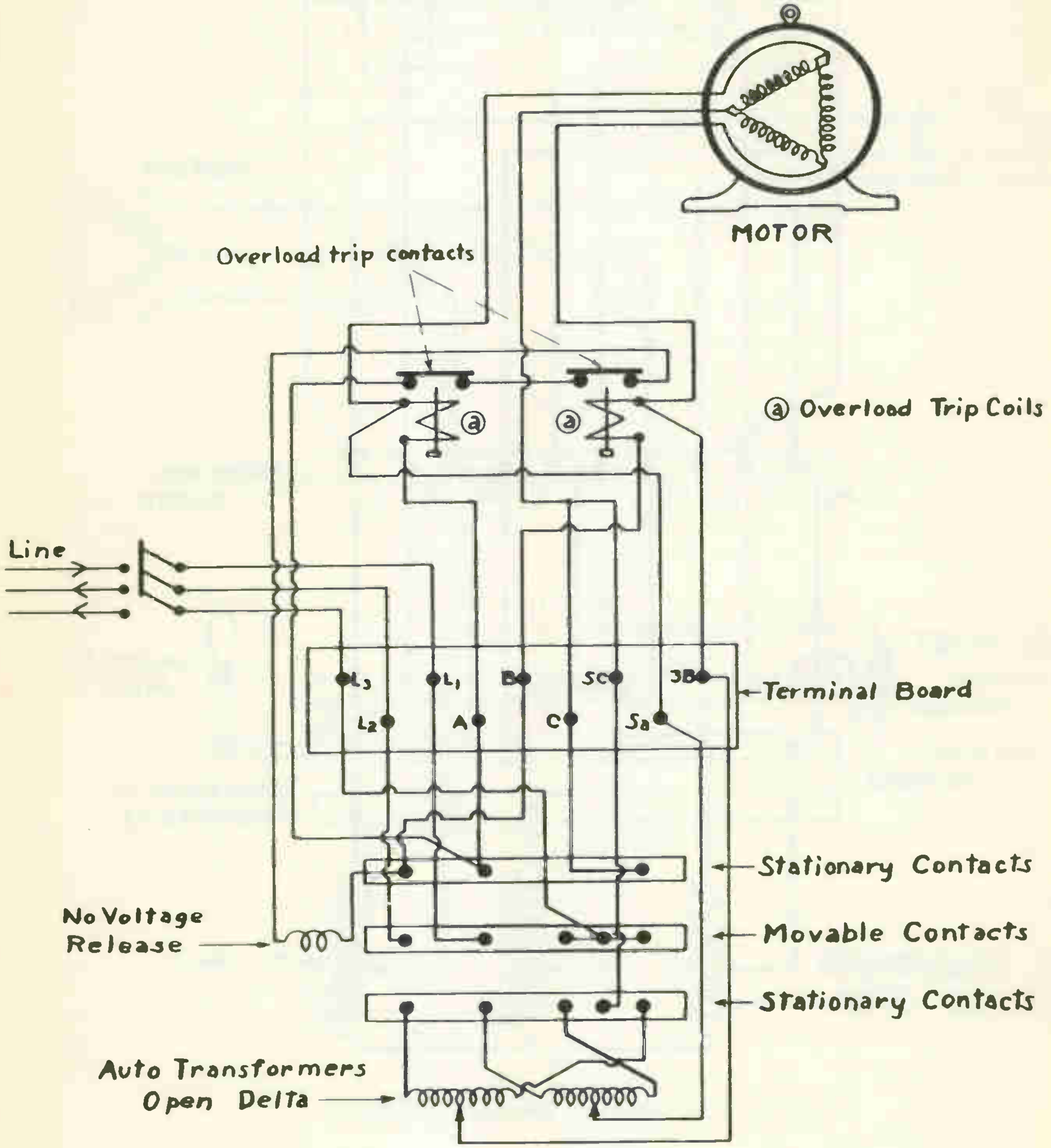


Fig. 2 Auto-starter (Westinghouse)

E. Automatic Reduced Voltage Starters

The General Electric Company automatic compensator shown in Fig. 3 controls approximately the same horsepower as the autostarter in Fig. 2. Notice, however, the contactors life is to be extended by the use of small blow out coils whose magnetic field will be strongest at the point of break. You will notice at the bottom of this Figure the details of the timing relay positions in the normal holding, and running positions. Notice too, the thermostatic overload release.

You should exercise great care in the tracing of this diagram, as thorough understanding will help you understand why many troubles develop and how you may find them. Trace:

1. Relay Magnet Starting Circuit
2. Relay Magnet Stick Circuit
3. Relay Motor
4. Holding Magnet
5. Auto Transformer Circuit
6. Running Magnet
7. Motor Run Circuit

2. Referring to Figure 4 we see one of the more modern types of starters. This unit developed and sold by the ALLEN BRADLEY COMPANY has many advantages and few disadvantages. Probably one of the great selling points on this starter is the fact that it has the silver alloy contactors instead of copper. The maintenance factor or upkeep is low.

   The system of starting and running is shown by the three representative figures or diagrams at the base of this page.

   Tracing - for a thorough understanding of this controller trace the following diagram circuits:

   1. Line Switch Start Circuit
   2. Line Switch Stick Circuit
   3. Motor Starting Magnet Circuit
   4. Motor Stick Magnet Circuit
   5. Time Relay Circuit
   6. Motor Start
   7. Auto-Transformer Circuit
   8. Running Magnet Circuit
   9. Motor Run Circuit

3. Refer to Fig. 5, where you will see one of the very latest motor starters. It is an efficient, flexible, safe, "sure operating", type of control which comes equipped with a timer unit that has a very wide time lag adjustment in the automatic motor controlled timer unit. Study this controller and its parts carefully.

   Tracing the circuits on this controller and its timer unit will help you in your understanding of the entire unit. The following may be traced:

   1. 1-MS Start Circuit
   2. 2-MS Start Circuit
   3. TS Start Circuit
   4. TM Circuit
   5. 1-MS Holding Circuit
   6. 2-MS Holding Circuit
   7. TS Holding Circuit
   8. Motor Start (Conducted)
   9. Motor Start (Induced)
   10. MR Circuit
   11. Motor Run Circuit

4. In referring to Fig. 6, you will notice a simple controller with no magnetic timer on it. There is a mechanical arrangement of time delay for this purpose. Some of the circuits that may be traced for this Figure are also shown in Fig. 6.

5. Another reduced voltage starter which has had some prominence in the past is shown in Fig. 7. Because of its high maintenance or upkeep factor it has been replaced with autotransformer type reduced voltage starters.

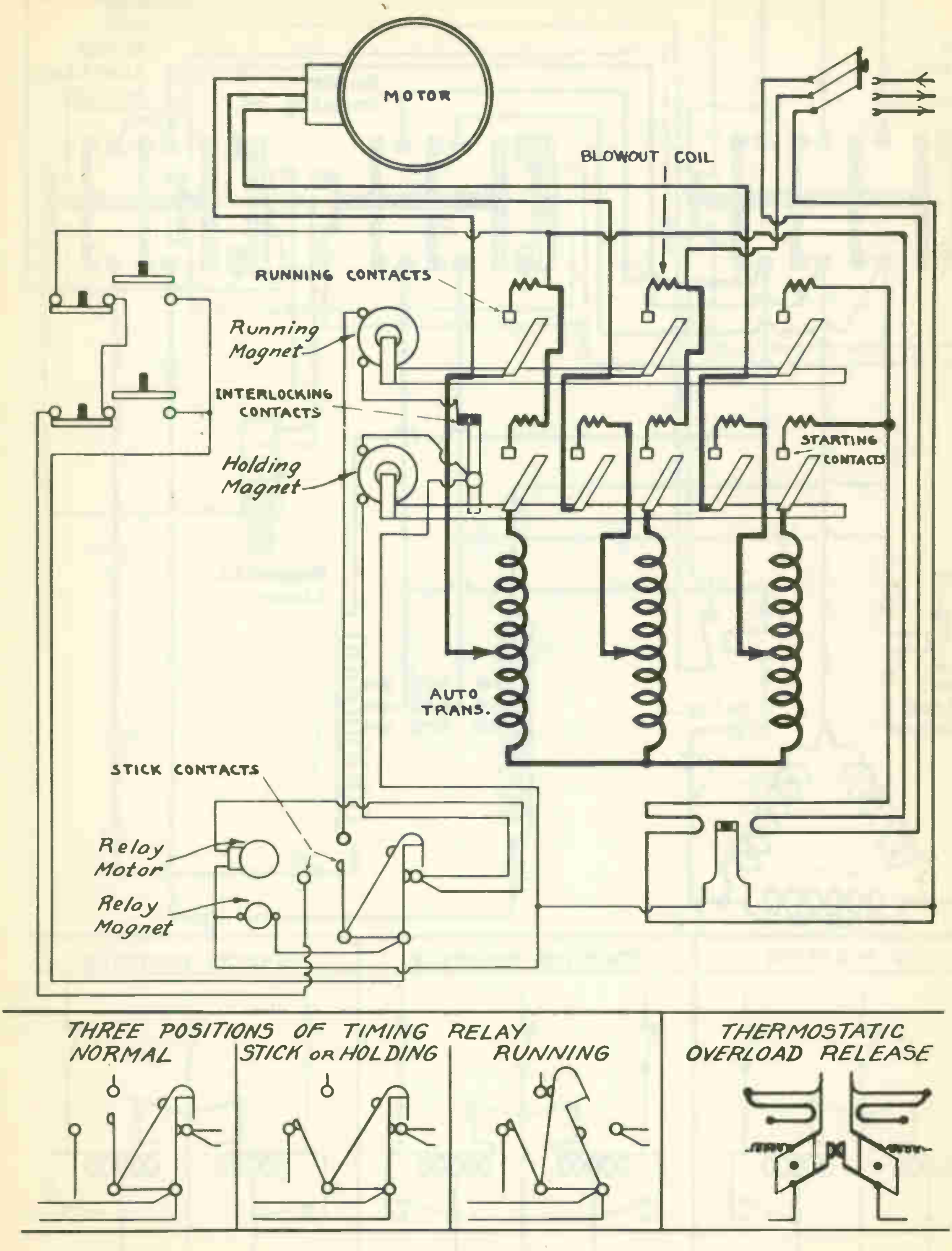

MOTOR
BLOWOUT COIL
RUNNING CONTACTS
Running Magnet
INTERLOCKING CONTACTS
Holding Magnet
STARTING CONTACTS
AUTO TRANS.
STICK CONTACTS
Relay Motor
Relay Magnet
THREE POSITIONS OF TIMING RELAY
NORMAL
STICK OR HOLDING
RUNNING
THERMOSTATIC OVERLOAD RELEASE

Fig. 3

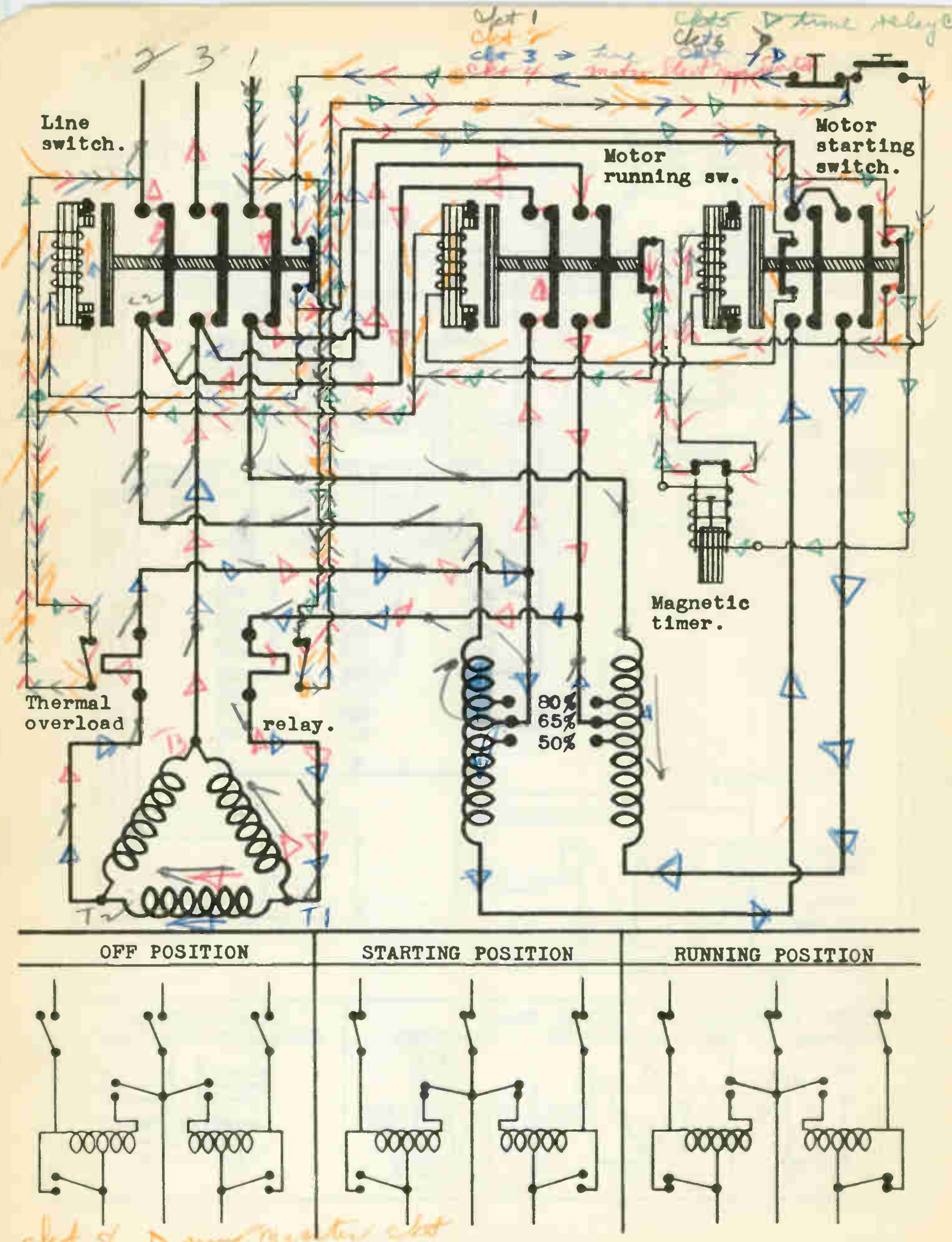
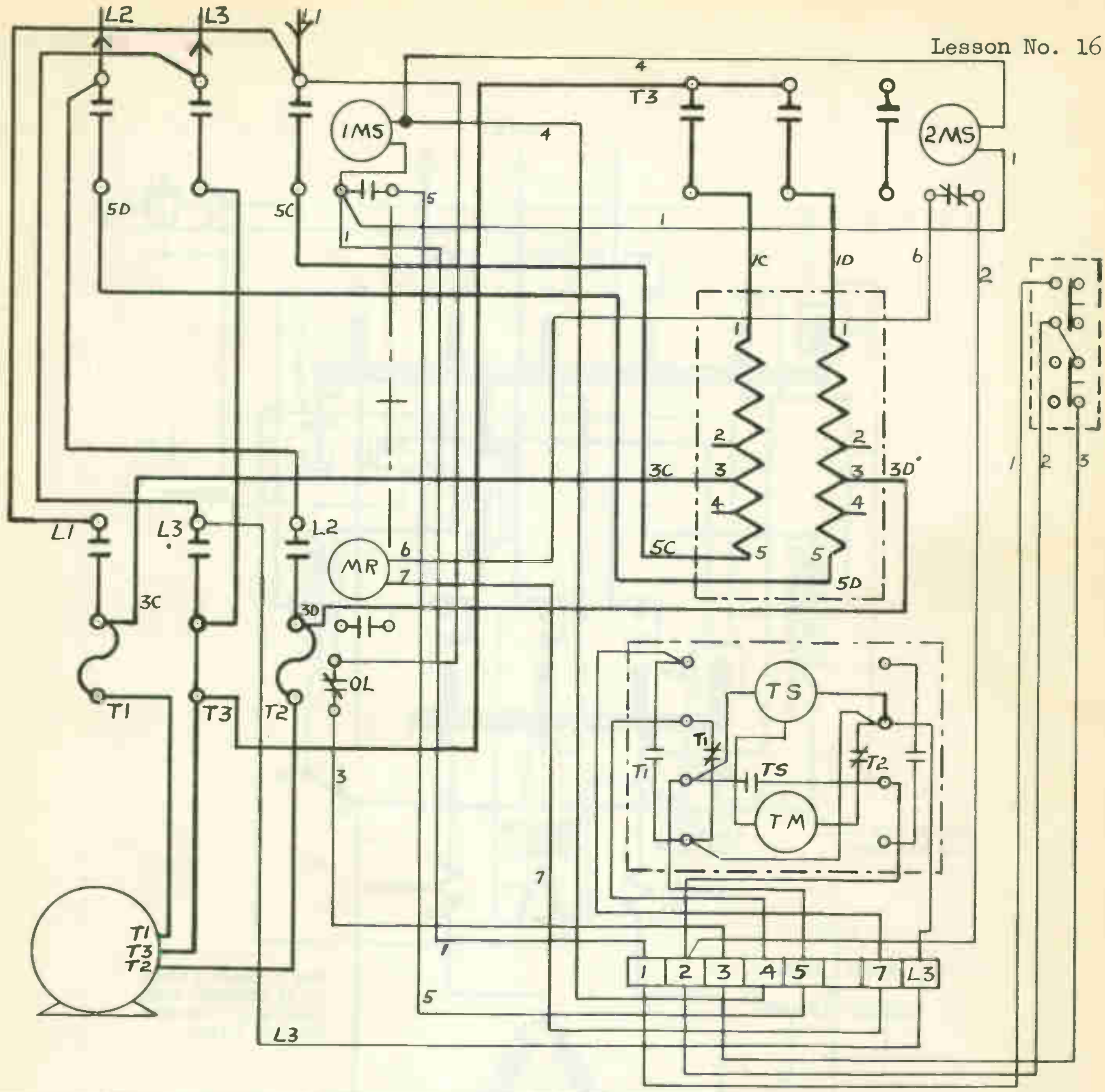


Fig. 4 Auto-transformer (Allen Bradley)



SCHEMATIC CONTROLLER DIAGRAM

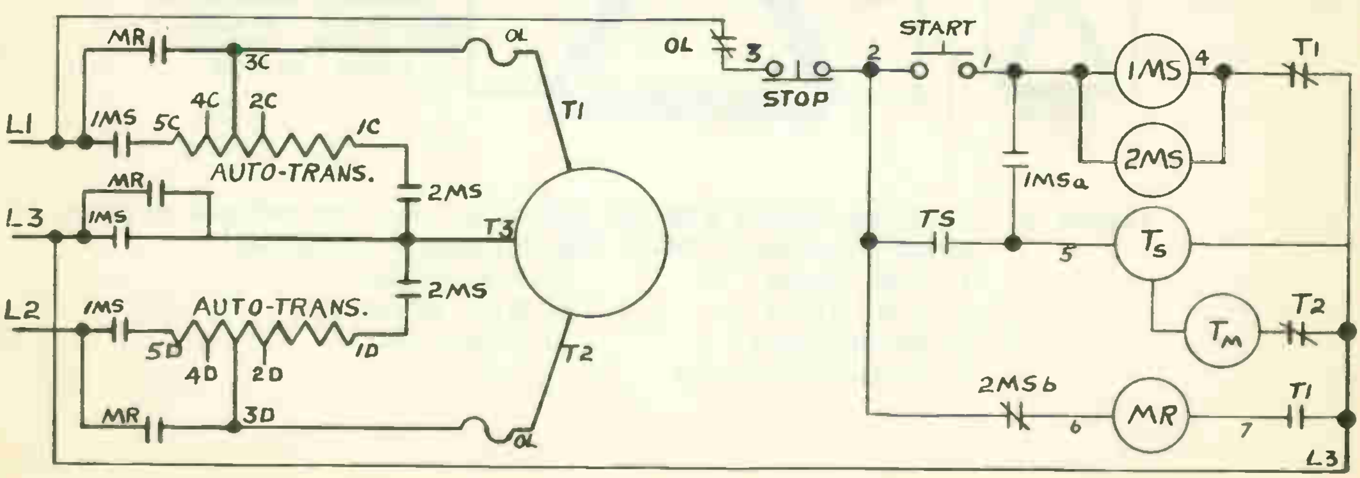


Fig. 5

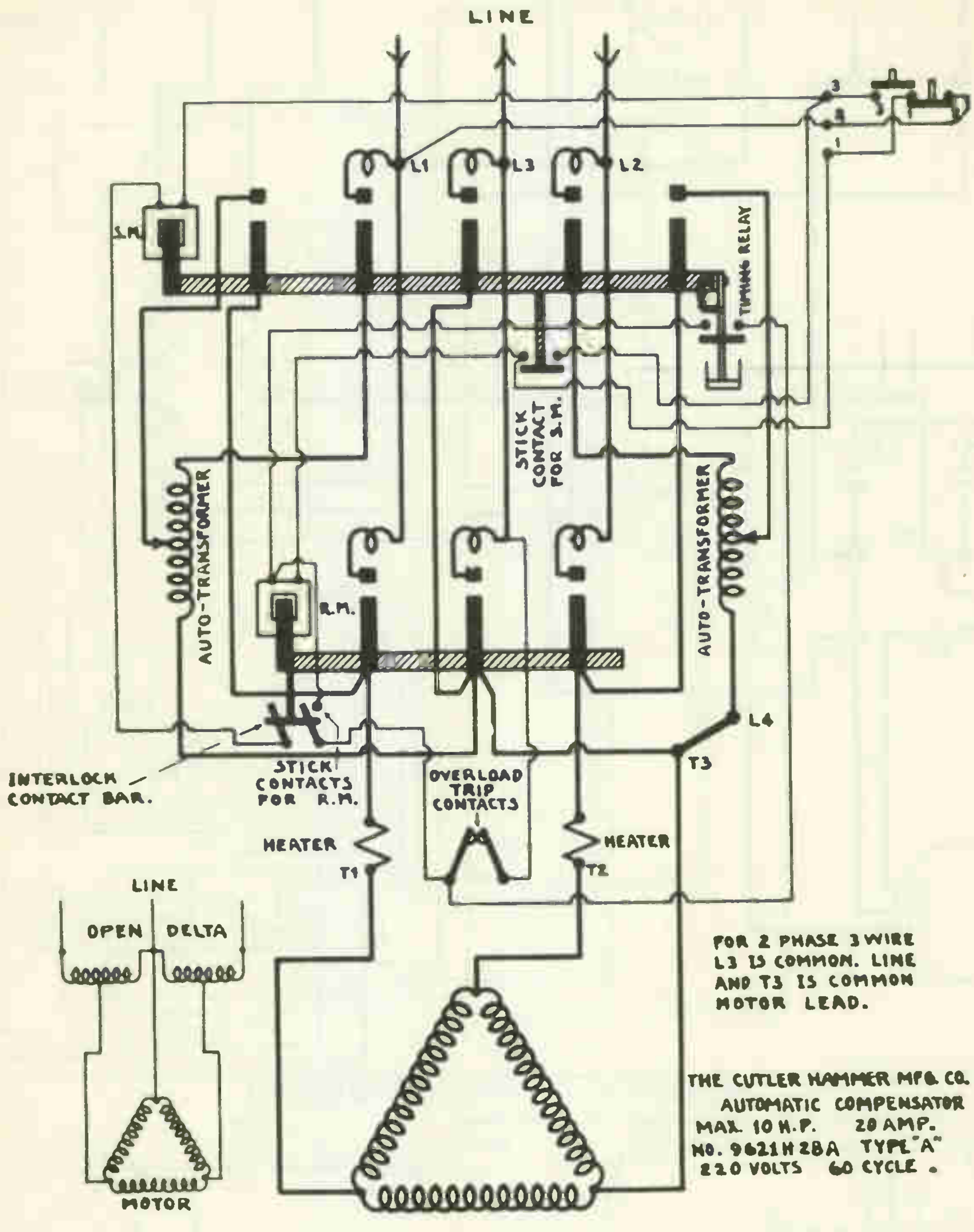


Figure 6. A Cutler Hammer Starter which is used for reduced voltage motor starting. Trace the following circuits:

1. S.M. Start
2. S.M. Stick
3. Motor Start
4. Auto-Transformer
5. R.M. Start
6. R.M. Stick
7. Motor Run

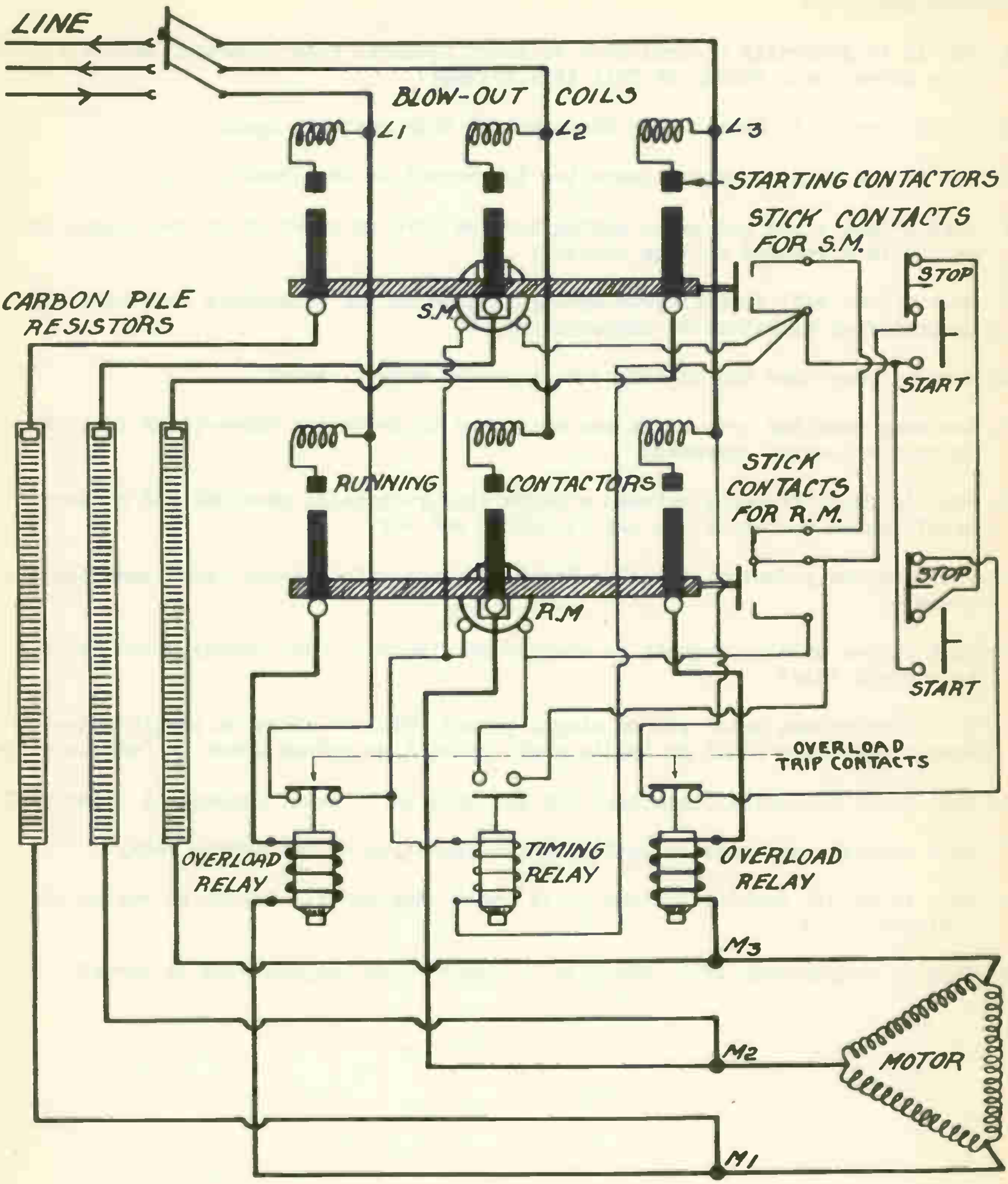


Fig. 7 Automatic resistance starter

F. Summary Questions

1. Why is it generally undersirable to start squirrel cage induction motors above five horse-power rating at full line voltage?

2. Which circuit is broken when the overload trip contacts open?

3. How is the holding magnet connected in respect to the line?

4. What effect would excessive spring tension have on a set or on one single contactor in a reduced voltage starter?

5. What effect will insufficient spring tension on the contactors have upon the operation of an automatic compensator?

6. What purpose does the shading coil on an AC magnet serve?

7. How many overload trip coils are necessary to protect a three-phase circuit against excessive currents?

8. What is the difference between a magnetically-operated overload and a thermal type? Which one would you say is better and why?

9. What are the principal troubles found in compensators aside from loose connections?

10. What causes holding magnets to chatter or vibrate? What remedy would you use to correct this?

11. Will a polyphase motor run on single phase? Will it start on single phase? What compensator fault or faults might cause a polyphase motor to "single phase"?

12. What is an electrical interlock and for what is it used? Mechanical interlock?

13. What circuits are made or broken by the operation of the timing relay?

14. What is an oil dashpot? Where is it used? How can its action be varied and limited?

15. What is compensator oil? Where is it used? What purpose does it serve?

NINE LEAD THREE PHASE MOTORS

Objective

To learn how to identify the leads of a nine lead motor and make proper connections, if the identifying tags have been lost.

References

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Lesson Content

NOTE: The nine lead motor is a dual voltage motor making it possible to operate the motor on either of two voltages without disassembling the motor. The most common operating voltages are 220 and 440 volts.

A. Types of Connections - Star or Delta

When completed, Fig. 1 will show a nine-lead star connected stator winding.
When completed, Fig. 2 will show a nine-lead four-pole delta connected stator winding.
Fig. 3 shows a symbol diagram of the star connection with the two possible voltage connections and the popular ASA numbering system used.
Fig. 4 shows a symbol diagram of the delta connection with the two possible voltage connections and ASA numbering system used.

B. Star or Delta

We must first determine whether the motor is connected star or delta.

On reference to Fig. 3 and 4, we find the star connected motor will have four separate circuits. The delta will have three separate circuits only.

A multimater or test lamp could be used for checking between leads for continuity; this would indicate whether the motor is star or delta connected.

C. Testing and Identifying the leads on a Nine-lead Star-connected motor, Fig. 1 and 3.

1. Find the three leads between which continuity may be obtained. Tag leads (7-8-9).

2. Find the other three circuits and tag them temporarily (1-4 2-5 and 3-6).

3. Apply the lowest name plate voltage to leads 7-8-9 and operate motor.

NOTE: All other leads are left disconnected.

4. Take a voltage reading across each of the three open circuits - approximately 58% of line voltage (127 volts if 220 volts is applied).

5. Connect 4-7 temporarily, motor still running, and measure voltage across 1-8 and 1-9.

Three sets of different readings are possible:

a. If voltages are approximately equal and approximately, 150% line voltage - tag permanently.

b. If voltages are approximately equal and approximately 58% line voltage - interchange 1-4.

c. If voltages are unequal - then connect 4 to 8 and try same procedure until both voltages are equal and approximately 150% line voltage. Now make the tags permanent.

6. Apply procedure under "5" to the two remaining circuits.

7. After all leads have been permanently tagged, motor still running, connect 4-5-6 together and read the voltage between 1-2-3 which should be approximately equal to 100% of the applied voltage.

D. Identifying Leads of a Delta Connected Motor (Rotational Method)

1. By making comparative resistance test, locate and permanently tag T1, T2 & T3.

2. Mark, tempoarily, leads T4 and T9 in the same circuit with T1; T5 and T7 in the same circuit with T2; T6 and T8 in the same circuit with T3.

3. Apply lower voltage to T1, T4 and T9, with "A" line to T1; "B" line to T4' "C" line to T9. Now measure the applied voltage.

CAUTION: Do not permit prolonged motor operation with incomplete connections. Use for phasing operation only.

4. Observe direction of rotation, (CCW preferred), reverse lines "B" and "C" if rotation is other than desired.

5. Change line connections to T2, T5, T7 with "A" line to T2, "B" line to T5, "C" line to T7. Observe direction of rotation. If reversed with respect to step 4, reverse lines "B" and "C", and also the identity of T5 and T7.

6. Repeat above procedure with 3rd group including leads T3, T6, and T8. Be careful to use the same line sequence, i.e., A line to T3, B to T6 and C to T8.

7. Tag all leads permanently.

8. Complete a single circuit Delta connection for operation on 440 volts, with

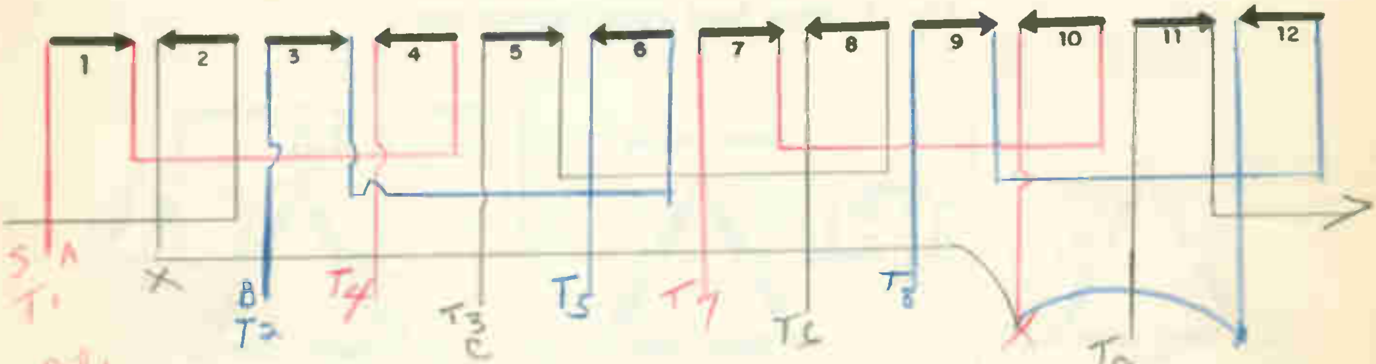

Fig. 1

Fig. 2

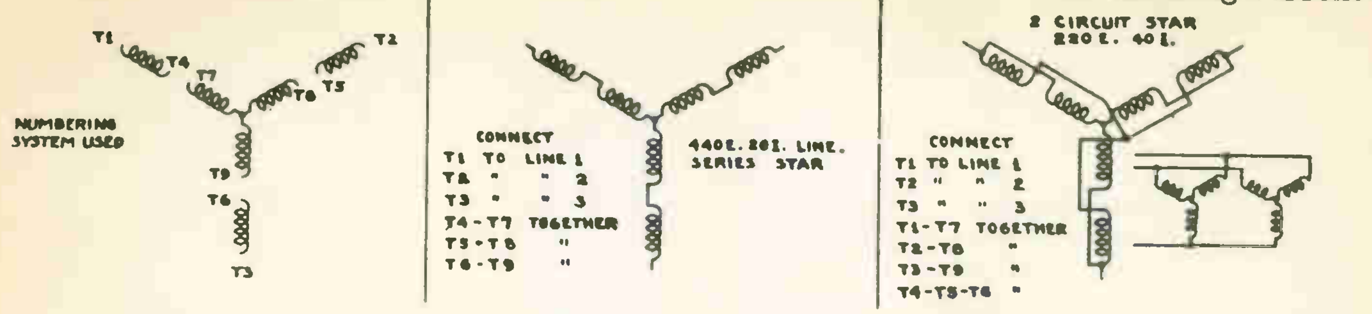

Fig. 3 Nine lead star connections

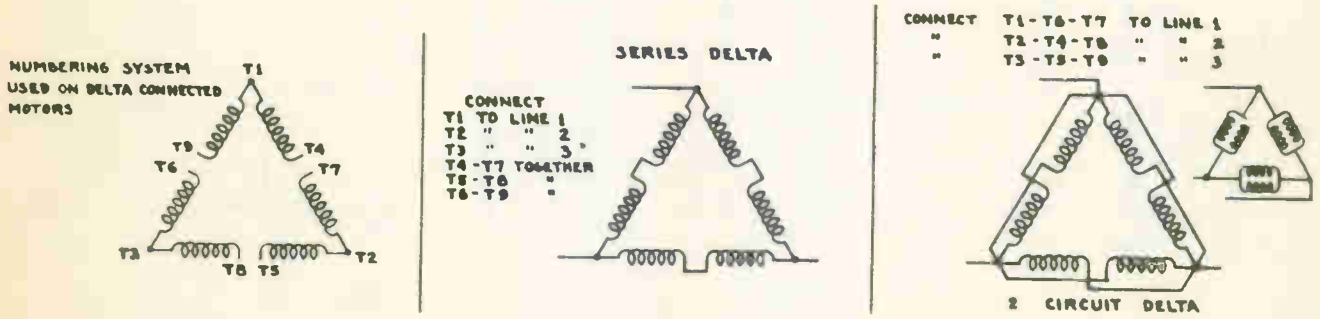

Fig. 4 Nine lead delta connections

line "A" to T1, line "B" to T2, and line "C" to T3' jumper T4 to T7, T6 to T9, and T5 to T8. Direction of rotation should remain unchanged with respect to that selected for phasing out leads. The voltage from the junctions or jumpers to the two adjacent line leads, should be 50% of phase voltage.

9. Measure voltage across T1 to T5 or T8, T2 to T6 or T9, T3 to T4 or T7. These readings should be the same and nearly equal to 86.6% of the line voltage.

10. Complete a double circuit delta connection for operation on 220 volts, with the line in the same position (T1, T2, T3). Jumper T1-T6-T7, T2-T4-T8, T3-T5-T9. Measure the voltage across each half phase. These readings should equal the line voltage.

E. Summary Questions

1. How many circuits should be found in a star connected dual-voltage motor?

2. How many leads should be found in a standard type of dual-voltage star connected motor?

3. When testing a star connected dual-voltage motor, what percent of applied voltage indicates proper lead identity when testing across one and one-half phases with line leads connected to T7-T8-T9. ______________________________

4. How many leads on a standard delta connected dual-voltage motor?

5. Does the horsepower of a given motor change when the connections are changed, on a nine lead motor, from star to delta? Explain.

STAR-DELTA MOTOR STARTERS

Objective

To learn more about star and delta connections. To learn the principles of this emergency starter and the uses to which it may be applied.

References

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Lesson Content

A General Information

The star-delta motor starter is a switching arrangement used to connect a three phase motor star when starting, and change the connection to delta for continuous operation. See Figs. 1-a, 1-b, and 1-c.

Manually operated - manually operated equipment consists of a three pole double-throw switch of the safety or enclosed type. Magnet cally operated starters for star-delta starting may consist of two sets of three contactors each with necessary holding and interlocking switches.

Commercial Application - commercial application is seldom made, except in cases of emergency, however, the information will help you to gain a better understanding of the windings, voltages, and current relationships encountered in star and delta connections.

B. Internal Motor Connections

The motor selected for star-delta starting must have an original connection of delta, with a full voltage rating equal to that of the supply lines. If three leads only are brought out, it will be necessary to disassemble the motor, separate the start and finish leads at the 3 junction points of a delta connected winding and bring out three start and three finish leads (6 total leads). If identity of start and finish leads of phases is lost during this operation, re-identification may be established through trial operation.

The Start Position or Connection - A star connection places two phase windings in series between any pair of line wires. The voltage per phase is thus reduced to 58% of the line voltage. Example: Phase voltage equals line voltage times 0.58, or 240 V x 0.58 = 139.2 volts per phase during the starting period.

Since the starting torque varies as the square of the percentage of normal full voltage applied, torque developed equals 0.58^2 or 0.3364 or 33.64% of full voltage torque. This may be considered as a disadvantage of the star-delta starter.

From Star to Delta - The change from star starting to delta run involves nothing more than moving the double throw switch from one position to the other with little loss of time. CAUTION: Do not start motor with delta connection. Phasing out of motor leads should be accomplished with the wye connection only.

Line voltage . . . . 250 Volts

Connect motor star for phasing out, assuming starts and finishes. If motor is properly phased, make the following tests:

Voltage across "A" phase . . . . 140 E Volts

Voltage across "B" phase . . . . 140 E Volts

Voltage across "C" phase . . . . 140 E Volts

With the motor improperly phased and connected star, make the following tests: (NOTE: do not connect the motor delta with improper phasing.)

Voltage across "A" phase . . . . 175 E Volts

Voltage across "B" phase . . . . 110 E Volts

Voltage across "C" phase . . . . 140 E Volts

Indicate which phase is improperly connected.

With motor properly phased, and connected delta, make the following test:

Voltage across "A" phase . . . . 250 E Volts

Voltage across "B" phase . . . . 250 E Volts

Voltage across "C" phase . . . . 250 E Volts

With motor properly phased, connect delta and bring up to full speed. Open 1 line from the 3 phase supply and make the following tests:

Voltage across "A" phase . . . . 210 E Volts

Voltage across "B" phase . . . . 250 E Volts

Voltage across "C" phase . . . . 225 E Volts

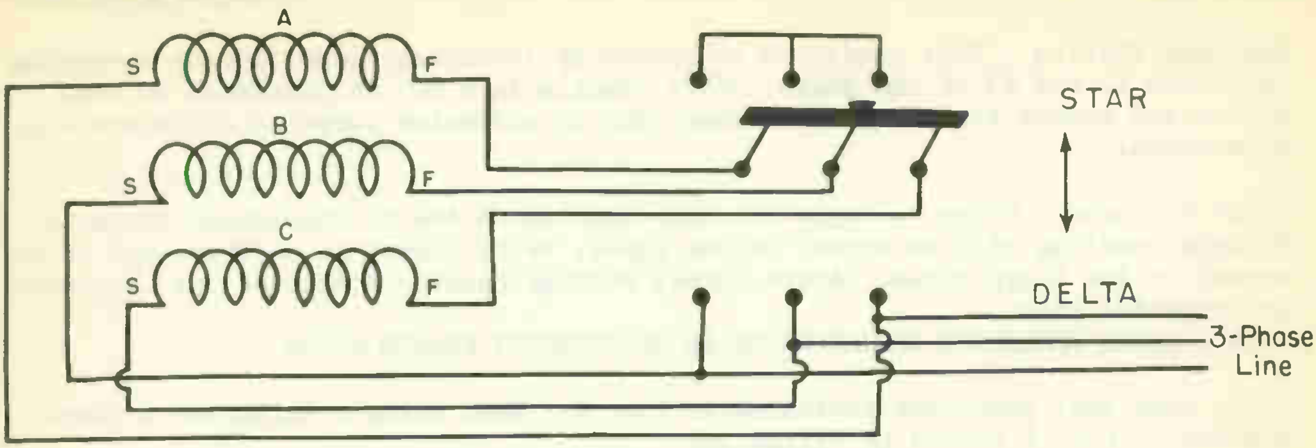
With motor properly phased, connect star and bring up to full speed. Open 1 line from the 3 phase supply and make the following tests:

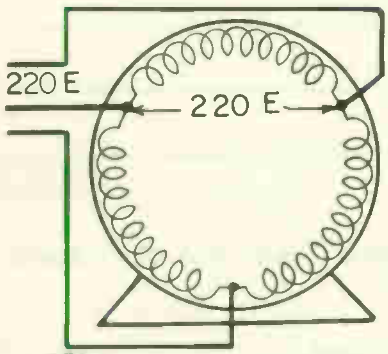
Voltage across "A" phase . . . . 110 E Volts

Voltage across "B" phase . . . . 130 E Volts

Voltage across "C" phase . . . . 130 E Volts

Fig. 1 This chart is the test chart used with the voltmeter method.





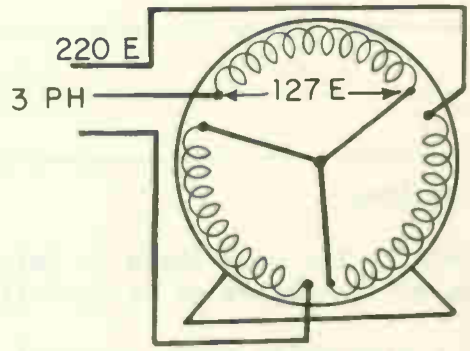
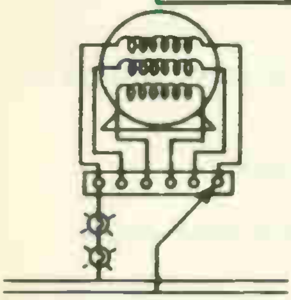
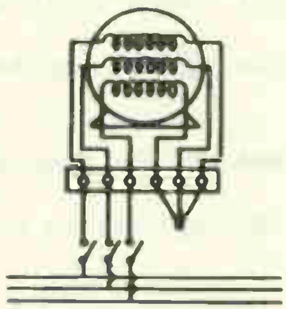


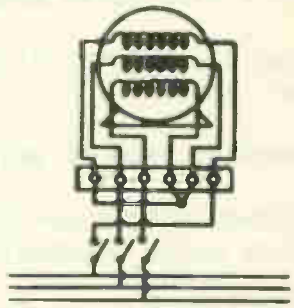
Fig. 2



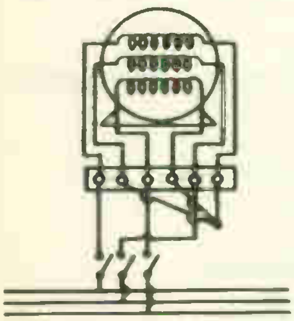
a. Testing to find the ends of the phases.



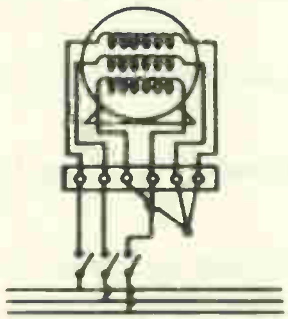
b. Assume 3 ends to be finishes and connect together. Connect 3 starts to line.



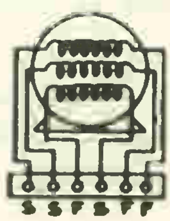
c. If motor is noisy reverse leads connected to phase "A" if no improvement see d.



d. Replace "A" leads and reverse leads of "B" phase. If no improvement see "e".



e. Replace "B" leads and reverse leads of phase "C". Motor should now operate.



f. When motor operates mark phases as shown above.

Fig. 3 The above six diagrams show the test-lamp method of lead identity.

Improper Phasing - This condition is caused by incorrect connection or reversing the leads (S and F) of one phase. This results in a 60° displacement between phases and causes the motor to overheat due to excessive currents which are also unbalanced.

Phase Voltages - Phase voltages are also unbalanced due to unbalanced currents. Voltage readings will be normal on one phase, below normal on another, and above normal on the third phase. Above normal voltage reading indicates the incorrectly connected phase.
NOTE: AVOID PROLONGED OPERATION OF AN INCORRECTLY PHASED MOTOR

Study over test procedure indicated in Fig. 3. When using a voltmeter a chart similar to Fig. 1 should be filled in.

B. Summary Questions

1. State briefly the four tests to determine the phase leads and the starts and finishes of the phases of an induction motor.
2. What is a star-delta motor starter? Where is it used?
3. Why does the electrical code advise against the use of this starter except in extreme cases?
4. What sort or type of switch is used for the star-delta starter?
5. What disadvantages are found in the application and use of the star-delta emergency motor starter?
6. When the switch is in the star or wye position, what is the voltage per phase relationship with that of line voltage?
7. Why should a motor with a star-delta starter never be started in the delta position? Would it harm the motor?
8. What torque is developed at the instant of starting when the motor is started star?
9. Explain how a star-delta starter can be applied to a motor which has only three external leads.
10. May the star delta starter be applied to a star connected stator?

SLIP-RING MOTORS

Objective

To learn the principal parts of the wound rotor induction motors, its uses, limitations, and the principles of operation.

Reference

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Lesson Content

A. Construction

1. Stator and Rotor.

The stator winding is phase wound, usually double-layer (2 layer) and may be connected star or delta for three phase operation. The delta connected stators are the more common.

The rotor winding is phase wound, also 2 layer, and usually connected star for three phase machines. Rotors for small motors are wire wound in the form of a LAP winding. Those of large machines are of ribbon or bus conductors connected in the same manner as wound wire windings, or bar conductors connected in the form of a WAVE winding.

2. Connections (internal)

The rotor winding is connected to a set of three slip rings, which provide a sliding connection to an external circuit containing a resistor unit. A slip ring is a continuous band of copper, bronz or alloy which is insulated from the shaft and other slip rings.

3. Connections (external).

The external resistor unit or "Y-box" consists of three legs connected in star. It may be wire or ribbon wound, or cast iron grids. It is designed for starting duty only, in some cases, and will be so rated. Generally, however, the unit is designed for continuous duty or control duty, and will have that rating stamped or marked on the unit.

4. Advantages.

The motor should always be started with all resistance inserted in the rotor circuit, Fig. 1, to obtain the following advantages:

1. Low Starting Current

2. High Starting Torque

3. Smooth Starting Action

Increasing the rotor circuit resistance serves to limit the rotor current, thereby, limiting the stator current drawn from the supply.

5. Starting Torque

Increased starting torque is due to a more favorable space relationship of the stator and rotor poles. In lesson No. 12 on motor characteristics, we learned that increasing the rotor resistance during starting periods decreased the angle of displacement between rotor voltage and current. This establishes the rotor pole in a more favorable position with respect to the stator pole, resulting in maximum useful reaction between them. (Compare Fig. 2-a and 2-b).

If the rotor resistance is increased above a certain critical value, the torque will be reduced as indicated by the curves in Fig. 2-c. Design of the rotor resistance unit should satisfy the requirements of the motor on which it is to be used.

B. Characteristics

Torque - The average slip ring motor will produce about 3 times normal full load torque, and will draw 2.5 times full load current at starting.

Speed Regulation - Speed regulation is good, usually will not exceed 5% of full load speed with all external resistance cut out. As resistance is inserted, speed regulation becomes rapidly poorer.

Speed of this motor may be controlled below normal by inserting resistance in the rotor circuit, but reduced speed is obtained at the expense of efficiency due to increased I^2R losses in the rotor resistance. The electrical efficiency of the rotor is equal to the ratio of the actual rotor speed to synchronous speed. For example, at 30% slip, the rotor efficiency is 70%. Of the power induced in the rotor, 30% is lost as heat in the rotor resistance. The remaining 70% is converted into mechanical power, but is not all available at the shaft due to friction and core losses.

When resistance is introduced into the rotor circuit, the rotor impedance is increased thereby decreasing the rotor current and torque, momentarily.

Since a given torque is required to drive any given load, the rotor current must be increased to bring the torque back to its original value. The rotor current is proportional to the induced rotor emf, or $I = \frac{\text{rotor voltage}}{\text{rotor impedance}}$

The air gap flux being constant, an increase in emf may be obtained only by this flux cutting the rotor conductors at a greater rate. Stator field rpm is synchronous and is determined by frequency and number of poles. The rotor RPM must decrease in order to increase the rotor emf and thus restore rotor current and torque to its original value. For a given value of torque, therefore, the slip must increase when resistance is introduced in the rotor circuit.

Applications - cranes, elevators, conveyers, printing presses, hoists, or in general, wherever improved starting characteristics and variable speed are required. It should not be considered as a general purpose motor due to increased cost of motor and control equipment over that of ordinary squirrel cage motors.

Maintenance - Some trouble will be encountered with the slip-rings, brushes, and holders, and the external resistor which do not exist in ordinary squirrel cage machines.

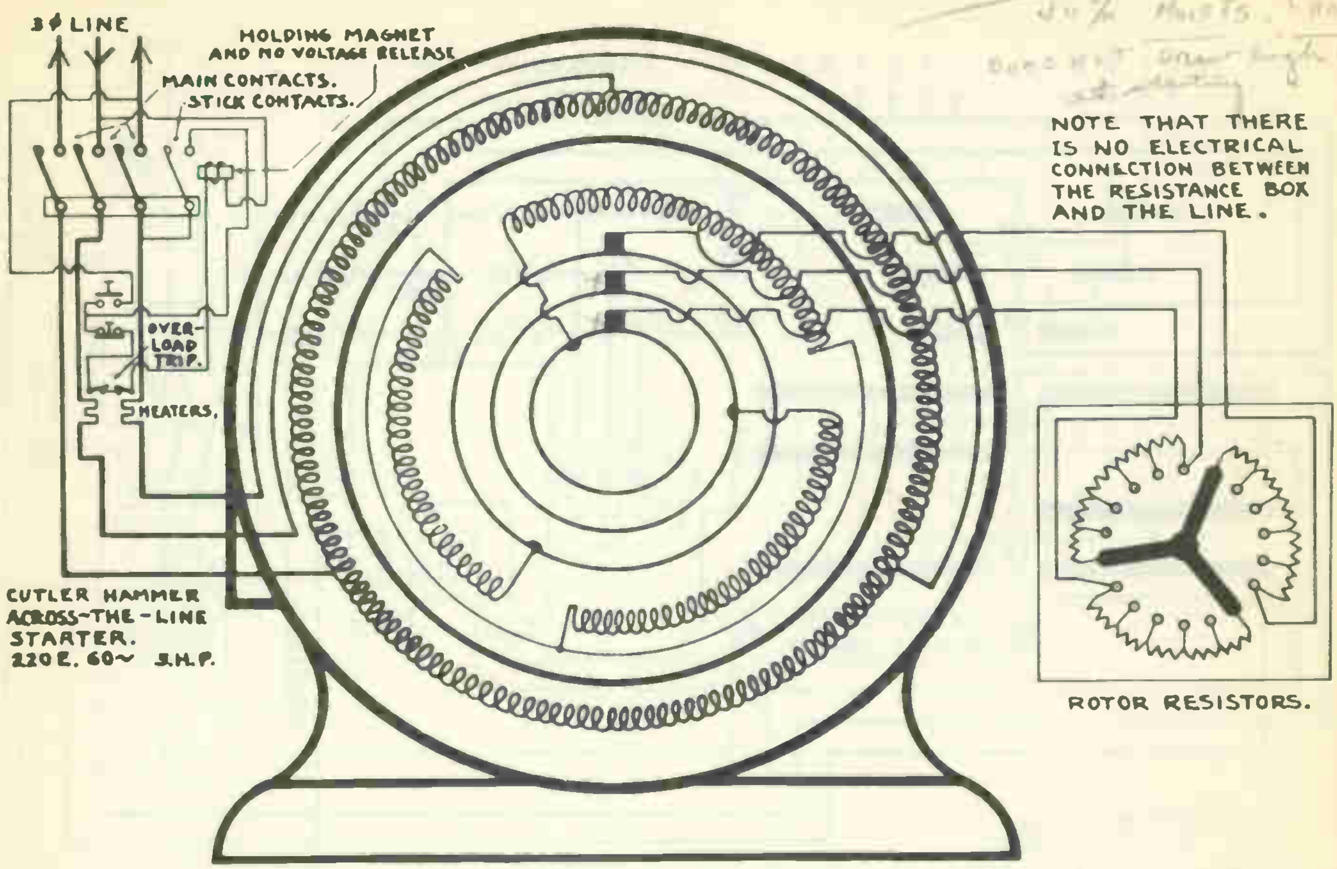


Fig.1 Slip-ring motor with a "Y" box including the electrical interlock connection block

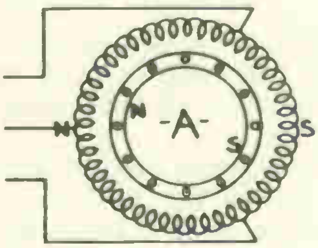


Fig. 2A Low resistance type note position of poles

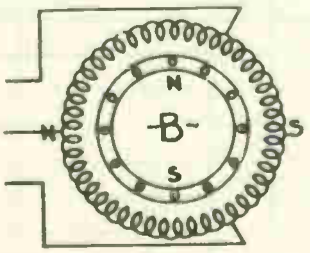


Fig. 2B High resistance type note position of poles

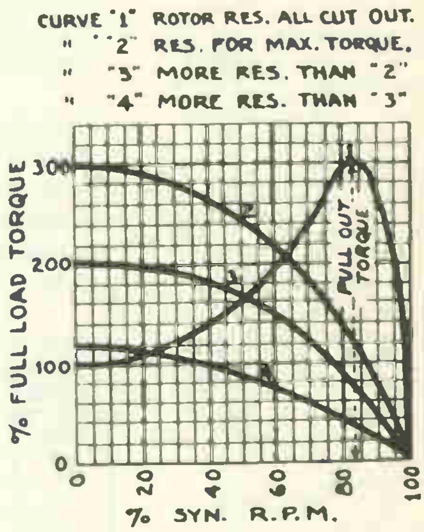
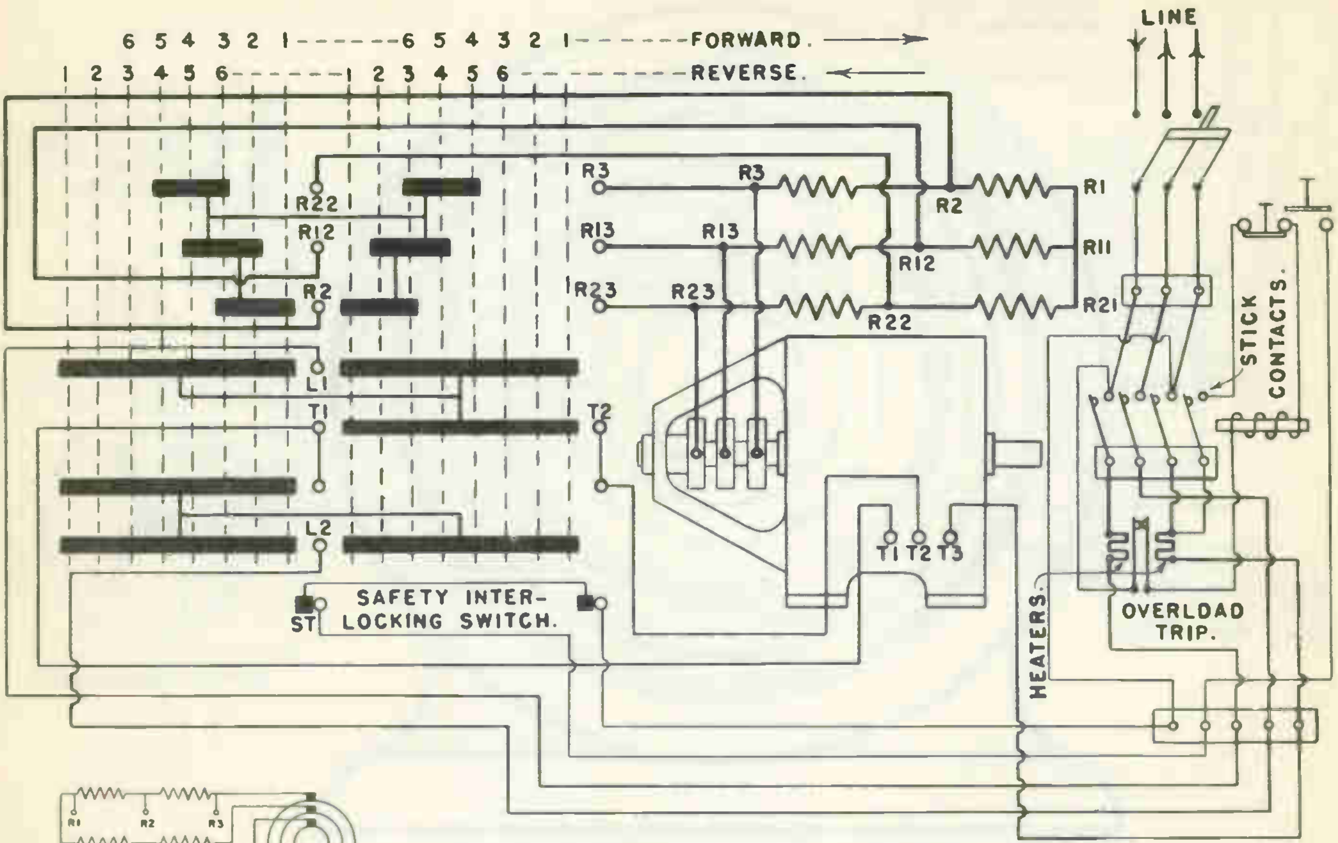
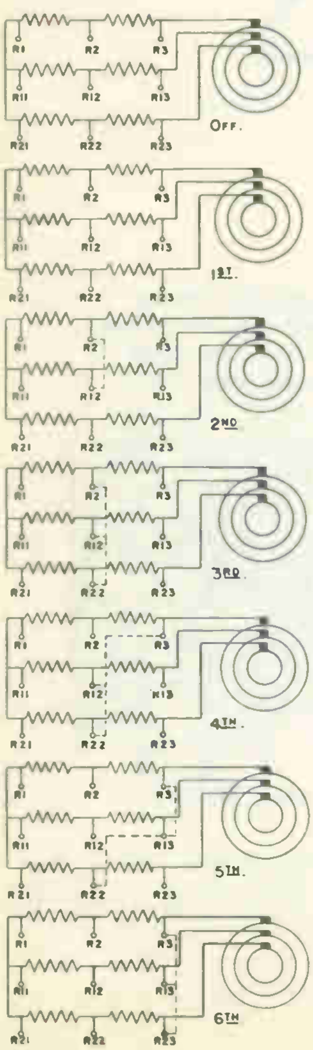


Fig. 2C Comparison curve for a slip ring motor and its controller.





The above diagram shows a slipring induction motor equipped with an across-the-line starter for applying power to the stator circuit, and a controller for cutting resistance in or out of the rotor circuit for starting and speed regulation purposes.

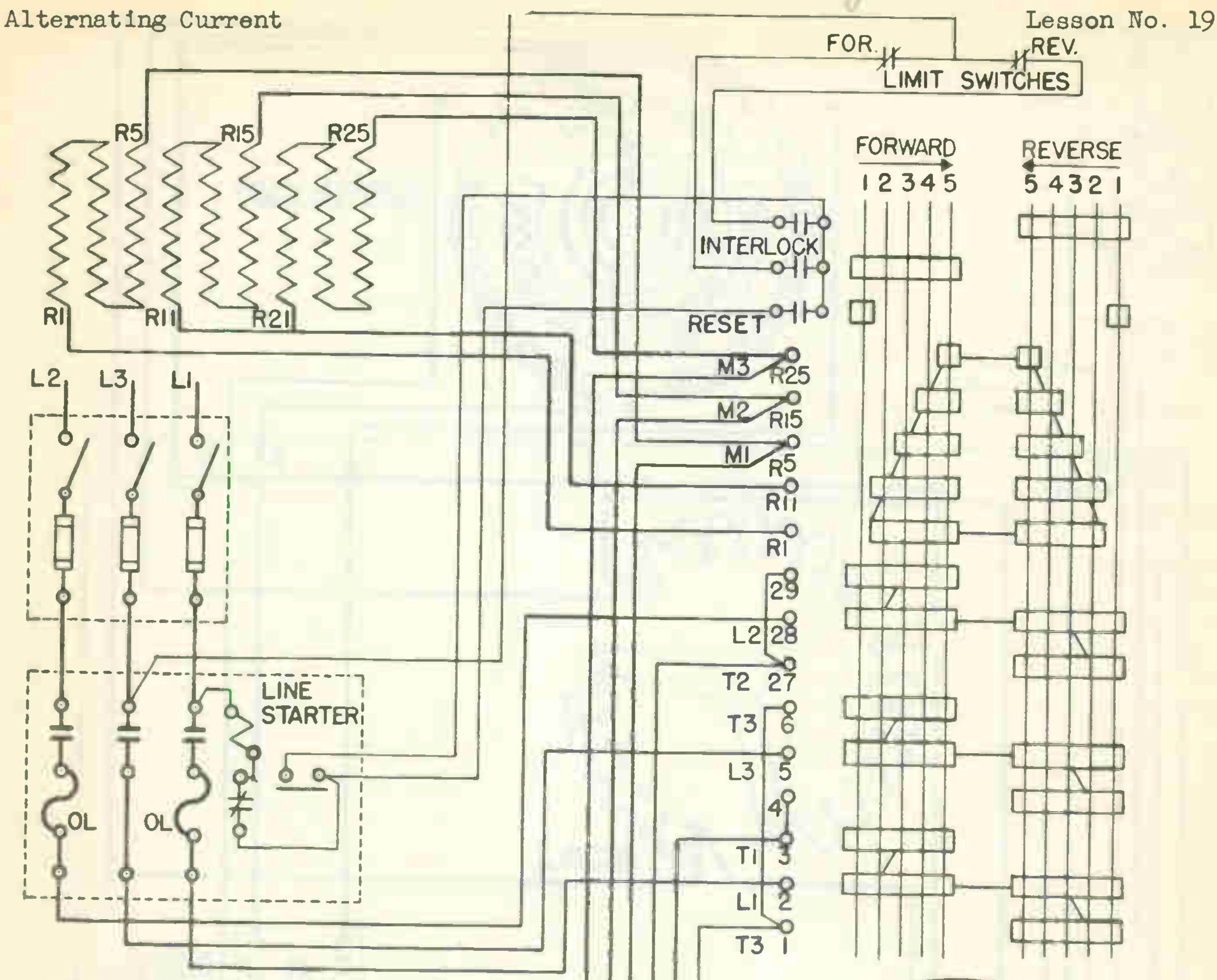
Note that the order in which the rotor resistors are short circuited is different from that employed by the controller shown on the reverse side of this sheet.

For smooth starting, all resistance should be in the rotor circuit when power is applied to the stator. To insure this condition, the above drum controller is equipped with a switch connected in series with the starting button on the cross-the-line starter. This interlocking switch is closed only when the controller handle is in the OFF position.

CONTACTOR SEQUENCE.

CONTACTS.	FORWARD.						OFF.	REVERSE.					
	6	5	4	3	2	1		1	2	3	4	5	6
R22													
R12													
R2													
R3													
R13													
R23													
L1													
T1													
T2													
L2													
ST													

Job 13 A



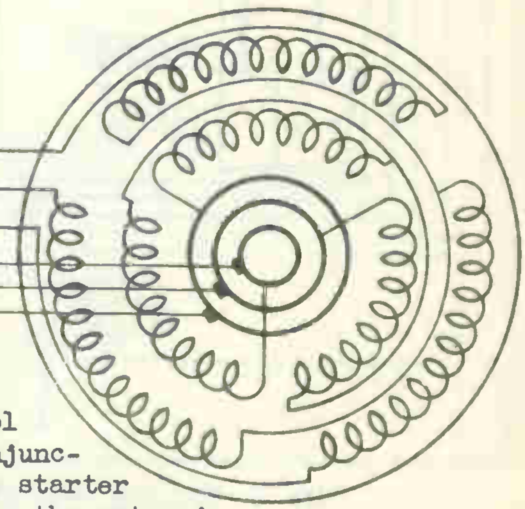
CIRCUITS—

MAGNET RESET, FORWARD— REVERSE—

MAGNET HOLDING, FORWARD—REVERSE—

STATOR, FORWARD— REVERSE—

ROTOR, FORWARD— REVERSE—



CONTACTOR SEQUENCE CHART

CON-TACTS	FORWARD 1	2	3	4	5	OFF	REVERSE 5	4	3	2	1
R-INT.											
F-INT.											
RESET											
R25											
R15											
R5											
R11											
R1											
T2,29											
L2,28											
T2,27											
T3,6											
L3,5											
T1,4											
T1,3											
L1,2											
T3,1											

Interlock switches are provided on the drum control and operate in conjunction with the line starter to prevent starting the motor in any control position except number one. This assures the presence of the resistor unit in the rotor circuit during the starting period. The travel limit switches will interrupt the relay circuit in the event the travel limit is reached by such machines as lathes, planers, shapers, hoists and cranes. The motor may be operated in the opposite direction only until limit switch recloses.

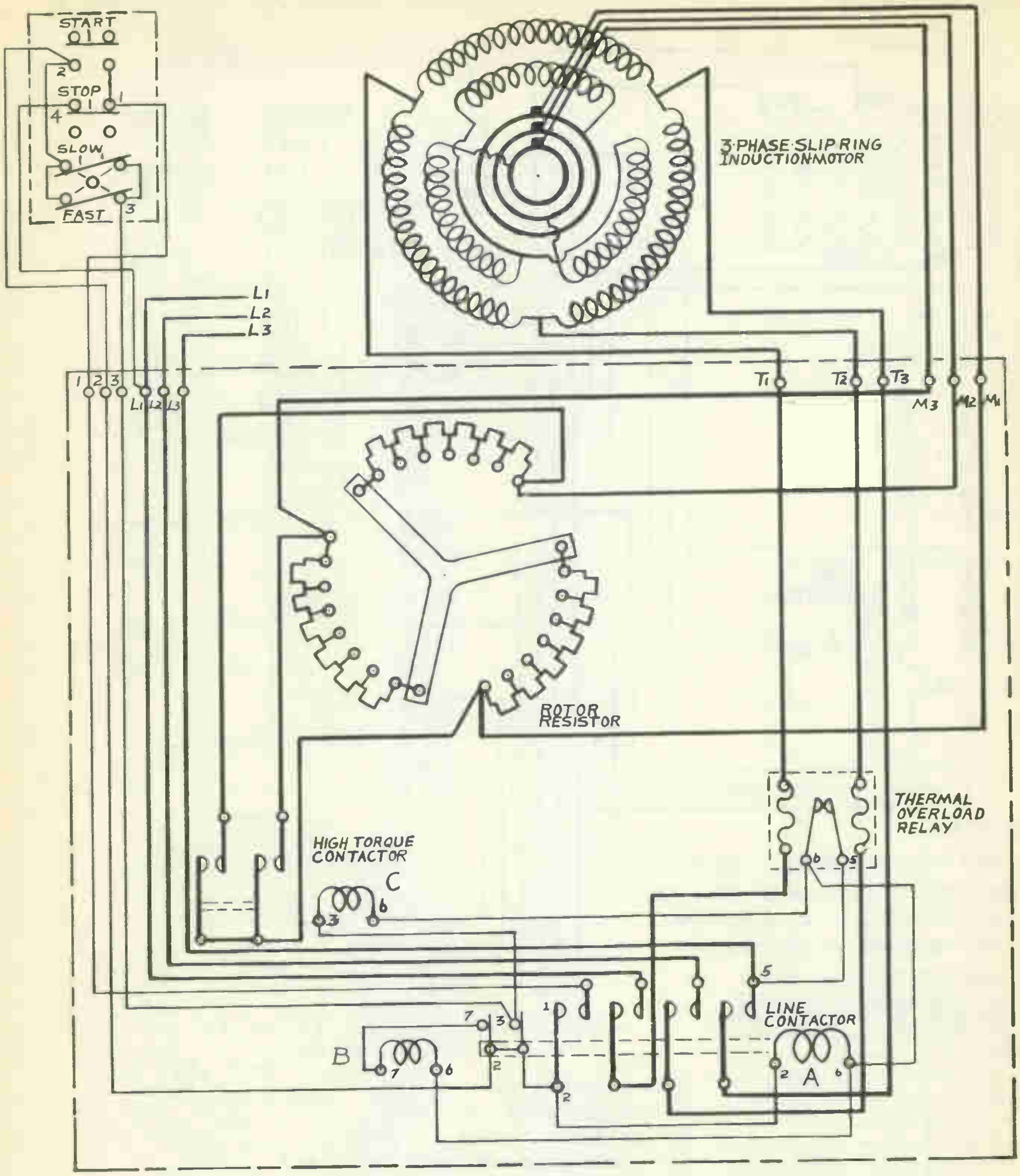


Fig. 5 Hosiery machine controller. This control is designed for use with a specially designed slip ring motor which contains a low voltage rotor winding. Operation is as follows: 1.Closing the Start switch at remote control station energizes relays A,B and C. 2. The stator is energized through the line contactors. 3.Contacts 7 and 3 are normally closed, but are opened by the action of timer relay B. 4.Relay C is energized momentarily and closes the high torque contactor which short circuits the rotor resistor and permits a current surge to the motor, thus improving the starting torque. 5.A change in speed may be obtained from remote control by adjustment of the Slow-Fast switch which controls relay C.

E Control Variations

Figures 3, 4 and 5 show some of the many variations of control types that may be encountered in the field. Although many controls are designed especially for a certain machine, it will be noticed that, with few exceptions, they are all basically the same unit.

F. Summary Questions

1. What are the advantages and disadvantages of an induction motor using a high resistance squirrel cage?

2. In what motor are the advantages of a high resistance squirrel cage type combined with the advantages of a low resistance squirrel cage type?

3. How does insertion of resistance in a rotor circuit increase the starting torque of the slip ring induction motor?

4. What advantages does the slip ring induction motor have over the low resistance squirrel cage type?

5. What is the customary connection of a slip ring motor stator?

6. What is meant by the term "phase wound"?

7. Explain how stator current is limited in the slip ring motor.

8. What are the torque and current characteristics of the slip ring motor at the instant of starting?

9. What formula may be used to determine the rotor current?

10. What are some of the applications of this type of motor? Maintenance problems?

A C METERS

Objective: To learn principles of operation, limitations, and applications of a-c meters.

References

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Lesson Content

A. General

This chapter is given under the assumption that the basic concepts of meters in general, are understood. It will be remembered that meters were discussed in previous departments.

B. Repulsion-type Instrument

This moving-iron instrument is extensively used for both current and voltage measurements. It is called the repulsion type because its operation depends upon the repelling force developed between two pieces of soft iron subjected to the same magnetic field. Its fundamental construction and the manner in which torque is developed in the repulsion instrument are indicated by Fig. 1A & 1B. One iron vane is attached, along one edge, to the instrument shaft. The other vane is attached to the field coil frame, so as to be stationary. With no current in the field coil the control spring holds the movable vane close to the fixed vane, and the pointer attached to the shaft, rests at zero. As soon as current flows in the field coil, both iron vanes are inductively magnetized in the same polarity, and their like poles, therefore, repel.

Scales - since the magnetism of each vane is proportional to the current in the field coil, the repelling force varies as the square of the current. See Fig. 2. This does not produce a uniform scale, but because the repelling force also varies inversely as the square of the distance between the vanes, the instrument has a substantially uniform scale, Fig. 3.

Moving Vane - Because of its method of mounting, the moving vane rotates with the shaft until the torque doe to the repulsion between the two vanes is balanced by the countertorque of the control spring, and the magnitude of field current is indicated by the position of the pointer.

When direct current flows in the field, the polarity of the magnetism induced in the iron vanes will depend on the direction of current through the field, but since both vanes are magnetized alike, the repelling force will be the same, regardless of the direction of current in the field. Therefore, with alternating current in the field, the magnetization of both vanes will reverse with each reversal of current through the field; the vanes will always repel each other; and torque will be developed to move the point along the scale.

Damping Methods - D-c instruments have within the instrument structure a damping mechanism which tends to retard the rapid movement of the needle up-scale or down-scale. Not so with the moving-iron instrument, since it is provided by supplementary means, usually sub-classified as:

1. Magnetic damping - accomplished by supporting a thin aluminum or copper vane between the poles of a small permanent magnet. Notice Fig. 4-a and Fig. 4-b in which the deflection of the moving system causes the damping vane to cut the flux of the damping magnet, thus inducing current in the vane. The field produced by this current interacts with that of the damping magnet tending to oppose the motion of the moving system and bring it to rest quickly.

2. Air damping - Fig. 5 shows a method of air-damping the meter movement. This method depends upon the resistance which air, in a closed chamber, offers to the movement of a light vane actuated by the moving member of the instrument. Air damping involves more precise construction than does magnetic damping, which more easily provides very high values of damping.

   "Rms" Current Indicated on Moving-iron Instruments - It has been stated that the torque developed in the moving-iron instrument results from the interaction of the coil flux and the flux induced in the iron vane, and that the polarity relation of these fluxes is the same, regardless of the direction of current in the field coil, graphically illustrated in Fig. 2. The instantaneous torque is proportional to the square of the instantaneous current and since the square of a negative quantity is a positive quantity, the negative half cycle of the field current gives a positive torque impulse; hence, there are two torque impulses for each cycle. Scale graduations are graduated in the terms of the square root of the average of the squares.

   A-c meter sensitivity is low, or it can be said, generally speaking, most a-c meters are of the lo-sensitivity type.

C. Inclined-Coil Instrument

Another variation or style of attraction moving-iron mechanism which, widely used in high-grade a-c instruments, is the Thomson inclined coil type shown in Fig. 6. This mechanically simple construction, used in both portable and switchboard instruments, provides a long, well distributed scale and satisfactory operating torque.

Operating Principle - The basic operating principle of the Thomson inclined coil instrument is that an iron vane free to move in a magnetic field, tends to take a position parallel to the flux. In the application of this principle, the iron vane is attached to a shaft passing through the center of the coil which produces the magnetic field so that, in aligning itself with the coil flux, the vane causes the pointer, attached to the same shaft, to move across the instrument scale.

With both the coil and the vane mounted at an angle of 45 degrees to the shaft, the shaft turns 180 degrees while the vane is turning from a position at right angles to the coil flux. This is shown clearly in Fig. 7. In practice, the full 180 degree rotation is not usable, because the torque characteristics of the moving-iron element would cause the scale to be badly crowded near the beginning and too widely separated near the center and toward full scale portions.

Consequently, the sealed graduation is started about 75 degrees up from the zero-torque position of the vane and is carried through the usual 90 degrees. This provides a scale in which the low end is expanded for greater accuracy and eas of reading, while the rest of the scale is not excessively expanded, Fig. 3.

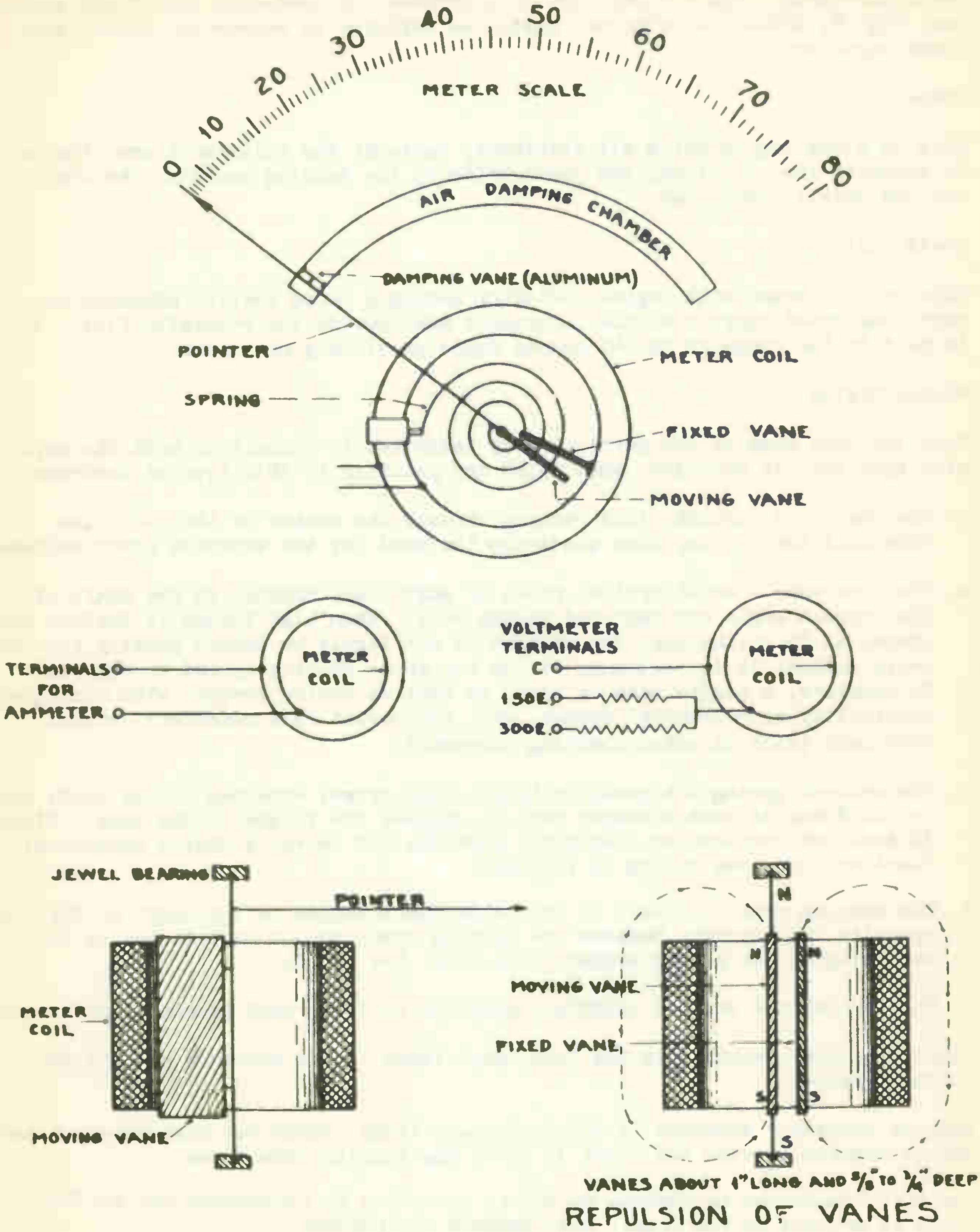


Fig. 1A. Moving iron type ammeter or voltmeter

Principal Parts - The cutaway view of a Thomson inclined-coil instrument mechanism, Fig. 6, shows its principal parts, as employed in commercial production. These parts are:

1. Frame

   This is a casting to which all stationary parts of the instrument are attached. It supports the coil form, the jewel holders, the damping magnets, the scale, and the shield, when used.

2. Field Coil

   This coil is wound with copper conductor having a cross section adequate to carry the rated current of the instrument and provide the requisite flux. It is held in the frame at the 45 degree angle previously mentioned.

3. Moving System

   This includes some of the parts already described in connection with the repulsion type and, in addition, some which are peculiar to this type of instrument.

   a. The shaft - a straight tube passing through the center of the coil. Its ends hold the pivots, thus obviating the need for the separate pivot holders.

   b. The iron vane - an elliptical piece of soft iron, mounted on the shaft at the correct angle and centered in the coil. When high torque is desired and where, as in voltmeters, the current is not likely to exceed greatly the full-scale rating, it is customary to use two vanes equally spaced in the coil. In ammeters, a single vane is used, so that excessive torque, with consequent possibility of mechanical damage, will not result from momentary current overloads (such as motor-starting currents).

   c. The control spring - a phosphor-bronze flat spiral attached to the shaft and to the frame in such a manner that it opposes the torque of the vane. Since it does not complete an electrical circuit, but serves a wholly mechanical function, only one spring is required.

   d. The damping vane - a piece of thin aluminum attached to the shaft on the side opposite the pointer; besides its damping function, it contributes to the balancing of the moving member. See Figs. 4-a and 5.

   e. The pointer and balance weights - similiar to those used in other instruments.

4. Jewel bearings - mounted in the instrument frame, these bearings support the moving member.

5. Damping magnets - attached to the instrument frame, these two high-strength permanent magnets provide the field in which the damping vane moves.

6. The scale-graduated in amperes or volts, according to instrument rating, the scale is mounted on the frame, just beneath the pointer.

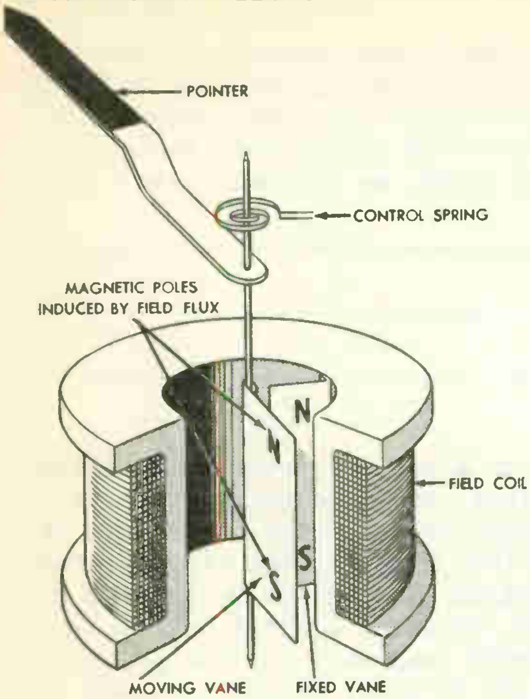


Fig. 1B *Essential parts of radial-vane form of repulsion-type mechanism*

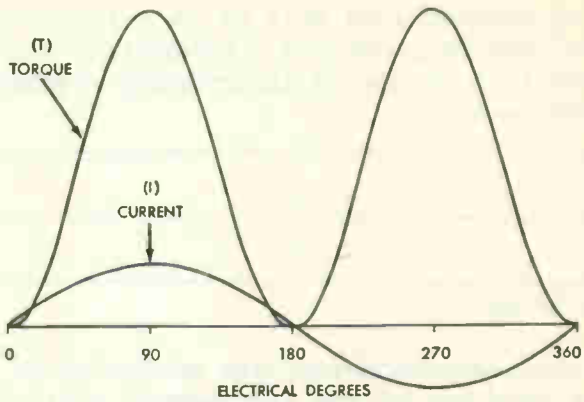


Fig. 2 *Relationship of current and torque in moving-iron instrument*

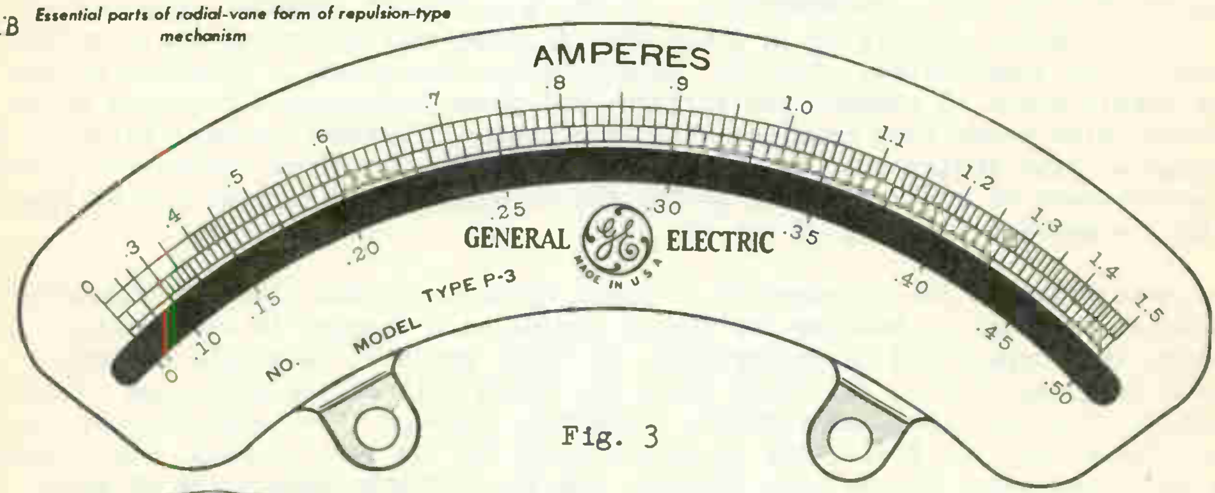


Fig. 3

Scale of typical inclined-coil ammeter

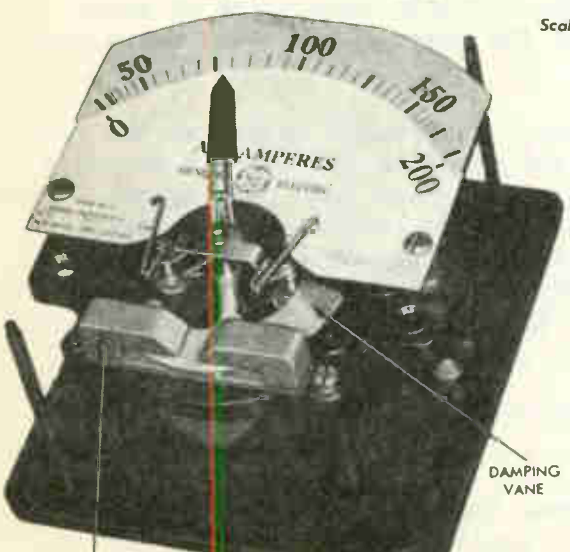


Fig. 4A *Rectangular switchboard instrument, with cover removed to show magnetic damping system*

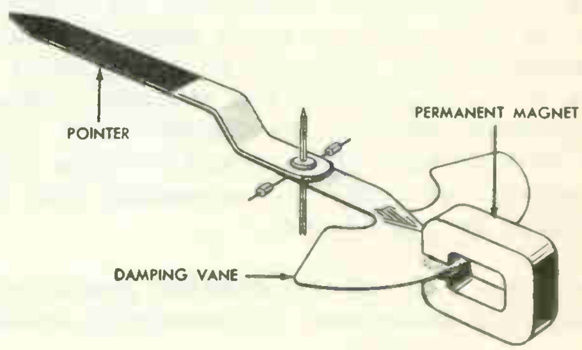


Fig. 4B *Magnetic-damping mechanism*

Applications - The Thomson inclined-coil mechanism is particularly suited to current measurements and is extensively used in high-accuracy portable indicating ammeters, as well as in switchboard-type instruments for both current and voltage measurements. Mechanical-design considerations render this mechanism unsuited to use in instruments requiring minimum depth, as in small panel instruments.

D. Watt meter

The electrodynamometer-type mechanism is adaptable to a greater variety of measurements than any of the instruments previously described, and is especially useful in a-c measurement. It provides a more efficient means of measuring low values of alternating current than is afforded by the moving-iron element, and also is often used for measuring a-c voltage. An additional function, not served by the d-c or a-c instruments already dicussed, is the measurement of power (watts). In a d-c circuit the power is simply the product of the current (amperes) and the pressure (voltage). Therefore, a separate instrument need not be used, except to check calculations, for power measurements. In the a c circuit, however, the current and voltage may not always be in phase that is, they may not reach their maximum values at the same instant, Fig. 8. Consequently, the power is affected by the phase displacement of current and voltage, and power measurement requires an instrument which takes into consideration this phase difference (power factor). The dynamometer-type instrument accomplishes this and is, therefore, extensively used for measurement of power, as well as for the measurement of current and voltage. Notice the mechanism in Fig. 9 and 10.

Power measurement - The measurement of power by means of the electrodvnamometer instrument is possible because the torque varies with changes in either field or armature and current and is proportional to their product. A simple wattmeter diagram is given in Fig. 11. This shows the field coil of the mechanism connected in series with the line, and armature connected, through a resistor, across the line. Therefore, the field flux is proportional to the line current the armature flux is proportional to the line voltage, and the instantaneous value of power in the circuit, the instrument reads the average of the power pulses and, hence, can be calibrated in watts. See Fig. 12.

It is interesting to note that the dyanmometer-type instrument indicates the real power of an a-c circuit, in which the power is not equal to the product of volts and amperes, but is equal to the product of the voltage and that part of the current which is in phase with the voltage. This is an important consideration in a-c measurement, because the current does not always reach its maximum value at the same instant that the voltage reaches its maximum, but generally either lags behind the voltage or leads it, depending upon whether the circuit load is preponderantly inductive or capacitive.

Operation - Fig. 13 illustrates graphically and vectorially the operation of the dynamometer instrument in measuring watts.

Fig. 13-A shows current, voltage, and power curves for one cycle when the current is in phase with the voltage. Under this circuit condition, the power at any instant is positive, since the voltage and current always have the same polarity and the product of two quantities of like sign is positive. With the dynamometer instrument connected in this circuit, as indicated in Fig. 11, the field flux and the

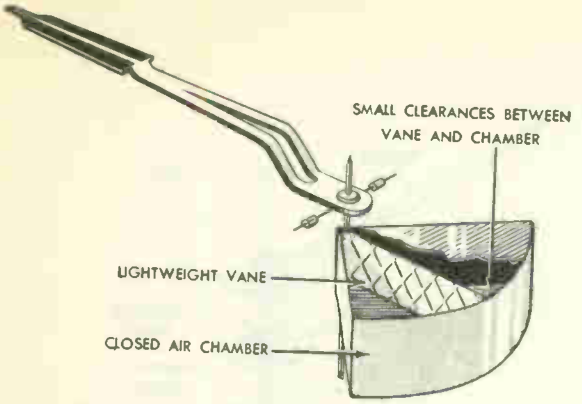


Fig. 5 *Air-damping mechanism*

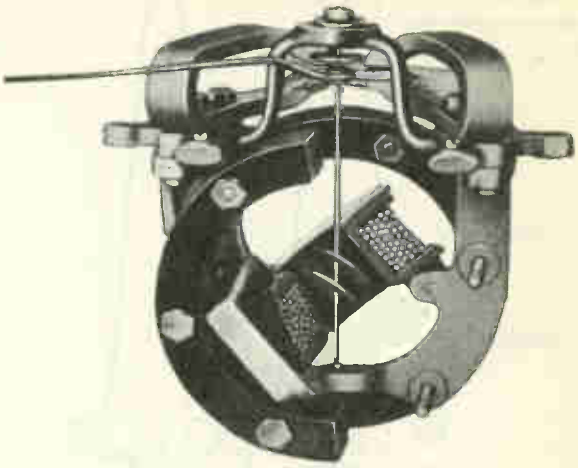


Fig. 6 *Cutaway view of inclined-coil attraction-type voltmeter*

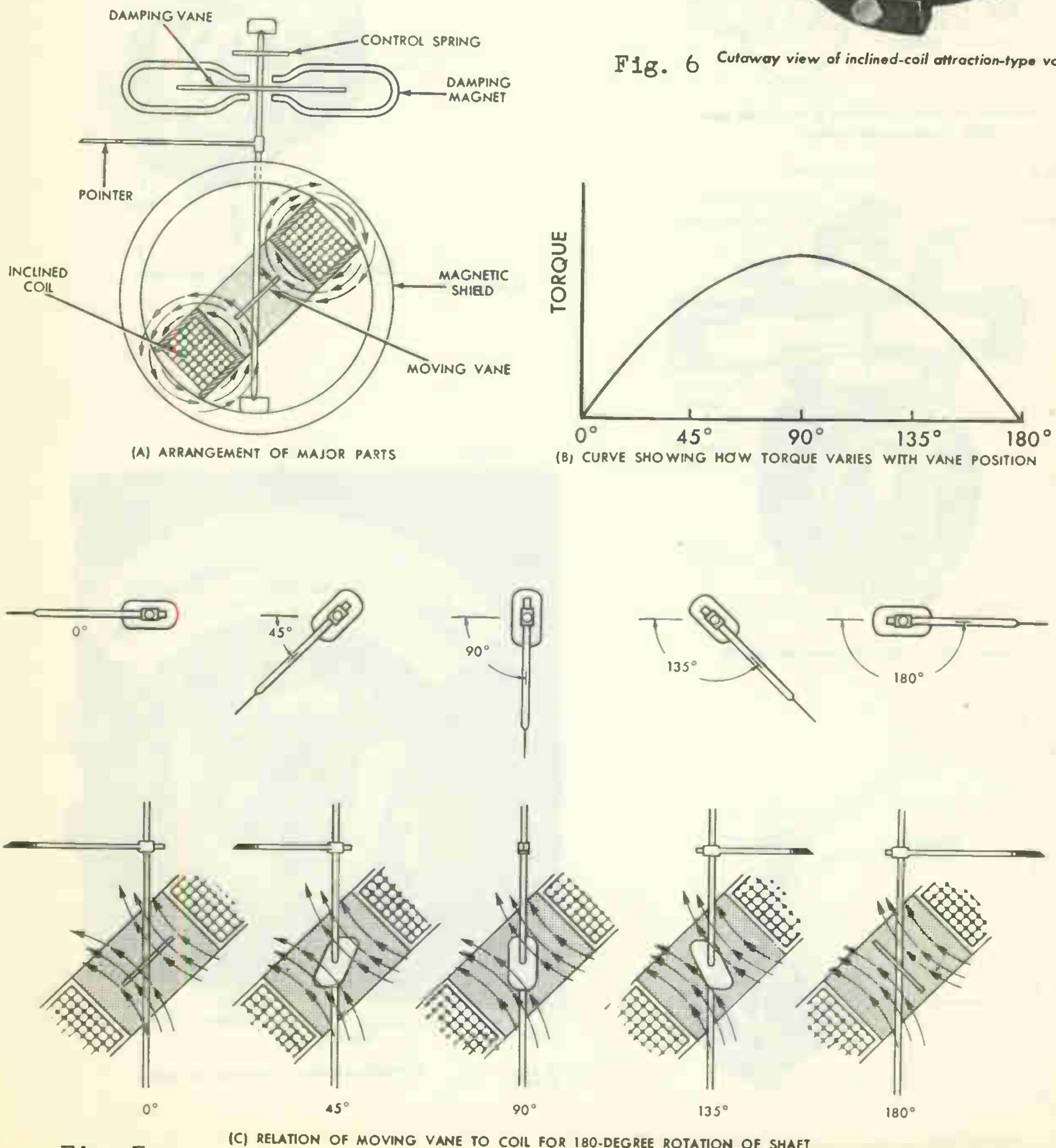


Fig. 7 *Flux diagram of inclined-coil instrument*

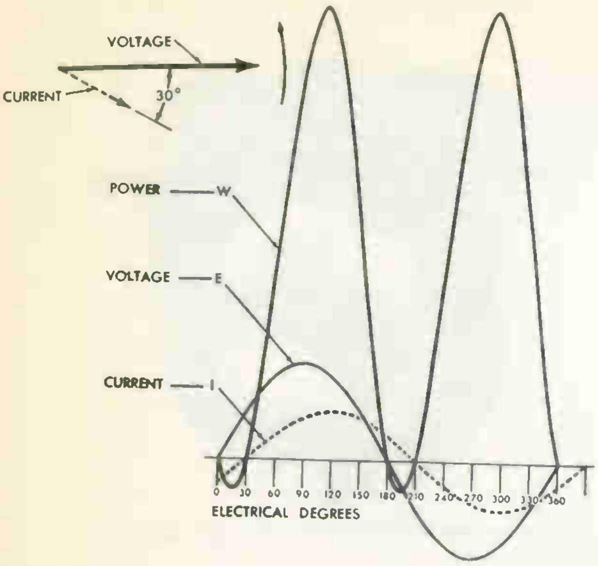


Fig. 8 *Current and voltage relations in a-c circuit with 0.866 lagging power factor*

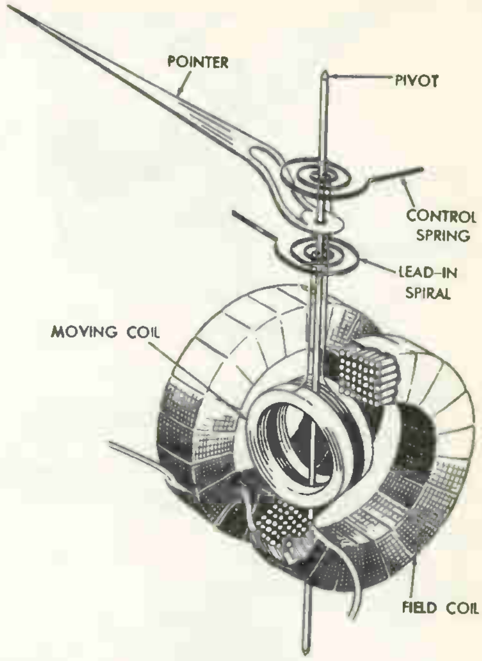


Fig. 9 *Diagram of dynamometer mechanism*

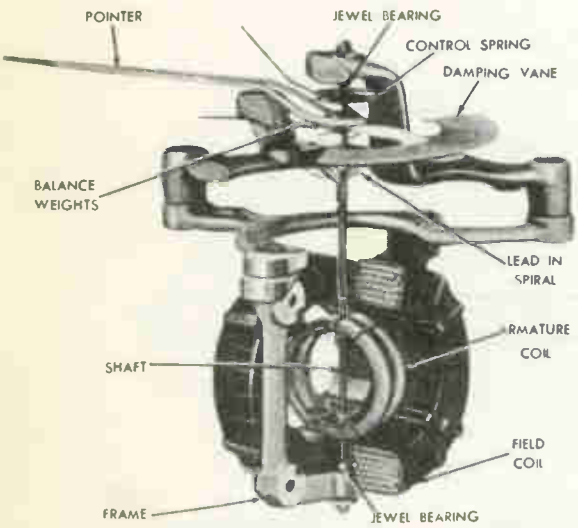


Fig. 10 *Cutaway view of dynamometer mechanism*

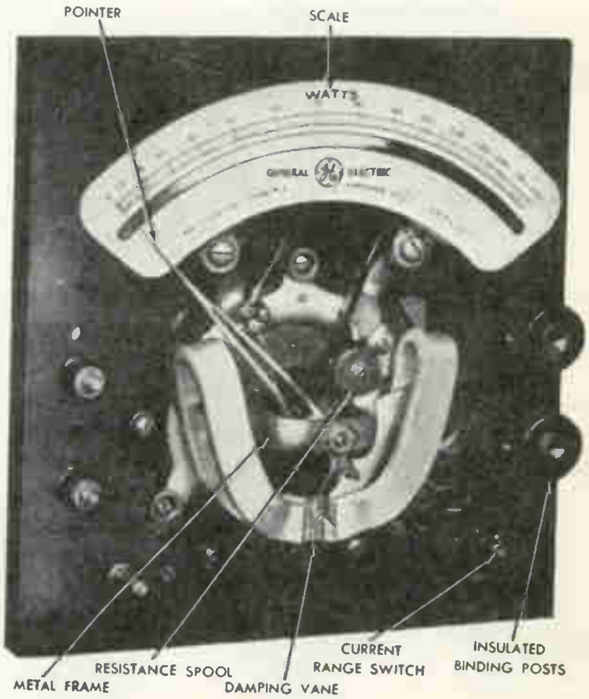


Fig. 12 *Portable wattmeter removed from case*

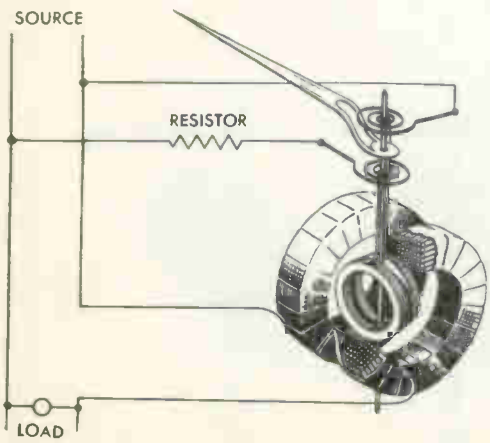


Fig. 11 *Dynamometer mechanism used as a wattmeter*

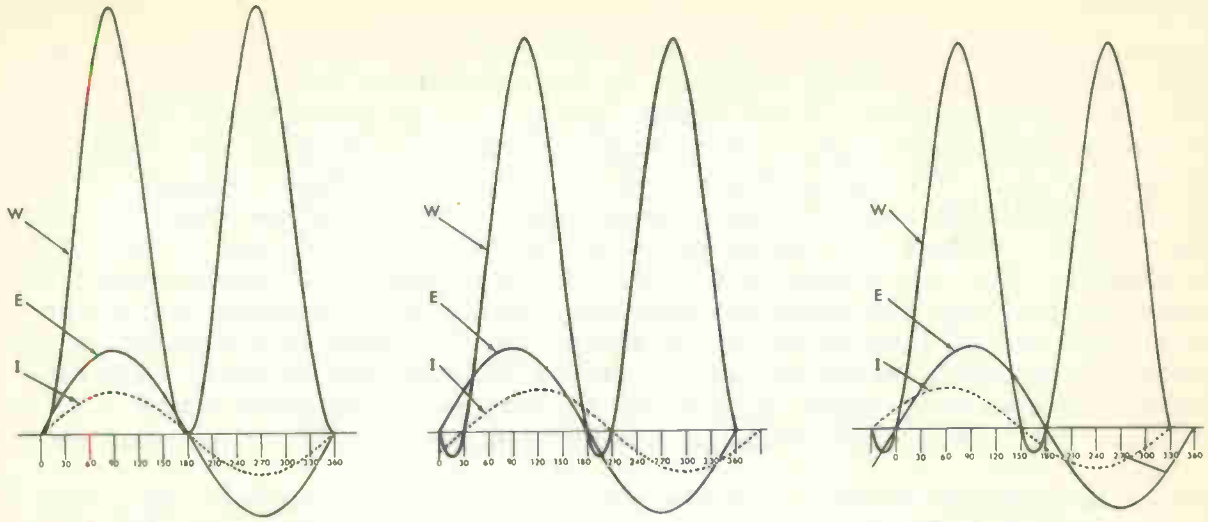
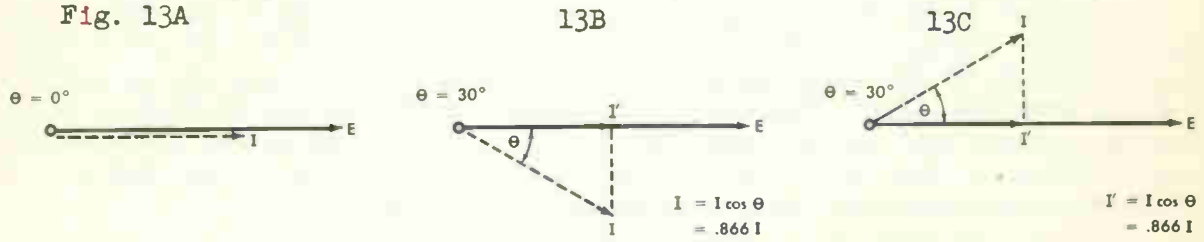


Fig. 13A 13B 13C



A — CURRENT IN-PHASE WITH VOLTAGE

B — CURRENT LAGGING VOLTAGE BY 30°

C — CURRENT LEADING VOLTAGE BY 30°

E = VOLTS	I' = IN-PHASE COMPONENT
I = AMPERES	W = WATTS

Fig. 13

Curves of voltage, current, and power for single-phase circuit

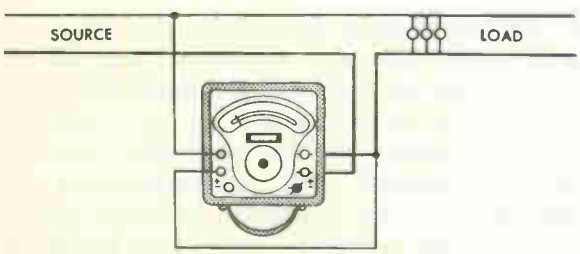


Fig. 14A *External connection diagram for wattmeter in a single-phase, two-wire circuit*

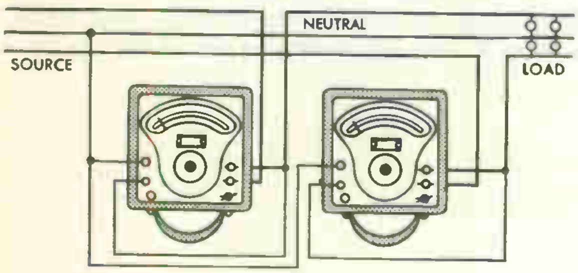


Fig. 14B *External connection diagram for two wattmeters in a single-phase, two-wire circuit*

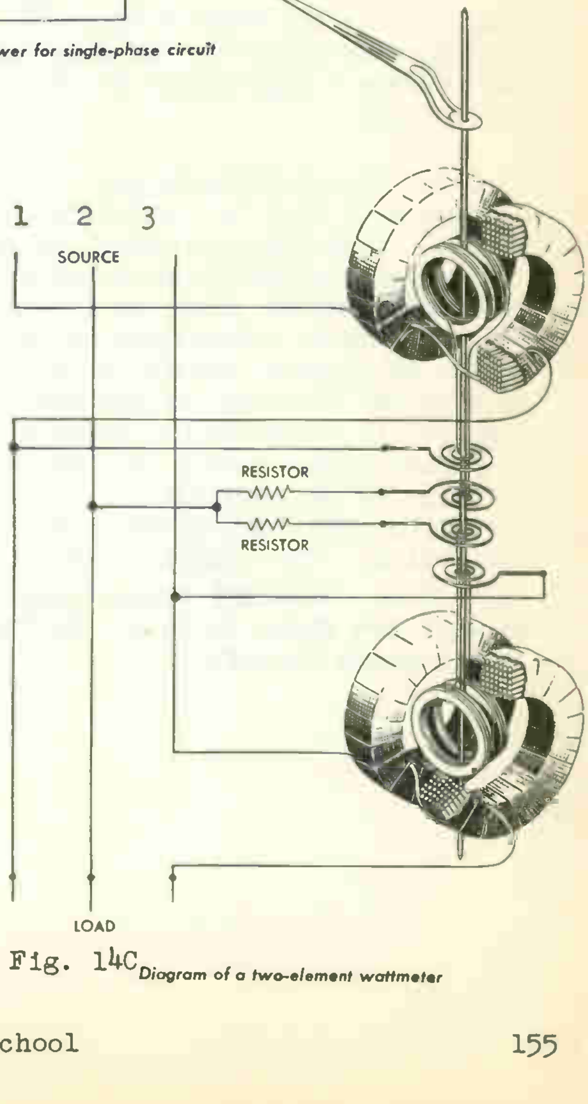


Fig. 14C *Diagram of a two-element wattmeter* armature flux will reach maximum values at precisely the same instant. They will also increase and decrease together, so the instrument torque will always be positive and the deflection of the moving system will be proportional to the average of the instantaneous product of voltage and current, which is the power, or, watts in the circuit. The vector diagram shows that the in-phase component of current for this condition is 1.00 times the maximum, since the phase angle is zero degrees. The current, voltage, and power relations when the current lags at an angle of 30° is shown in Fig. 13A. Under this condition, the product of current and voltage is sometimes positive and sometimes negative, depending on whether the values being multiplied are of like or unlike polarity, and the power is indicated as partly positive and partly negative. In the vector diagram, the in-phase component of the current is seen to be equal to 1 times the cosine of the phase angle, or in this example, 1 x 0.866. The cosine of the phase angle is called the power factor.

Since the in-phase component of the current is the power factor, the power is equal to the current times the voltage times the power factor. In a circuit of 0.866 lagging power factor, the field flux and the armature flux do not reach their maximum values at the same instant, but the field flux reaches its maximum 30° behind the armature flux. Therefore, the torque never reaches as high a value as when the current and the voltage are in phase, but always has an average value corresponding to the product of voltage times current times power factor. Thus, the instrument indicates the actual power in the circuit.

If the current was leading the voltage, as indicated in Fig. 13c, the condition existing would be as vectorially represented. This indicates that the in-phase component is the same whether the current is lagging or leading. The wattmeter reading also would be the same for the leading as for the lagging current, since the average torque would be the result of the instantaneous product of current and voltage.

In connecting a dynamometer instrument, the instantaneous polarity of the flux of each coil must be considered, since this governs the direction of the turning moment. When the instrument is employed in voltage or current measurement, the coils are internally connected in the correct polarity relationship and the user need not consider polarity in connecting the instrument in the circuit. But when the dynamometer instrument is used for power measurement, the instantaneous direction of current through each coil is determined by the polarity of its connection in the circuit; so the user must connect the instrument properly if its deflection is to be in the correct direction. This is especially important in polyphase instruments. To indicate the manner of connection, it is customary to identify one terminal of each coil as "plus-minus" (±); the terminal so marked should be connected to the same side of the line to ensure correct direction of deflection. The external connections for a single-phase wattmeter are shown in Fig. 14-a. External connections for two wattmeters in a single-phase, two wire circuit are shown in 14-b. In Fig. 14-c, we see a two-element wattmeter connected to a 3 phase Circuit.

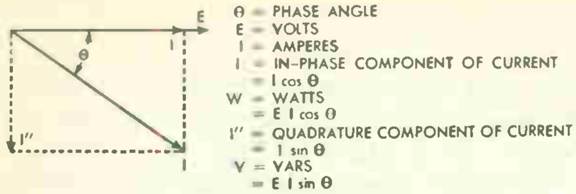


Fig. 15 *Vector diagram showing relation of vars to voltage and current in single-phase circuit*

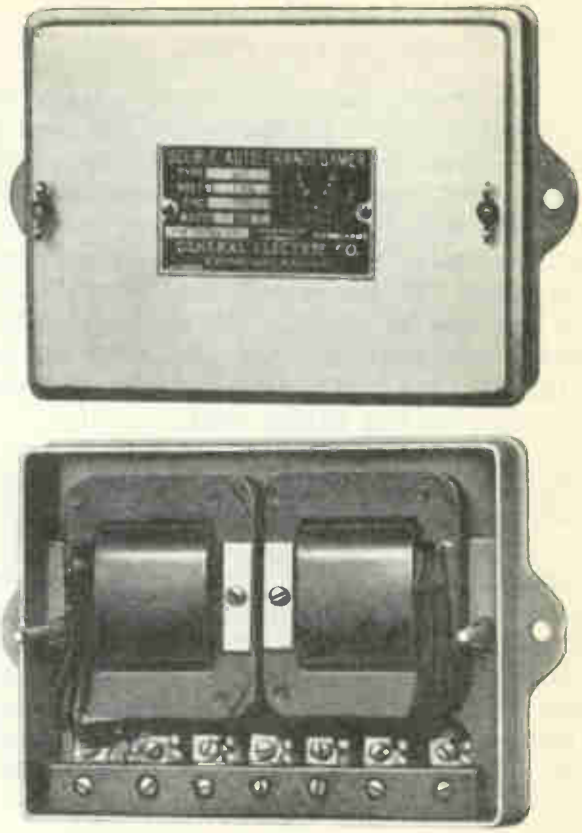


Fig. 16 *Autotransformer for adapting dynamometer instrument to reactive-volt-ampere (var) measurement*

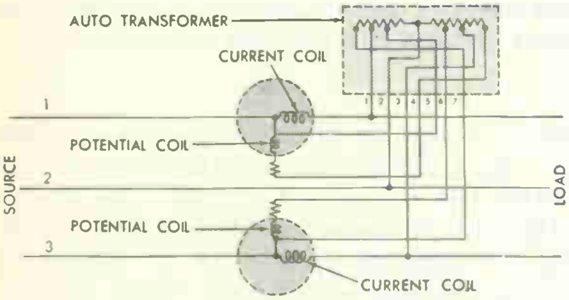


Fig. 17 *Connections of dynamometer mechanisms and autotransformer for measuring vars*

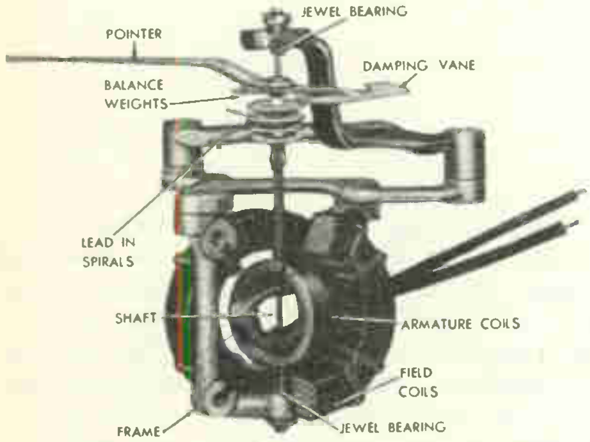


Fig. 18 *Cutaway view of mechanism of crossed-coil power-factor meter*

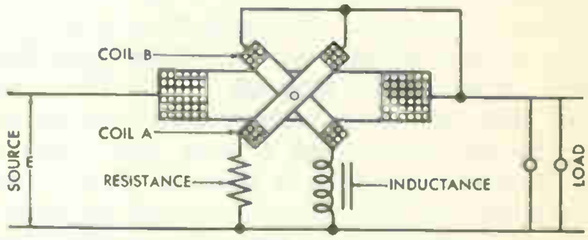


Fig. 19A *Diagram of single-phase, crossed-coil power-factor meter*

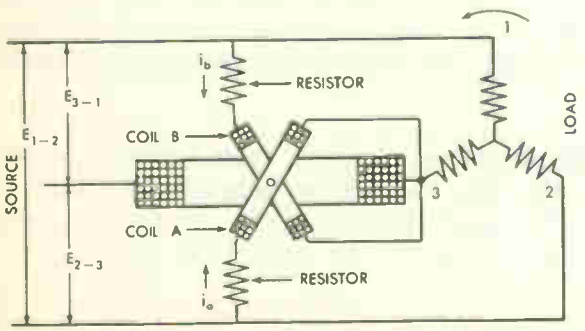
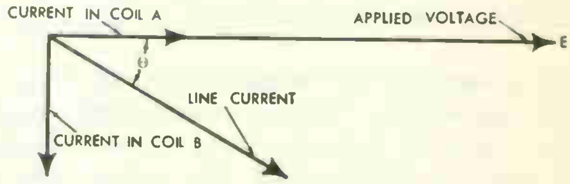


Fig. 19B *Diagram of three-wire, three-phase, crossed-coil power-factor meter*



Vector diagram showing relationship of voltage and currents in single-phase, crossed-coil power-factor meter

Fig. 20

E Varmeter

In the measurement of power, watts, (E I Cos θ), the dynamometer instrument has wide application. With few basic changes this instrument principle can be applied to the measurement of reactive volt-amperes called "vars" (E I Sin θ), Fig. 15. It has been previously explained that the wattmeter indicates the product of the circuit voltage and the component, of the wattmeter indicates the product of the circuit voltage and the component of the current which is in phase with the voltage: the varmeter, on the other hand, indicates the product of the current component which is 90° out of phase with voltage. This measurement is accomplished by providing means for shifting the phase of the voltage across the potential coil so that the flux of this coil is in phase with that produced by the quadrature component of the current in the field coil.

Applications - The method employed to throw the voltage in phase with the quadrature component of current depends upon the circuit. In a single-phase circuit, an external impedance network is connected in series with the potential circuit so that the current through the instrument armature will lag the voltage by 90 degrees. In a two-phase circuit, in which the phases are normally 90 degrees apart, it is necessary only to cross-phase the potential windings of a polyphase wattmeter; that is, to connect the potential coil of each element to the phase opposite to that in which the current coil of the element is connected. In a three-phase circuit, autotransformers are used to obtain the requisite phase shift, Fig. 16. Typical connections for a three-phase, three-wire circuit are shown - Fig. 17.

F. Power-Factor Meters

Crossed-coil Type - One form of power-factor meter is the crossed coil type, so named because of its armature structure, Fig. 18. This instrument can be designed for either single or polyphase service. In either instance, the mechanism employs one fixed coil, through which the line current flows and two moving coils, which are mounted on a common shaft at an angle with respect to each other. The moving coils are connected across the line, through resistors, or through a resistor and a reactor, in such a manner that there is suitable phase difference between the currents in the two coils and so that the torques of the two coils oppose each other. Instruments for single-phase or two-phase service, the construction is equivalent; to mounting the moving system of a wattmeter and a varmeter on a common shaft so that the torque is proportional to the ratio of watts and vars in the measured circuit. Since this ratio varies as the phase angle between the current and the voltage, the instrument can be calibrated in terms of any function of the phase angle and is normally calibrated in terms of the cosine of the phase angle, which is the power factor of the circuit.

For power-factor measurement in a balanced three-phase circuit, the moving coils are connected, through resistors, across two phases, in such a manner that the coil torques are in opposition. Thus, the instrument measures the ratio of power in the two phases and its deflection varies according to the power factor.

1. Single-phase Power-Factor Meters

Fig. 19-a shows a schematic diagram of a single-phase cross-coil power-factor meters, and Fig. 18 shows the mechanism of a commercially constructed instrument incorporating the design features indicated in the diagram. The crossed coil

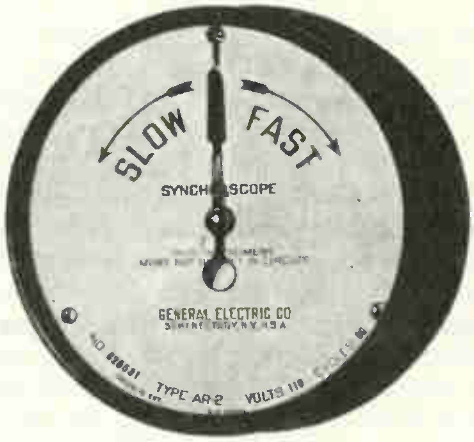
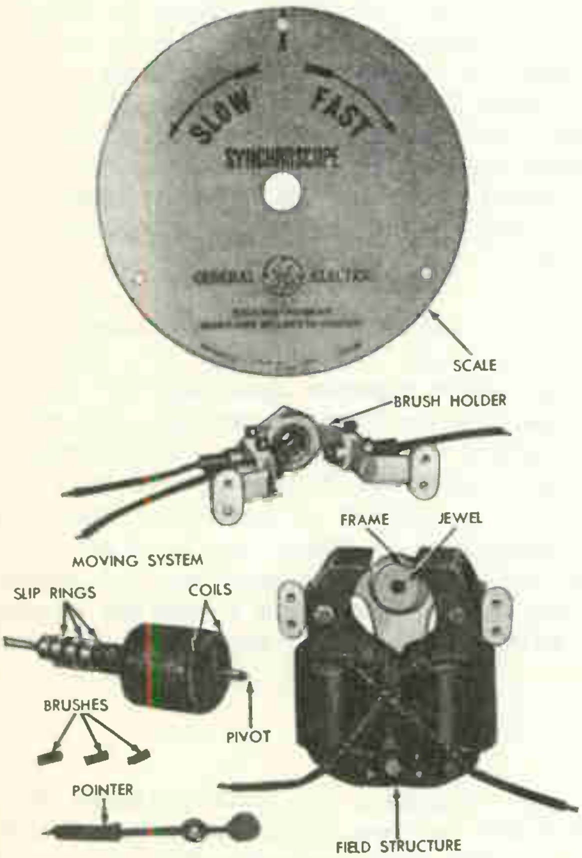


Fig. 21 *Typical crossed-coil synchroscope*



Disassembled mechanism of crossed-coil synchroscope

Fig. 22

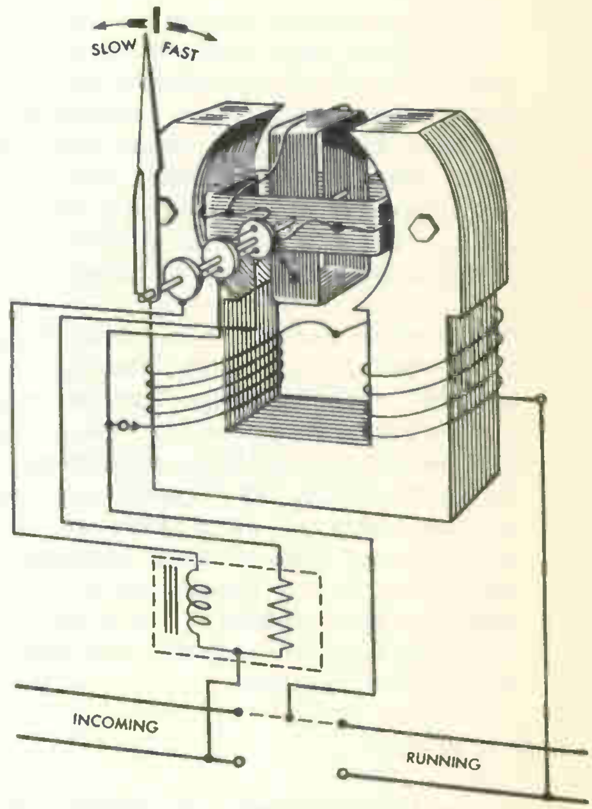


Fig. 23 *Crossed-coil synchroscope, construction and connections*

mechanism is sometimes built with separate elements for the coils receiving in-phase and quadrature potential currents. Notice the three-phase unit shown in Fig. 19B.

The construction of the instrument resembles that of a single-phase wattmeter in that stationary field coils, mounted on the frame, carry the line current and provide the flux with which the moving-coil flux reacts to produce deflection torque. It differs from the wattmeter in that it has no control spring and that it has two armature coils which are mounted on the same shaft in such a way that their axis are approximately 90 degrees apart. One of these moving coils is connected across the line through a non-inductive resistor; hence, its flux reacts with that of the field coil to produce torque proportional to the in-phase, component of line current. The other moving coil is connected across the line through an inductive reactor which causes the current in this coil to lag practically 90 degrees behind the voltage so that its torque is proportional to the line current component which is 90 degrees out of phase with the voltage. It is not feasible to obtain a full 90 degrees lag in the reactive potential circuit, but the desired phase displacement of coil fluxes is obtained by making the mechanical angle between the coils equal to the phase angle of the two potential circuits; this permits the instrument to indicate accurately.

2. Instrument reaction at Unity Power-Factor

When a power factor meter is connected in a circuit of unity power factor, the entire line current is in phase with the voltage; therefore, full torque is developed in the armature coil whose voltage is in phase with the line current. Since the quandrature component at unity power factor, is zero, no torque is developed in the coil whose current is lagged 90 degrees behind the applied voltage. The moving system, therefore, assumes a position in which there is a maximum flux alignment between the field (current) coil and the "active" armature coil. The pointer is so positioned on the shaft that, under this condition, the instrument indicates a power factor of 1.00.

3. Instrument reaction at "Less than Unity" Power-factor. - When an instrument is connected in a circuit having less than unity power factor, Fig 20, the "reactive" coil develops torque in a direction which depends upon whether the quadrature component of field current is leading or lagging the applied voltage and is of a magnitude dependent upon the amount of lag or lead. This torque tends to align the "reactive" coil with the field coil. It is opposed by the torque of the "active" coil produced by the in-phase component of current. The final position of the pointer depends upon the resultant of these two torques and is an index of the phase angle. Because the deflection is a resultant of opposing torque, the crossed-coil power-factor meter does not require a control spring, and its lead-in spirals are designed for minimum torque so that they will not affect deflection.

G. Synchroscope

When the two machines are operating at the same frequency but with voltages out of phase, the angular position at which the rotating vectors coincide to provide a resultant that is fixed in space is determined by the phase relationship of the two potentials. When the incoming machine and the running machine are not operating at the same speed, there is a continual shifting of the phase angle between the two potentials that causes the resultant flux vector to rotate, in a direction dependent upon which of the machines is operating at the higher speed, and at a rate dependent upon the difference between the frequencies of the machines. When two machines are at the same frequency and same phase relationship, the pointer is stationary and one end is at the index mark indicating synchronism, see Fig. 21.

Construction of the Crossed Coil Synchronscope - The crossed-coil synchroscope, Fig. 22, resembles, to some extent, the crossed-coil power-factor meter, as might be expected, since one of the functions is to indicate the phase angle between two electrical quantities. Preformance requirements, however, necessitate a construction in which the moving element is free to rotate. To permit this rotation, the current is carried to the moving coils by means of brushes and slip rings, instead of by lead-in spirals.

The principal parts of the cross-coil synchronscope are:

1. The frame - which supports the field structure, brush holders, bearings and scale.

2. Field structure - which consists of a laminated iron core with windings on each leg.

3. Moving system - consisting of:

   a. Shaft
   b. Armature coils, mounted on shaft and set nearly perpendicular to each other.
   c. Slip rings, to which the armature coils are common to one - slip ring and separately connected to the others.
   d. Pointer, attached to the shaft in the same plane as the coil of the resistive circuit.

4. The scale - marked, as in other types of synchroscopes, to indicate the phase and speed relationships of the two machines.

5. Impedor - usually mounted externally and connected to the slip rings so that one armature coil is in series with a resistor and the other is in series with a reactor.

Operating Principle - The armature is connected across a potential, normally that of one phase of the incoming machine, with one coil supplied with the in-phase current through the resistor and the other coil supplied with current approximately 90 degrees out of phase (lagging) through the reactor (Fig. 23); therefore; a rotating field is produced by the armature coils. The field coil is connected across the corresponding phase of the running machine so that a bipolar a-c field is produced.

The magnetic forces tend to move the armature to that position where the rotating field coincides with the stationary field at the instant it has maximum strength. The windings in which the rotating field is produced are free to move, so they assume the position that brings the fields into alignment. When the two machines are operating at the same frequency, the armature maintains a position dependent upon the phase angle between their potentials; when they are operating at different frequencies, rotation of the armature is produced, at a speed and in a direction governed by the relative speed of the two machines.

H. Other a-c Electrical meters

Such meters as frequency meters, integrating instruments, telemeters, rectifier instruments, theremocouple instruments, do not come within the scope of this lesson.

J. Summary Questions

1. What is meant by meter "damping"?

2. Name two types of meter damping.

3. Why are most meters only "scaled" to a complete scale sweep of 90°?

4. Explain how a power factor meter works.

5. Explain how a varmeter works.

POWER AND POWER FACTOR IN THE AC CIRCUIT

Objective

To learn about power in the a-c circuit, the various factors which affect the power-factor of a circuit and how to calculate the factors of predominately capacitive, inductive, and a mixture of those factors which are ever present in an a-c circuit.

References

Lesson Content

A. Alternating Current Power

The power of a d-c circuit is always equal to the product of voltage and current, i.e., W equals ExI, because E and I will always be in phase with each other.

In the a-c circuit containing reactance (XL or X_c) in addition to resistance, the line current will not be in phase with its voltage. It may lag or lead the voltage applied. If both X_L and X_c are present, the phase relationship between E and I is determined by the predominating X.

B. Apparent Power - Due to the possibility of out of phase conditions, the product of E and I in the a-c circuit is equal to the unit of apparent power, or volt-amperes (VA).

$$VA = E \times I; \qquad KVA = \frac{E \times I}{1000}$$

If the circuit is totally resistive, or inductive reactance equals capacitive reactance, E and I are in time phase, therefore, E line x I line equals Watts. The rule applies to any current or component part of the current which is in phase with voltage applied.

It was previously pointed out that a totally reactive circuit causes the current to lag (due to X_L) or lead (due to Xc) the applied voltage by 90° Since resistance is present in all circuits, totally reactive circuits are a practical impossibility. Any ordinary circuit will carry a line current which is displaced from the voltage by an angle less than 90°. If XL and Xc are both present and equal in value, being 180° out of phase, they cancel, resulting in an "in phase" condition for E and I. This condition is described as resonance which was outlined in lesson 5.

True Watts - E x I in a resonant circuit, (I line and E line are in phase), is the true watts of that circuit. Therefore, I equals $\frac{W}{E}$, in this circuit, the entire current being an active component.

Lagging currents - The actual line current drawn by apparatus such as induction motors, furnaces, transformers, welders, etc., will lag the applied voltage. It may be considered as being made up of two components or parts:

1. Active - this in phase component is in phase with the voltage, and is converted into another form of energy, sometimes known as working current.

2. Reactive - this is also called magnetizing component which magnetizes the iron

or magnetic circuit of inductive apparatus. Due to the choking effect of inductive apparatus, this current is at zero value when the voltage is maximum, i.e., it lags the voltage by $\frac{1}{4}$ cycle or 90°.

Leading Currents - Since the capacitor possesses high reactive properties, the greater part of the charging current drawn by it is also reactive, but leads the voltage by 90° elec.

Wattless Power - The reactive component of current is known as wattless or circulating current. This fact is clearly illustrated for lagging and leading currents in Figure 1-a and Figure 1-b.

Instantaneous Power - The instantaneous power is equal to the product of the instantaneous values of E and I. If polarities of E and I are respected, the power loops above and below the zero axis line are of equal magnitude at 90° displacement, therefore, the total power is zero since a positive cancels a negative. Fig. 1-c shows the condition for an in phase current.

All power loops are above the zero axis line because the product of E and I at any instant gives a positive quantity of power.

A modified condition is illustrated in Fig. 1-d, where I lags E by an angle of 30°. The positive power loops are much greater in area than the negative loops. The power of the circuit is equal to the difference between the areas of the positive and negative loops. Conditions similar to this are encountered in any average power circuit.

Solution of these conditions is greatly simplified by the use of the right triangle shown at 2-a, where angle theta (θ) displaces the line voltage and line current.

$$\text{Cosine } \theta \text{ equals } \frac{\text{base line}}{\text{hypotenuse}} \quad ; \quad \text{sine } \theta = \frac{\text{opposite side}}{\text{hypotenuse}}$$

Fixed relationships for any given angle between the lines are indicated by the formulae.

Figure 2-b shows the proper position of the two component parts, as well as the sum of the 2 parts. The active current is plotted on the base line in phase with E. Reactive component is 90° out of phase with E and the active current is plotted on the opposite side. The hypotenuse is obviously the sum of the 2 components.

Calculations - It is now apparent that if the geometric relationships are known for any given angle (refer to the chart of trigonometric functions in lesson No. 1), we may find the value of unknown quantities providing two values are known (1 line and 1 angle other than 90°, or 2 lines of a right triangle).

EXAMPLE: $$\text{Cos } \theta = \frac{\text{Base line}}{\text{Hypotenuse}} = \frac{\text{Active Current}}{\text{Line Current}}$$

$$\text{Sin } \theta = \frac{\text{Opposite Side}}{\text{Hypotenuse}} = \frac{\text{Reactive Current}}{\text{Line Current}}$$

It also follows: Base Line = Hypotenuse x Cos θ

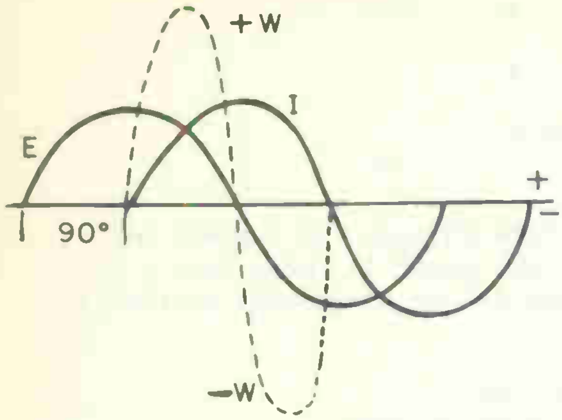


Fig. 1A, Current lage 90°

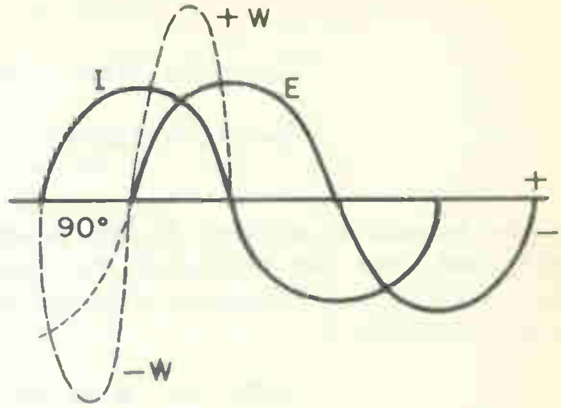


Fig. 1B, Current leads 90°

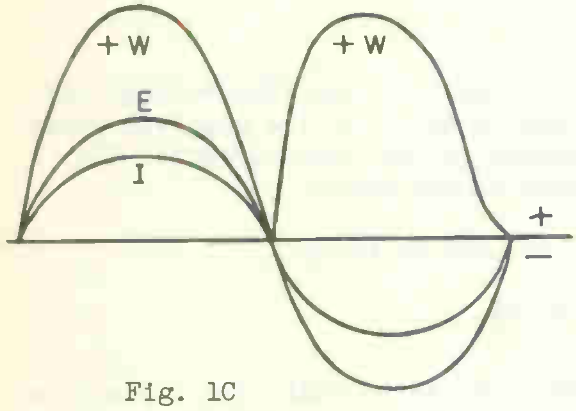


Fig. 1C

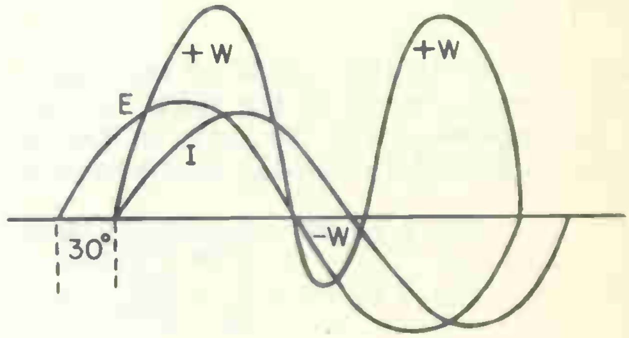


Fig. 1D

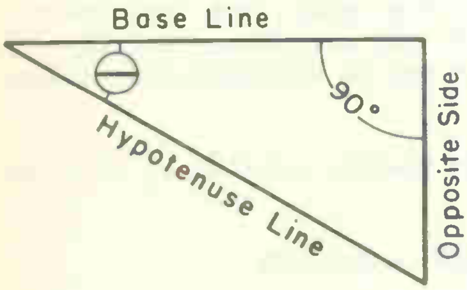


Fig. 2A

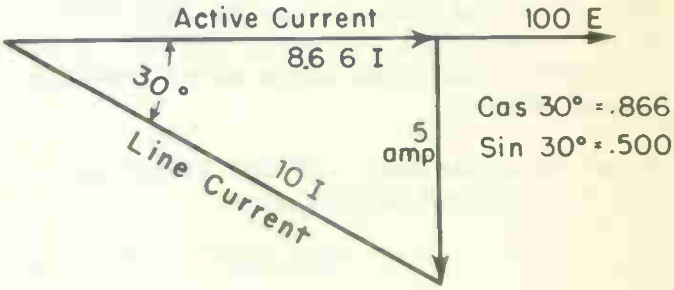


Fig. 2B

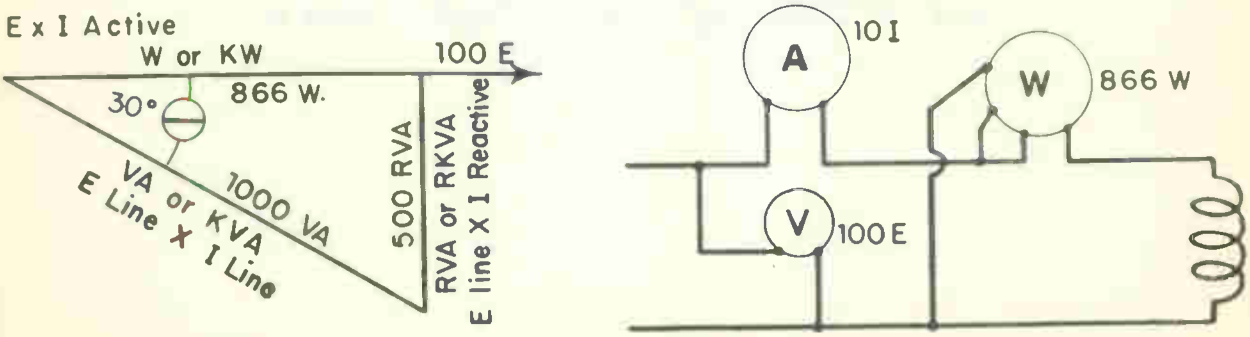


Fig. 2C

$$\text{Active Current} = \text{Line Current} \times \cos\theta$$
$$8.66 = 10 \times .866$$

$$\text{Opposite Side} = \text{Hypotenuse} \times \sin\theta$$

$$\text{Reactive Current} = \text{Line current} \times \sin\theta$$
$$5 = 10 \times .500$$

The same reasoning applies to the power vector. Line voltage and current may be ascertained from the voltmeter and ammeter readings, power in watts from a wattmeter, RKVA from a VAR-meter (though varmeters may not be frequently available in average circuits.)

$$W = VA\ \cos.\ \theta \text{ or } 1000 \times .866 \text{ or } 866\ W$$
$$W = E \text{ line} \times I \text{ active or } 100 \times 8.66 \text{ or } 866W$$
$$\text{Reactive } VA = VA.\sin\theta \text{ or } 1000 \times .500 \text{ equals } 500\ RVA$$
$$RVA = E \text{ line} \cdot I \text{ reactive} = 100 \times 5 \text{ or } 500\ RVA$$

C. Power Factor

Power factor is the cosine of the angle (θ) which displaces the line voltage and line current, or it is the ratio of the true power in watts to the apparent power in voltamperes, also the ratio of the active current to the line current. The angle theta (θ) is usually designated as the power factor angle.

$$\cos\theta \text{ or } PF = \frac{\text{active Current}}{\text{line Current}} = \frac{8.66}{10} \text{ or } .866 \text{ or } 86.6\%$$

$$\cos\theta \text{ or } PF = \frac{W}{VA} = \frac{866}{1000} \text{ or } .866 \text{ or } 86.6\%$$

Thus we observe that 86.6% of the apparent power supplied to this circuit is true power in watts which is converted into another or useful form of energy. The power factor of the circuit may be indicated by the power factor meter, but that instrument is not always present in the circuit. However, VM, AM, and WM are usually available, and from these meter readings, power factor may be determined as illustrated above.

Power Calculations - If the trigonometric chart is not readily available, solution may be obtained as follows:

$$RVA = \sqrt{VA^2 - W^2} = \sqrt{1000^2 - 866^2} = 500\ RVA$$

$$W = \sqrt{VA^2 - RVA^2} = \sqrt{1000^2 - 500^2} = 866\ W$$

$$VA = \sqrt{W^2 + RVA^2} = \sqrt{866^2 + 500^2} = 1000\ VA$$

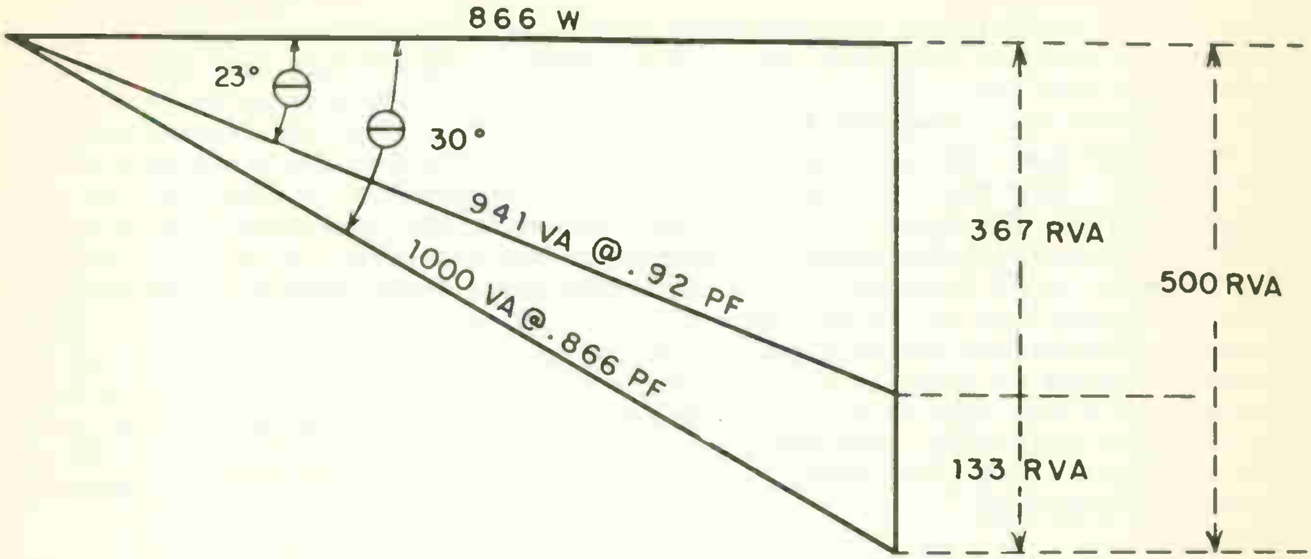

866 W
23°
30°
941 VA @ .92 PF
1000 VA @ .866 PF
367 RVA
500 RVA
133 RVA

Fig. 3

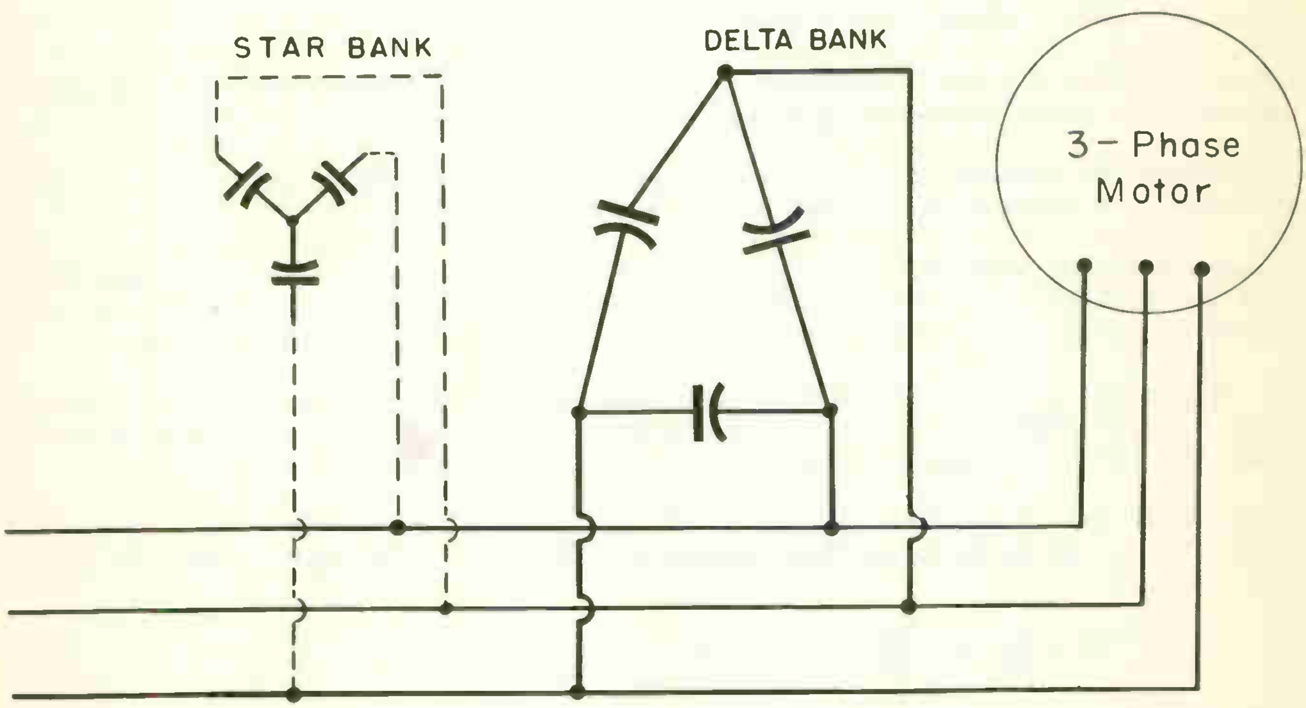

STAR BANK
DELTA BANK
3 - Phase
Motor

Fig. 4

D. Power Factor Correction

This may be accomplished by connecting capacitors in parallel with the circuit to supply the reactive component of power required by the circuit, and thus avoid drawing it from the supply lines. In a previous lesson on meters, we learned that the wattmeter registered the true power only, and that the line current might be much greater than indicated by that meter. If power rates are based on W or KW consumption, they must be comparitively high to compensate for the reactive power supplied also. The presence of reactive current in the line wires limits their capacity to carry active current. Power rates for industrial or factory circuits may be based on KW consumption with a sliding scale determined by power factor, with increased cost per KW at lower PF, or by KW consumption and maximum ampere demand. The maximum demand meter registers the maximum current if drawn for a pre-selected period of time, say 15 min., and a given charge is made per ampere month, regardless of how long this current is drawn beyong the timing period, whether it be 15 hours or 15 days. Various power companys determine power rates and PF penalties from a "cost-plus" basis, with of course, the approval of the Interstate Commerce Commission.

Power rates and PF penalties very frequently, encourage the consumer to minimize ampere or KW demand by scheduled operation of apparatus, also by installation of capacitors, or rotating capacitors (synchronous motors which will be dicussed in another chapter)

The power factor of the circuit considered above 86.6% without correction added. By formula:

$$RVA = \sqrt{VA^2 - W^2} = \sqrt{1000^2 - 866^2} = 500 \text{ RVA}$$

$$RVA = VA \times \sin\theta = 1000 \times \quad 500 = 500 \text{ RVA}$$

If a capacitor of 500 Va capacity is connected in the circuit to supply this amount of RVA, the power factor of the circuit is raised from 86.6% to 100%.

The capacitor absorbs the reactive component of current (5I), reducing the line current to a value equal to the active component (8.66 I).

Power factor of 100% may not prove economical however, due to cost of capacitors and low penalities imposed at near unity or 100%. When in question, consult the power or public service company to determine the most economical condition.

It is general practice to amortize the cost of capacitors over a period of about 6 or 7 years, that is, discounts on the power bill or penalties avoided should return the investment made in capacitors in that period of time.

Suppose we select an intermediate PF of 92% and determine RVA required from the capacitors. VA to be drawn from supply at 92% PF. .92 equals Cos 23°; Sin 23° = .3907

$$VA = \frac{W}{PF} = \frac{866}{.92} = 941 \text{ VA}$$

RVA to be drawn from the supply.

$$RVA = VA \times \sin\theta_1 = 941 \times 3907 = 367 \text{ RVA}$$

The capacitor must supply RVA equal to the difference between the RVA at 86.6% PF and that drawn at 92% PF.

Capacitor Capacity = 500 - 367 = 133 VA

If the PF were raised from 92% to 100%, it would require 367 VA additional capacity in the capacitor. Fig. 3 shows a graphical solution of the above.

From the foregoing example, we observe that the amount of correction required increases as PF approaches unity or 100%. As stated before, it may prove more economical to maintain circuit PF at some intermediate value rather than near or at 100%.

Motor Power-Factor - The power factor of the induction motor is an inherent characteristic determined by its design. It will be at its maximum value with normal voltage applied, and when fully loaded or slightly overloaded.

When operating idle the power factor of a well designed motor should not exceed 30%, and may be as low as 10% or even 15%, because under this condition the current drawn is largely reactive. The active component drawn is that required to compensate for losses in the machine, such as windage and friction, and I^2R of the copper and the iron losses.

Reactive or magnetizing component of current drawn by a well designed motor should generally not exceed 18% to 22% of its full load current rating. This current is practically constant regardless of the load imposed on the motor. Since the active current drawn by the motor depends upon the load imposed, it is obvious that PF of the motor is improved by increasing the ratio of active to reactive current. It is important to choose the correct size motor (in hp) for a given load. Over motoring should be avoided in the interest of circuit power factor.

E. Three-phase Power Calculations

Assuming θ at 30°, PF = 86.6%, 220E, 10I

VA total = E Line x I line x 1.732

VA - 220 x 10 line x 1.732 = 3810.4VA

W total = E line x I line x 1.732 x Cos θ

W = 220 x 10 x 1.732 x .866 = 3299.8 W

$$\text{I per line} = \frac{\text{VA total}}{\text{E x 1.732}} = \frac{3810.4}{220 \times 1.732} = 10\ \text{I.}$$

$$\text{I per line} = \frac{\text{W total}}{\text{EX 1.732 x PF}} = \frac{3299.8}{220 \times 1.732 \times .866} = 10\ \text{I.}$$

$$\text{PF} = \frac{\text{W total}}{\text{VA total}} = \frac{3299.8}{3810.4} = .866 \text{ or } 86.6\%$$

RVA = VA total . Sin θ 3810.4 x .500 = 1905.2 RVA

$$\text{RVA} = \sqrt{VA^2 - W^2} = \sqrt{3810.4^2 - 3299.8^2} = 1905.2\ \text{RVA}$$

$$W\ total = VA\ total \times \cos\theta = 3810.4 \times .866 = 3299.8\ W$$

$$W\ total = \sqrt{VA^2 - RVA^2} = \sqrt{3810.4^2 - 1905.2^2} = 3299.8\ W$$

1. Power factor correction equipment installation.

   Fig. 4 illustrates the connections made for capacitors to a three phase power circuit. Two possible types of capacitor banks are shown, and the installation should be as close to the motor terminals as practical, to confine the reactive component to a minimum part of that circuit.

2. Class examples

   In Figs. 5, 6, 7, 8 and 9 there will be a class discussion and examples of actual meter readings.

3. Condenser Connections.

   Condensers are connected in parallel with inductive apparatus to supply all or part of the reactive current required for magnetization purposes, and thus avoid drawing it from the supply lines, thus correcting the power factor of the circuit.

4. Disadvantages of low power factor

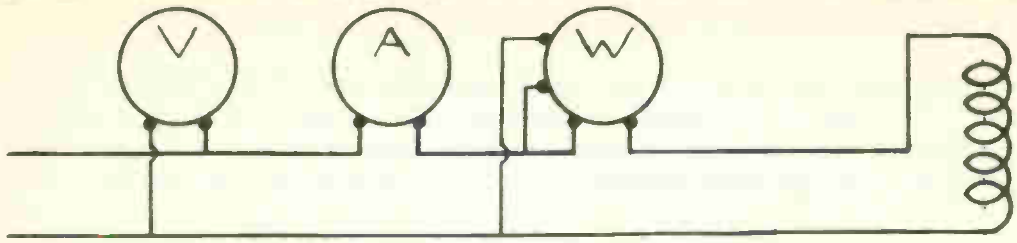
   a. Greater cost of power due to PF penalities imposed on power bill.
   b. Larger generators, transformers, transmission lines and apparatus will be required to carry a given K.W load.
   c. Increased line wattage loss and line voltage drop.
   d. Voltage regulation is poor on circuits of low power factor.

5. Causes of Low power factor

   a. Under loaded induction motors.
   b. Induction furnaces.
   c. Electric welders, or in general any inductive apparatus requiring magnetizing current for its operation.

6. Methods of correcting low power factor

   a. Fully load, or slightly overload induction motors.
   b. Static condensers.
   c. Synchronous motors. Condensers used for PF correction are rated in Kva.



V.A. = E x I = ______ x ______ = ______ V.A.

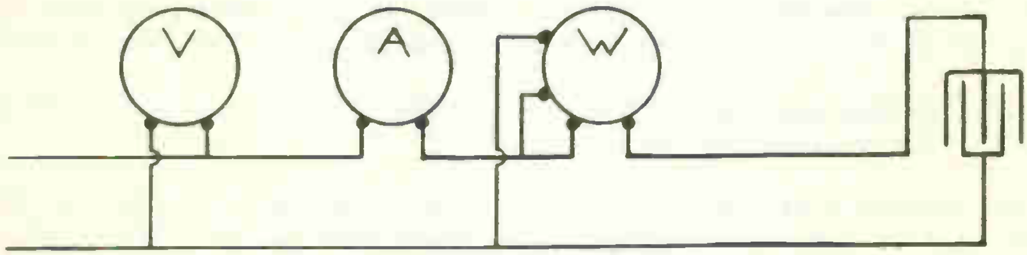
W = W.M. reading --------- = ______ W.

Active I = $\frac{W}{E}$ = ____________ = ______ I.

P.F. = $\frac{W}{V.A.}$ = ______ = .______ = ______ %.

Fig. 5

CAPACITIVE CIRCUIT



V.A. = E x I = ______ x ______ = ______ V.A.

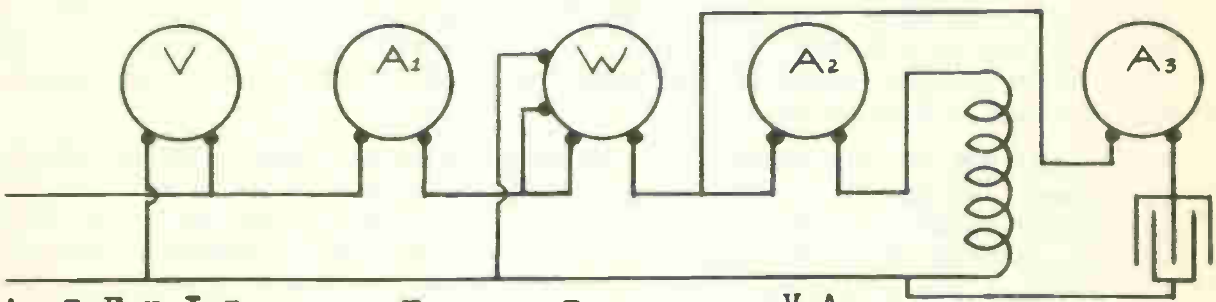
W = W.M. reading --------- = ______ W.

Active I = $\frac{W}{E}$ = ____________ = ______ I.

P.F. = $\frac{W}{V.A.}$ = ______ = .______ = ______ %.

Fig. 6

INDUCTANCE-CAPACITIVE CIRCUIT



V.A. = E x I = ______ x ______ = ______ V.A.

W = W.M. reading --------- = ______ W.

P.F. = $\frac{W}{V.A.}$ = ______ = .______ = ______ %.

Fig. 7

E. Measuring Watts in Three Phase, 3 wire circuits

The measurement of power in this circuit requires the use of at least 2 single phase wattmeters. To obtain accurate indications from these meters, correct connections must be made and also proper interpretation made of the readings, due to the possible phase relationships encountered at various power factors in the three phase circuit.

1. Procedure for phasing or polarizing two single phase wattmeters.

1. Arrange meters (Fig. 10-a) with the individual current coils in series with the same line.

2. Connect one lead of each potential element to its own current coil (line side) by means of a jumper. Connect the other lead of each potential element to a 2nd line wire which is not to carry a current coil connection.

3. Now apply power to the circuit, motor operating under the load condition that the power of the circuit is to be measured under. Check meter readings which should be equal, since they are both measuring the same power. If they are not, one or both meters are likely inaccurate. (NOTE: Do not attempt to make adjustments in meter readings unless you have a "standard" meter for comparison).

   If one or both meters read backwards, reverse the leads of the potential element to obtain a positive reading.

4. Identify the terminals of the current and potential elements which are connected to the line side of the circuit as $\pm$. The other lead of the individual current coils are merely identified as the load terminals.

5. Now transfer the current element of W2 to the 3rd line wire, being careful to connect the $\pm$ terminal to the line side of the circuit, the other to the load side of the circuit. Also avoid making any changes in the connections made for the potential elements. (Fig. 10-b).

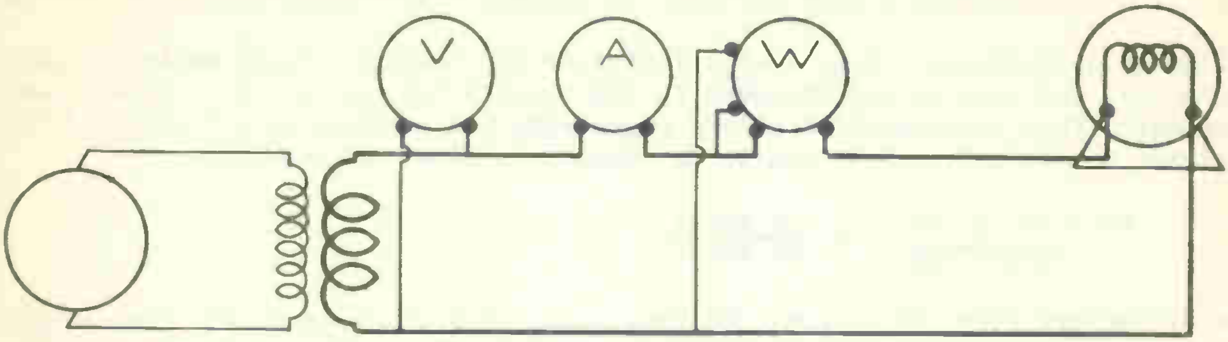
6. The meters are now correctly connected in the circuit, and the power of the circuit is equal to the algebraic sum of the readings, i.e., $W = W_1 \pm W_2$.

   It should be observed that the meters will not read alike even with a perfectly balanced three phase load unless the PF of the circuit is exactly 100%. As the PF decreases to 90%, 80%, 70%, etc., one meter will indicate a smaller, and the other a larger percentage of the total laod. Both continue to read positive however, and W total = $W_1 + W_2$.

   At exactly 50% PF, one meter will indicate the total power, and the other will read zero. As the PF is reduced below 50%, the low reading meter will read backward, indicating negative power. The other will continue to read positive, but reading will be reduced in value. Since the backward reading is unintelligible, reverse the leads of the potential element on this meter to obtain a positive reading. The total power of the circuit is equal to the difference between readings of W 1 and W 2, or W total = W 1 - W 2.

   Due to the possible behavior of the 2 meters at various power factors in a three phase, three wire circuit, the formula for W total must be written:

   W total = $W_1 \pm W_2$ to accommodate any PF condition.



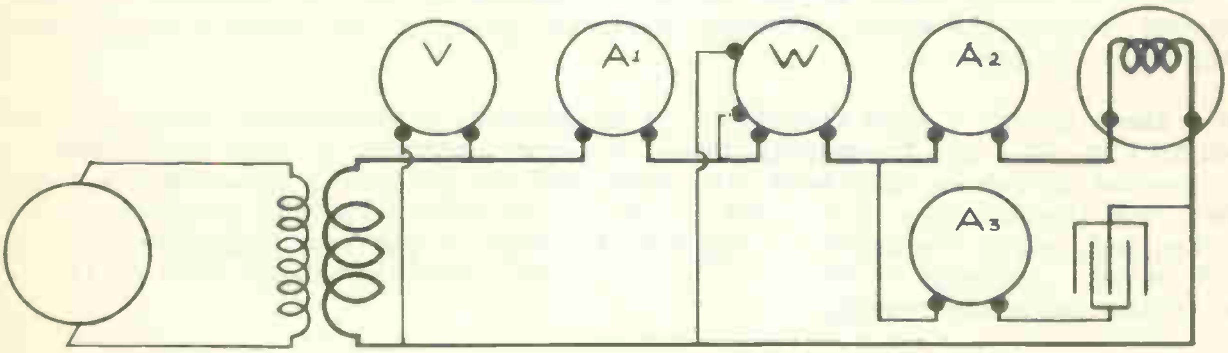
V.A. = E x I = ______ x ______ = ________ V.A.

W = W.M. reading ----------- = ________ W.

Active I = $\frac{W}{E}$ = ____________ = ________ I.

P.F. = $\frac{W}{V.A.}$ = __________ = .______ = _____ %.

Fig. 8 Fully loaded induction motor without power factor correction



V.A. = E x I = ______ x ______ = ________ V.A.

W = W.M. reading ----------- = ________ W.

P.F. = $\frac{W}{V.A.}$ = __________ = ______ = _____ %.

Fig. 9 Fully loaded induction motor with power factor correction

This also emphasizes the necessity for polarizing or phasing out two units when used in a three phase, 3-wire circuit, if correct indications are to be obtained.

Wattmeter connections - Fig. 10-c illustrates the 2 single phase meters properly connected, and with Am and VM added in the circuit for current and voltage measurement. This complement of meters represents the minimum number required to register W total, E, and I, and so determine the PF of the circuit.

$$PF = \frac{W_1 \pm W_2}{E.I.1.732} = \frac{W\ total}{VA\ total}$$

The wattmeters show, of course, the true power in W absorbed by the circuit and, due to the fact, the current required to carry a given wattage may be relatively high when the PF of the circuit is low, there is danger of overheating the current element of the WM on the low PF loads. To indicate this, it is customary to connect an AM in series with the I element of the WM to make sure that its I rating is not exceeded.

High Power Measurements - Fig. 10-d shows the equipment required to measure W, E, and I in a high voltage, high power circuit. Note that it will be necessary to match the units, i.e., meters and instrument transformers, due to the ratios involved. Also observe the ground connections made for safety of personnel and equipment.

Three Phase wattmeters - The schematic diagram for a 3 phase, three wire WM is shown in figure 10-e. This meter consists of nothing more than two individual single phase WM's in the same case, therefore, the same connection scheme will apply as for two separate single phase units. Since both potential elements (moving elements) are mounted on the same pinion or shaft, the torsion or turning moment is always equal to the sum or difference of the two separate torques developed, hence, the meter indicates the total power of the circuit regardless of the power factor.

When a three phase, 4 wire circuit is to be metered, 3 wattmeters, connected as shown in Fig. 10-f are frequently used. A current element of each instrument is connected in series with each line wire, and the potential elements are connected from the separate line wires to neutral as shown. Phasing procedure is not required, since the meter readings will always be positive regardless of the PF value. A change in PF will not affect the relative values here as it does in the two meter arrangement.

In this case, W total is found by adding W_1, W_2, and W_3, and

$$PF = \frac{W_1 + W_2 + W_3}{E \times I \times 1.732}$$ assuming a balanced load condition from each line wire to neutral.

MEASUREMENT OF THREE PHASE POWER

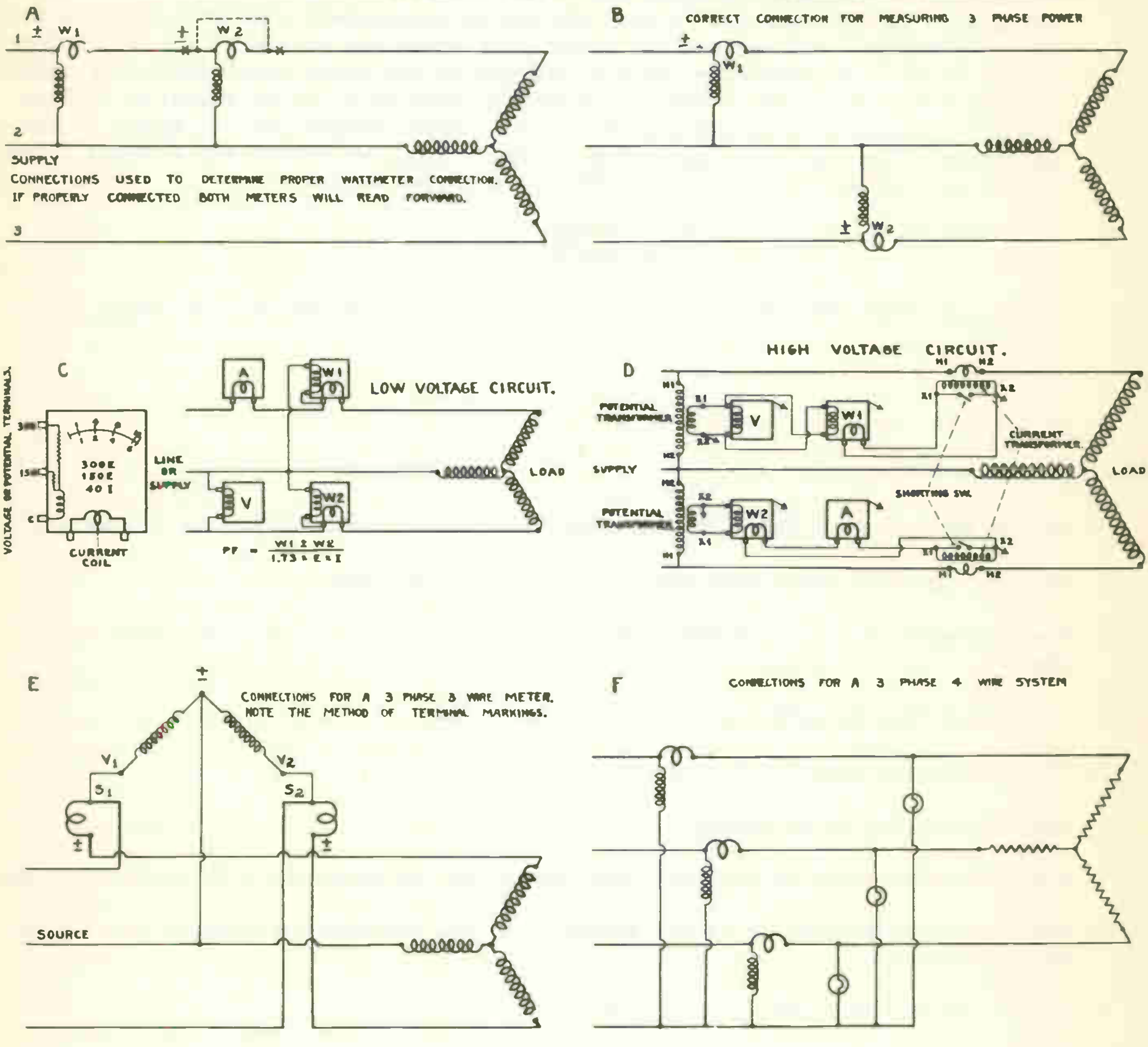


Fig. 10A-F

Efficiency - Generally, there is no point in making a PF test on a motor which is operating idle or unloaded. Since the dynamometer is not always available for motors of integral HP size, the prony brake or other methods of loading the motor must be resorted to. A very desirable arrangement consists of a d-c generator provided with resistor or other load apparatus to absorb the electrical output of the d-c generator which is driven by the motor under test. By adjusting the load connected to the d-c generator terminals, it is possible to load the motor under test to the desired value. Motor output will be equal to the generator output plus the generator losses. Thus, we obtain all factors necessary to determine the PF and the efficiency of the motor.

$$\text{Motor Efficiency} = \frac{\text{Motor Output}}{\text{Motor Input}}$$

Exact procedure for this test will be outlined in the job section under Job 14.

G. Summary Questions

1. Is the product of E and I in the single phase a-c circuit equal to the watts?
2. Define: Apparent watt; volt-ampere; KVA; reactive power.
3. What is meant by power factor? General formula for PF in single phase? Three phase?
4. Is it possible to have a PF of over 100%?
5. What means are employed to correct low power factor?
6. What causes low power factor?
7. What procedure must be followed when measuring the power in a three phase circuit?
8. Under what conditions is it not possible to add alternating current quantities arithmetically?
9. If one wattmeter reads backward, what does it indicate?
10. Explain "power penalities" and what may be done to lessen those penalties.

TRANSFORMERS

Objective

To learn the principles of polarizing, phasing, paralleling, and connections of distribution power transformers.

References

Lesson Content

A. General

The transformer is an essential piece of equipment which effects economical electrical energy distribution. It can be defined as a piece of electrical apparatus which changes voltage and current values without a frequency change. Basic operating principles have been discussed in previous departments.

B. Construction

Basically a power transformer consists of:

1. Primary Winding - winding connected to the source of power.

2. Secondary Winding - winding connected to the distribution load. Voltages are induced by electromagnetic induction and is, of course, dependent upon the ratio of turns and the coefficient of coupling between primary and secondary. The voltage-turns formula is often expressed as:

$$\frac{\text{Voltage (Pri.)}}{\text{Voltage (Sec.)}} = \frac{\text{Turns (Pri.)}}{\text{Turns (Sec.)}} \text{ or } \frac{Ep}{Es} = \frac{Np}{Ns}$$

3. Iron Core - laminated and in three general classes: (Fig. 1)

   a. Core - high voltage type
   b. Shell - Medium and Low voltage type
   c. Distributed - low voltage type

C. Classification

1. Transformation of Energy

   a. Step up - low to high voltages. Used to increase generating station to transmission line voltages. Copper costs reduced by decreasing the value of transmitted currents.

   b. Step down - High to low voltages. Used for transmission line to consumer distribution lines with usable voltages of 7200 to 110 volts, depending upon application and demand.

2. Single phase coil and magnetic circuit arrangements, Fig. 1.

   a. Core transformers - conductors are wound around the core. Used for single phase high voltage transmission and distribution work.

b. Shell transformers - conductors are wound through and around the core. Usually has fewer turns and a higher voltage per turn than the core type.

c. Modified shell - in this distributed core type, conductors are common to the two super-posed shell transformers. Sometimes referred to as a single core type transformer with a divided magnetic circuit.

3. General Circuit Application

a. Single Phase - usually consists of one set of primary and secondary windings which have "in phase" fluxes for one or more magnetic circuits, may be used individually or in power distribution banks.

b. Poly-phase - usually consists of two or more sets of primary and secondary windings, which have at least two displaced phase magnetic circuits through the core. This transformer has a disadvantage over single phase units, in that the entire unit must be disconnected so repair or service can be done to any part of it safely.

4. Various Cooling methods

a. Air cooled - no-liquid cooling, sub-classified as:

1) Natural - winding case open at the top and bottom; as the temperature rises the air becomes lighter causing rise, etc.

2) Forced - winding case closed at the bottom except for fan or blower opening. The opening at top allows "air-blast" to pass. It requires approximately 100 cu. feet of air per minute per kw of load to do a good job of cooling, except on special type of units, such as overload type, etc. The blast pressure will usually be low to prevent winding damage (1 to $1\frac{1}{2}$ oz. per square in.- up).

b. Liquid Cooled (sometimes called oil immersed) - unit is cooled by an oil extracted from mineral deposits. This efficient means of cooling is also an excellent insulator, preserves insulation from oxidation, increases breakdown insulation resistance, and will restore insulation qualities in case of puncture. It must have a low viscosity (flow easily at operating temperatures), negligible decomposition, contain no moisture, and be free from dirt, sulphur compounds, acids, alkalis, or any other ingredient which may impede the life or harm windings and metals. Good transformer oil should withstand a "flash-test" of at least 16,500 volts and preferance is given to oil with a 22,000 volt test. Fig. 1 shows the circuit for a flash-test unit. A practical test can be made without this unit for the detection of water.

(Thrust a white-hot nail into an oil sample. If it "sputters or crackles" water is present).

If either test indicates unsatisfactory oil, it can be cleaned and de-moisturized by:

1) Centrifical separator - a high speed centrifical force unit which, because of the difference in specific gravities of oil and water, will effectively segregate the oil from other unwanted materials. Very similiar in operation to a farmer's cream and milk separator.

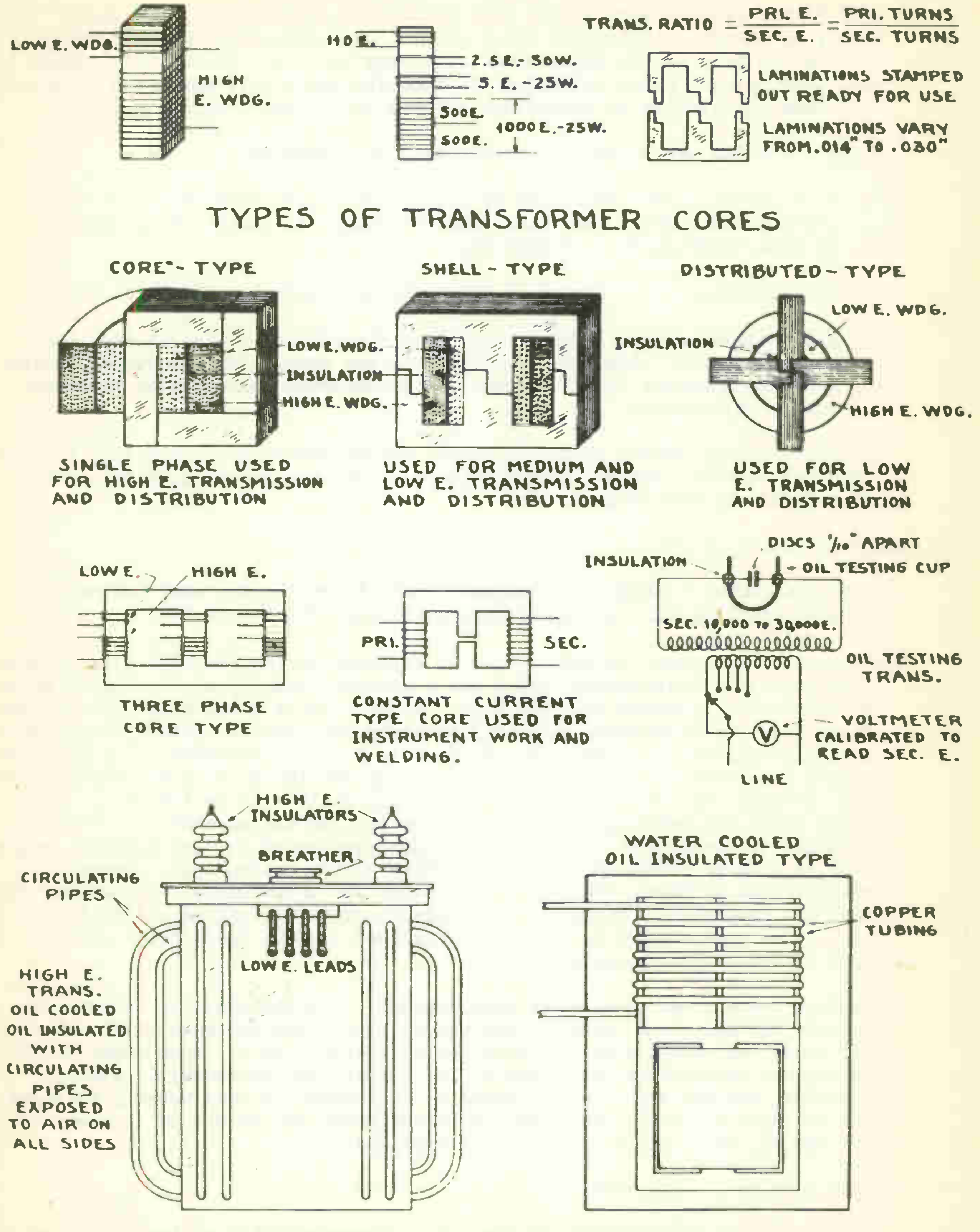


Fig. 1 Transformers

Hysteresis — loss of action in iron core

2) Filter Press - More widely used of the two, it consists of a filter unit with a circulating motor and a multi-filter disc-trap which is connected on the jets of the transformer receiving service. Another unit which is used by many power companies, in a mobile truck unit which can be moved from sub-station to substation. These units cost from $20,000 up.

Liquid cooling can be brought under three main headings:

a. Self cooled - oil circulated by convection action transfers heat from windings and core to the case. Its efficiency is increased by the use of fins, corrugations, radiators, tubes, etc.

b. Forced Cooled - oil forced to circulate by external centrifical pumps.

c. Water cooled - water carries away heat the oil has picked up from the core and coils. Sometimes refrigerants are pumped through copper tubing which is immersed in oil in case the transformer units are in isolated vaults underground.

Another cooling medium is the "PYRANOL" method which is, in reality, a jelly compound used for indoors units in place of the mineral cooling oil method. It reduces the fire hazard.

5. Characteristics of output

a. Autotransformer - single winding multi-tapped transformer used for reduced voltage starting etc. Refer to lesson 15, for full discussion.

b. Current Transformer - a transformer so designed to isolate high line voltages from measuring instruments, which has a primary, usually of few turns, which is connected in series with the line. Because it is a known ratio transformer, it is possible to measure secondary currents and indicate primary currents on properly calibrated scales. The ratio of current transformation is approximately the inverse ratio of turns, i.e., suppose the primary has one turn and the secondary has one-hundred turns then the ratio will be 100 to 1. Both phase angle and ratio are affected by the load on the secondary. Secondary currents of nearly all current transformers are rated at five amperes, regardless of primary currents. If the secondary should become open, tremendous open circuit voltages would likely puncture the transformer and endanger equipment and personnel. To avoid this danger a short-circuiting switch is provided. At no time should an energized connected current transformer have an open circuit in the secondary.

c. Voltage transformer (potential transformer) a transformer so designed as to have minimum error in ratio and phase-angle. For voltages of 34,000 volts and above the secondaries are rated at 115 volts; for voltages under 34,000 volts, the secondaries are rated at 120 volts. The secondary is always grounded, and the scale of the meter is calibrated to read primary voltages. For voltages up to 13,800 volts, the transformer may be oil or in some cases air cooled; over 13,800 they are oil immersed.

6. General Service Classification -

a. Distribution - transmission of electrical energy at high voltages and low currents, to minimize line losses.

Hi is on the right side by the high voltage side. Hi's is on left low side

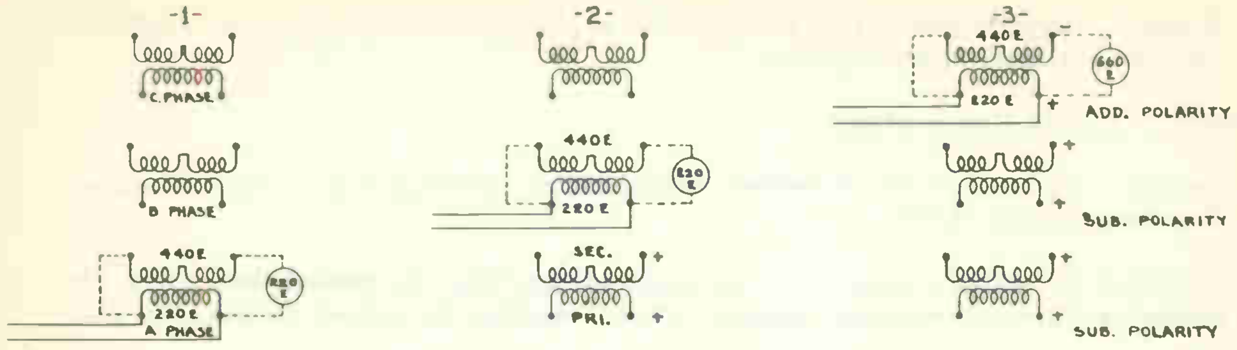


Fig. 2 Polarizing transformers

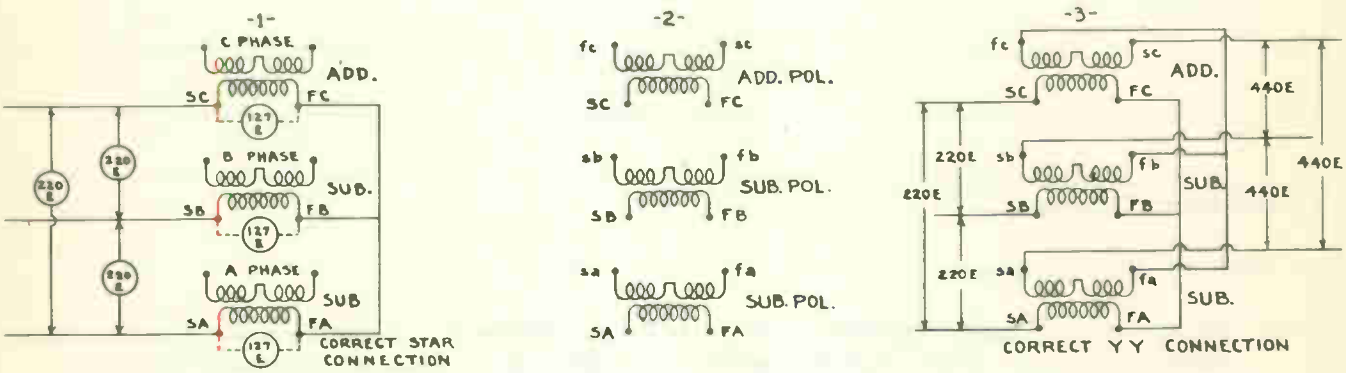


Fig. 3 Phasing out transformers

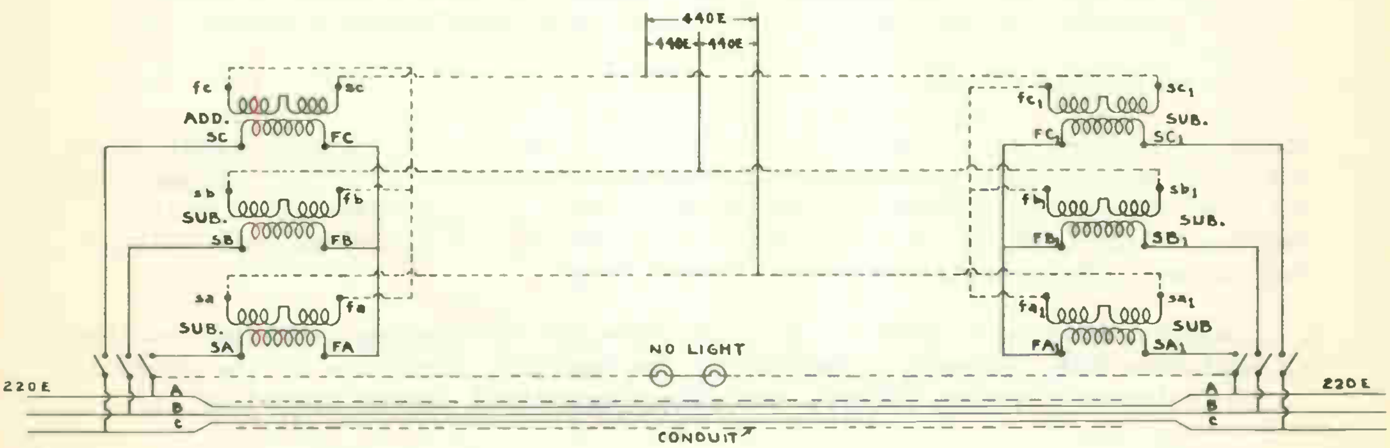


Fig. 4 Paralleling transformers

b. Power - comparatively low voltages at higher currents. This type of service is the customer-type service.

7. Special Circuit Connections

a. Series - for a job of increased voltages or possibly for a limited street lighting application.

b. Parallel or shunt - applications where short-time increased loads are demanded such as carnavals, county fairs, canning factories in season, etc.

8. Locations of use

a. Indoors - often air cooled, used in protected areas under cover for power and instrument use.

b. Outdoor - liquid cooled for power sub-stations, etc. Usually of the tongue and groove type lids and with other protection against the elements of nature.

D. Transformer Losses

1. Core or Iron Losses

a. Hysteresis - heat conversion due to flux reversal. Depends upon frequency, amount of core iron, and magnetic flux density. With a constant frequency and a given quality of iron, it varies as voltage 1.6, and is minimized by the use of annealed silicon steel in the core.

b. Eddy-currents - circulating currents in the body of the iron resulting in the heating of the iron. They are minimized by laminating the core.

c. Magnetic Leakage - circulating currents which are losses, caused by poor design of the unit, in general. The leakage can be minimized by using a high permeability iron or steel in short large-area magnetic paths.

2. Copper or winding losses

These losses for all practical purposes, may be very small in small-unit sizes but is of appreciable percentage importance in large units. Total copper losses will, of course, be dependent upon primary and secondary currents as well as loading factors, which will also vary the power factor and cause poor voltage regulation. The general classes of losses are:

a. Conductor Heating (I^2R)- because of currents circulating in resistive wire.
b. Conductor Eddy Currents - because of the metallic structure of the conductor.
c. Stray losses - tanks, clamps, and other structural losses caused by (b).

E. Transformer Connections -

1. Single Phase

a. Distribution - Usually a direct voltage and current transfer, used for light and power loads.

b. Polarizing - means to identify the leads and mark the transformer with a notation as to whether the terminals are additive or subtractive polarities. Instructions for polarizing are: (See Fig. 2).

1. Connect primary of one phase of the transformer to a suitable a-c supply - rated voltage or less.
2. Measure both primary and secondary voltages.
3. Connect voltmeter as shown in 1, 2, and 3, Fig. 2, and note whether instrument indicates the sum or the difference of the primary and secondary voltages. If sum is given, additive polarity is indicated; if difference, subtractive polarity is indicated.

c. Phasing out - means to set up starts and finishes so as to prepare transformers for connections in banks. Instructions for phasing out are: (Fig. 3).

1. Assume three ends of the three primary phase to be "finishes" and join them together. Connect three remaining "starts" to line.

2. Take voltmeter reading on each primary phase.

3. If readings are not equal, reverse the leads of one phase and test again. If still unequals, replace leads and reverse the next phase. Repeat until equal readings are obtained, and then mark the ends connected together "F" and those attached to the line "S". The starts and finishes of the secondary winding may be determined from the transformer polarity, if known.

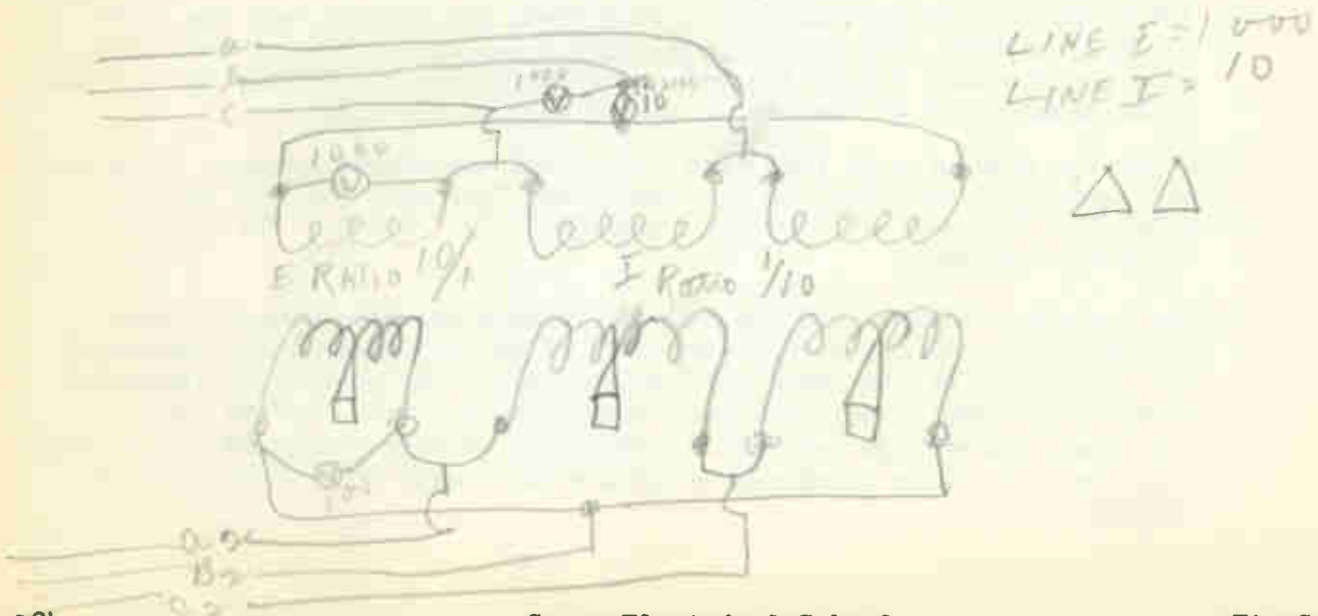
d. Combining or Paralleling - means to increase the capacity of a bank without disturbing the established connections made thereto. Instructions for this job are, (Fig. 4):

1. After the transformers have been polarized, phased out, and the leads properly marked, they may be paralleled. Identification of each line will be necessary before the primary windings are connected, and a symmetrical arrangement of the transformer leads is essential.

2. After the ends of each line have been found and marked connect the primary leads "SA" and "SA_1" to the same line; "SB" and "SB_1" to the next wire; and "SC" and "SC_1" to the remaining line. Connect the primary finishes together.

3. The secondary connections are made by joining the secondary finishes and then connecting corresponding ends of the different phase together, "sa" to "sa_1" "sb" to "sb1" and "sc" to "sc_1". To prevent an incorrect connection, connect only one secondary wire, say from "sa" to "sa_1" and check the voltage between the remaining secondary terminals. Connect together only those terminals between which there is NO DIFFERENCE IN VOLTAGE.

CONNECTION	ΔΔ	ΔY	YY	YΔ	VV
VOLTAGE Primary					
Line	1000	1000	1000	1000	1000
Phase	1000	1000	580	580	1000
RATIO	10:1	10:1	10:1	10:1	10:1
Secondary					
Phase	100	100	58	58	100
Line	100	173.2	100	58	100
CURRENT Primary					
Line	10	10	10	10	5.8
Phase	5.8	5.8	10	10	5.8
RATIO	1:10	1:10	1:10	1:10	1:10
Secondary					
Phase	58	58	100	100	58
Line	100	58	100	173.2	58



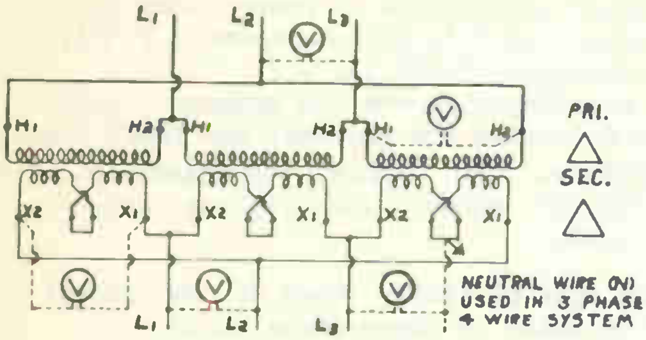


Fig. 6A Delta-Delta

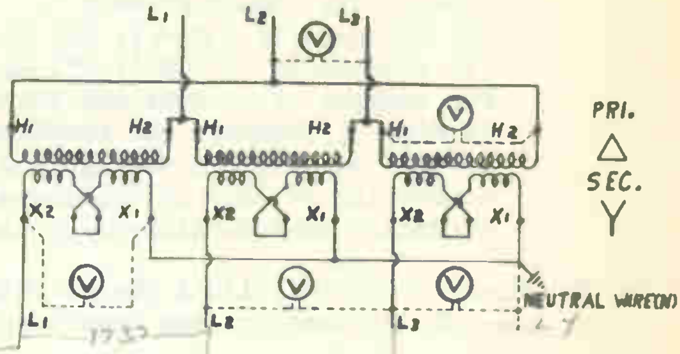


Fig. 6B Delta-Star

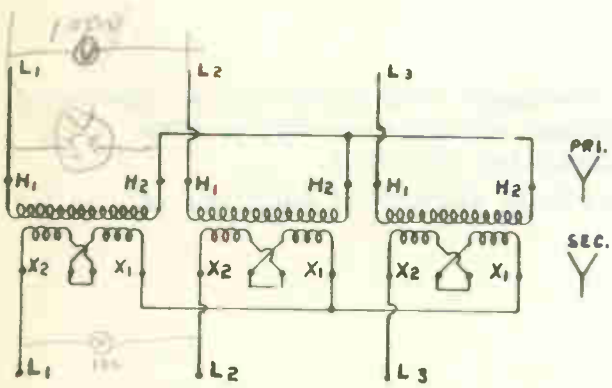


Fig. 6C Star-Star

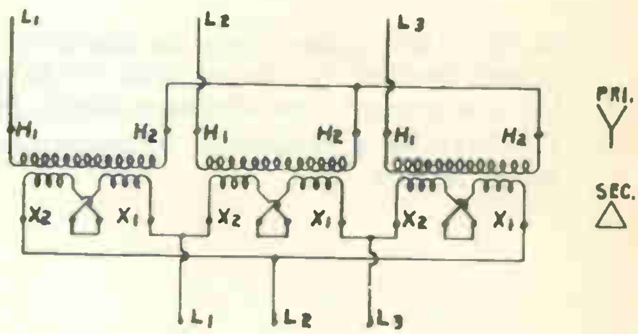


Fig. 6D Star-Delta

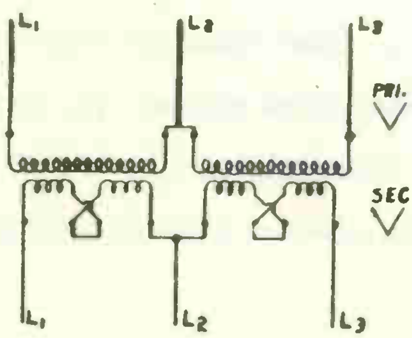


Fig. 6E Open Delta

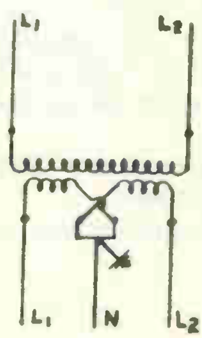


Fig. 6F Single phase

e. Bank formation

Some of the common primary to secondary connections in power banks are: (1) delta-delta (△△); (2) delta-star (△Y); (3) star-star (YY); (4) star-delta (Y△); (5) open delta-open delta (VV).
For example of current and voltage relationships see the prepared chart in Fig. 5. Compare the readings to determine the greatest and least line to line step-up for voltage and currents. Fig. 6 shows the schematic connection of each of the above. Fig. 6- shows a single-phase tapped-secondary distribution-to-customer unit.

2. Two Phase - two individual phases from two sets of lines. Used to some extent in some old systems but has been largely replaced by three-phase units.

3. Polyphase - a three phase power transformer which may be efficiently utilized when increasing the capacity of a bank.

F. Regulations (A.I.E.E.)

1. No additive connections on distribution to customers over 9,000 volts. (Decrease "flash-hazard"). Below 9000 volts can be either additive or subtractive.
2. All instrument transformers shall be of subtractive polarity.
3. It shall be a violation to remove nameplates from electrical machines or transformers.

G. Summary Questions.

1. What does a power transformer basically consist of, and explain each part?
2. Explain the various core types and the uses of each.
3. What is a step up transformer used for? Step down?
4. What are some applications of single phase transformers? Polyphase?
5. What methods are used for cooling transformers? What determines the method which is to be used?
6. Explain the flash test for transformer oil. What other practical test can be used and what does it indicate?
7. When transformer oil must be processed, what three methods can be used to do a satisfactory job?
8. Explain current transformers. Potential transformers.
9. Explain transformer losses.
10. Which connection of transformers gives the greatest line to line step down for voltages? Currents?

SYNCHRONOUS MOTORS

Objective

To learn more about the operation and use of this "zero-slip" polyphase motor.

References

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Lesson Content

A. General

Synchronous motors operate at synchronous speed, or in exact step, with the applied frequency and rotating magnetic field of the machine.

When in normal operation, the synchronous motor has no slip, or "zero slip" as it is often called. The speed of these motors is inversely proportional to the number of poles in the stator and directly proportional to the frequency of the applied line voltage, and as long as the number of poles and frequency remain unchanged the speed will not vary.

Therefore, a synchronous motor is a constant-speed motor and can be used where a certain speed must be accurately maintained at all times.

Another great advantage of synchronous motors is that their power factor is very high, and they can actually be operated at leading power factor in order to improve the power factor on a system which is loaded with inductive equipment.

In many cases synchronous motors are used only for power factor correction, and are operated without any mechanical load attached. In such cases the motors are connected to the system or lines and allowed to run idle or float on the lines, with their d-c field poles strongly excited; so that they draw a leading current from the line and thus neutralize the effects of the lagging current produced by induction motors or other inductive equipment on the line.

When these machines are used for power factor correction in this manner they are called synchronous condensers; because their effect on the system is the same as that of a static condenser, which also supplies leading current.

Synchronous motors are made for power drives and power-factor-correction in sizes ranging from a few horse power to 50,000 kv-a or more.

Power companies have synchronous condensers, as large as 50,000 kv-a. connected directly to lines of 13,200 volts for correcting the power factor on their systems.

Special synchronous motors are made in very small sizes for the operation of electrical clocks and such devices. Some of these small motors operate on a fraction of one watt of electrical energy. Refer to Fig. 1-a.

B. Small Synchronous Motors.

Due to their constant speed characteristics, small synchronous motors, A, are widely used in stroboscopes, mechanical rectifiers, electric clocks, recording devices, timing relays, demand meters, etc. These small motors operate similarly to the large power types except that the small units are not separately excited, the poles on the rotor being produced by magnetic induction from the stator. Turning at synchronous speed, the rotor is polarized and is in the position shown when the stator current is maximum. As the current diminshes, momentum carries the rotor to the vertical position just as the main poles reverse and as the hard steel rotor still retains its poles, it is again attracted to the horizontal position and rotation continues. Shading coils are employed to make the unit self starting. Speed is determined by frequency, if frequency is constant, speed will not vary.

Subscynrhonous Clock Motor - B, consists of a 2 pole stator and an iron rotor with 16 or more salient poles. The motor is not self starting, but when operating at synchronous speed, 2 diametrically opposite poles are attracted to the field poles as the flux of the field is increasing. Because of the inertia of the rotor, it continues to rotate while the flux is decreasing and passing through zero. The next pair of poles is then attracted by the field flux, as it increases in the opposite direction. Although the stator has only 2 poles, the speed of the motor is the same as that of a motor having the same number of stator and rotor poles. EXAMPLE - at 60 cycles the speed is 450 RPM, corresponding to the 16 rotor poles. Because the rotor speed is much less than that corresponding to the 2 stator poles, the motor is said to operate at Subsynchronous speed.

Self-Starting Induction-Reaction Subsynchronous Motor - C, This motor is a 2 pole single phase, combination induction and synchronous motor with a shaded pole field and a squirrel cage rotor. In this particular motor there are 6 rotor slots, so proportioned that they produce 6 salient poles on the rotor which give the synchronous (or reaction) motor effect. At starting, the induction motor torque must be sufficient to overcome the tendency of the salient poles of the rotor to lock in with the stator poles. The motor operates as any induction motor, the rotor tending to accelerate to nearly synchronous speed. EXAMPLE- At 60 cycles, the induction motor torque tends to accelerate the rotor nearly to the 2 pole synchronous speed of 3600 RPM. The motor is so proportioned that at 1200 RPM, the 6 pole synchronous speed, the reaction torque due to the pulsating stator pole flux reacting with the 6 rotor poles, predominates over the induction motor torque developed at that speed. The rotor, therefore locks in with the stator poles and runs synchronously at 1200 RPM. At its operating subsynchronous speed, the motor develops simultaneously induction motor and synchronous motor torque. This type is used chiefly with timing devices.

C. Construction and Excitation

Synchronous motors are constructed almost exactly the same as alternators; in fact, an alternator may in many cases be operated as a synchronous motor. Synchronous motor have the a-c armature winding or element and a d-c field the same as alternators.

Small synchronous motors are sometimes made with stationary field poles which are excited by direct current, and with a revolving a-c armature to which the line current is fed through slip rings.

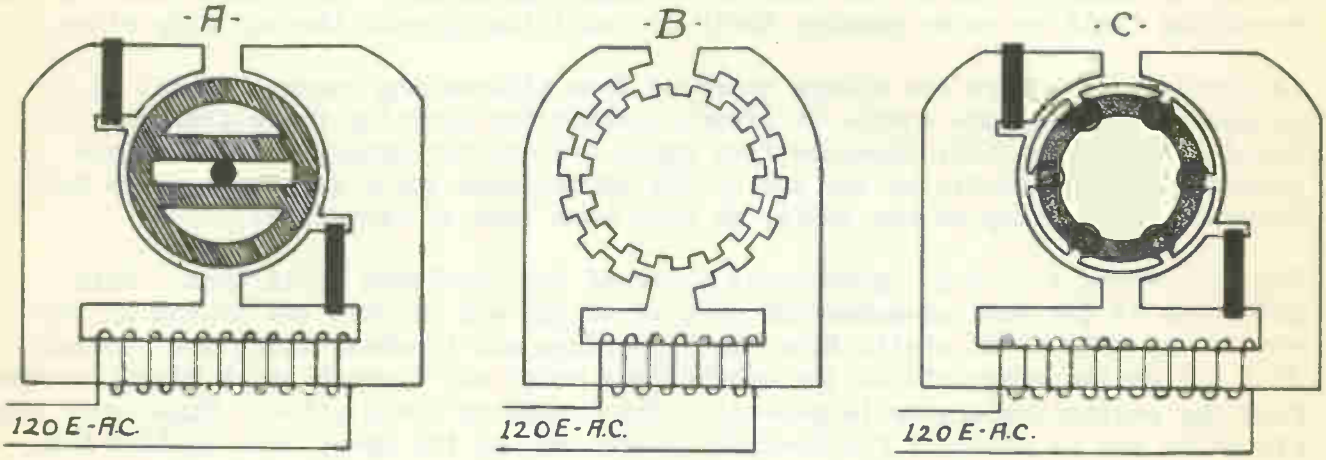


Fig. 1A Small synchronous motors

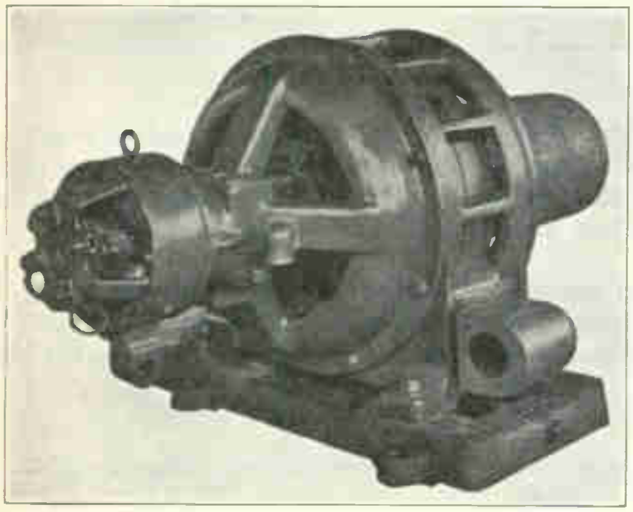


Fig. 1B This photo shows a 75 h. p. synchronous motor of the revolving field type. Note the small exciter-generator which supplies D. C. to the field of the large motor. (Photo courtesy General Electric Co.)

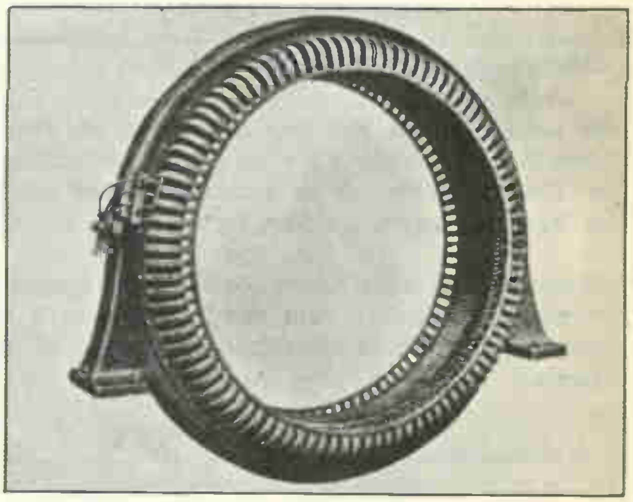


Fig. 2 Above is shown the stator of a large synchronous motor. You will note that the stator, frame, core, and windings are the same as those used for alternators.

Most medium and all large-sized synchronous motors, however, are made with revolving fields, the same as large a-c generators. On these motors the alternating current line-energy is fed to a stationary armature or stator winding which sets up a revolving magnetic field, the same as in induction motors. The field poles on the revolving field or rotor receive their d-c exciting current through slip rings.

As synchronous motors are always operated from alternating current lines, it is necessary to have some source of direct current for exciting their fields. This field supply is usually obtained from small d-c exciter-generators, which are either mounted directly on the end of the synchronous motor shaft or may be belt-driven from a pulley on the shaft, or from some type of rectifier.

Fig. 1-b shows a 75-h.p. synchronous motor of the revolving field type. This motor has it d-c exciter-generator mounted on the end bracket and driven by the end of the main motor shaft. Note the slip rings and brushes, which are located just inside the end-plate of the synchronous motor and through which direct current from the exciter-generator is passed to the revolving field poles. This motor has six poles and is designed for 60-cycle operation, so its speed will be 1200 RPM.

Fig. 2 shows the stator of a large slow-speed synchronous motor, and Fig. 3 shows a large diameter revolving field for a synchronous motor of this type.

Large synchronous motors with a great number of poles can be made to operate at very low speeds and are, therefore, frequently used to drive slow-speed pumps or machinery by direct connection.

D. Damper Windings

In addition to the d-c windings on the fields of synchronous motors, they are us-usually provided with a damper winding consisting of short-circuited bars, similar to the squirrel-cage windings used on induction motors. This damper winding can be clearly seen on the outer ends of the poles of the field rotor in Fig. 3.

Damper windings are provided on synchronous motors to obtain sufficient starting torque to enable the motors to start with some load attached, and also to prevent what is known as hunting. Hunting of synchronous motors will be explained a little later.

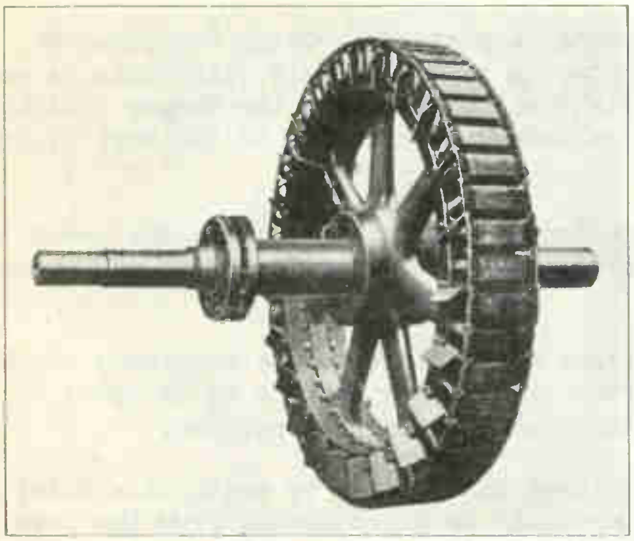


Fig. 3 Revolving field or totor of a large slow-speed synchronous motor. Note the squirrel-cage damper winding attached to the pole faces and also the slip rings through which the D.C. is passed to the revolving field poles.

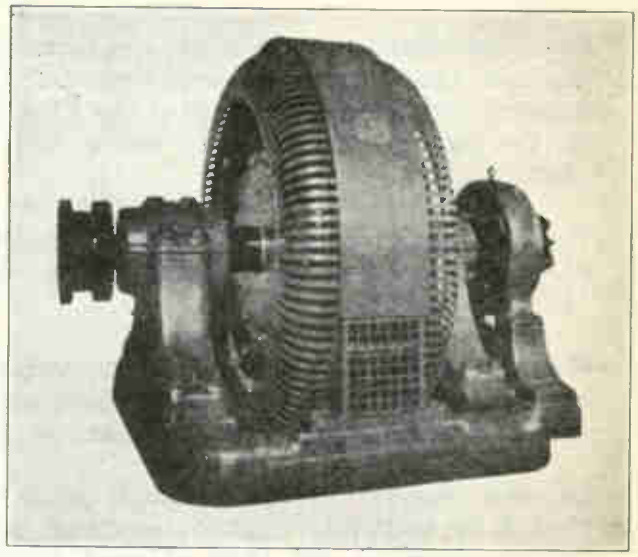


Fig. 4 This photo shows a 2000-h. p., 2300-volt, synchronous motor which operates at 100% power factor. The D.C. exciter-generator is shown on the right-hand end. (Photo courtesy General Elec. Co).

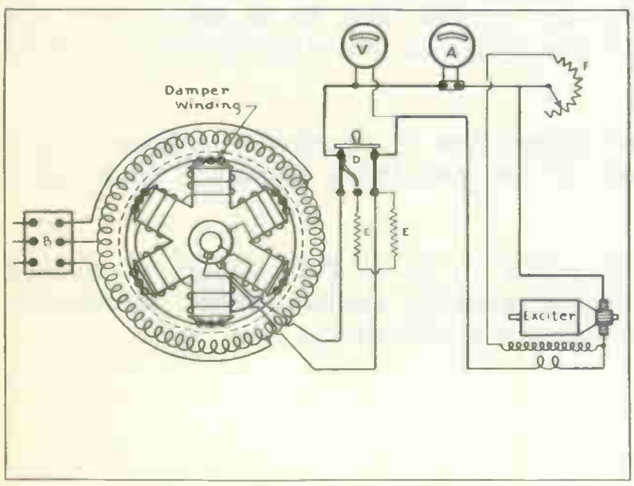


Fig. 5 The above diagram shows the connections for the stator and field of a synchronous motor and also the exciter-generator field discharge switch and instruments.

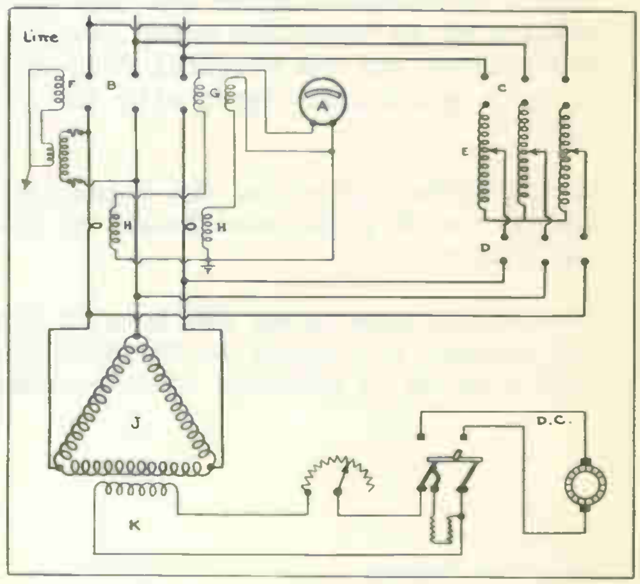


Fig. 6 Diagram of connections for a large synchronous motor with a compensator for starting at reduced voltage. Also note the protective device connected with a circuit-breaker in the line leads.

E. Operating Principles

When synchronous motors are started, their D.C. fields are not excited until the rotor has reached practically full synchronous speed; so the starting torque to bring the rotor up to speed must be produced by induction.

When the stator winding of a synchronous motor is excited by being connected to the a-c line, it immediately sets up the rotating magnetic field with which we are already familiar. The rotating flux of this field cuts across the damper winding of the revolving member or rotor and induces secondary currents in the bars of this winding.

The reaction between the flux of these secondary currents and that of the revolving stator field produces the torque necessary to start the rotor in motion and bring it up to speed.

When some of the older type synchronous motors were used to drive machinery which had to be started under load, they were often started and brought up to speed by means of a separate induction motor just large enough for this purpose.

In some cases, the synchronous motor is attached to the load by means of a friction clutch or magnetic clutch, so that the rotor could be disconnected from the load during starting and then allowed to pick up the load by means of the clutch after the rotor had reached synchronous speed and its d-c field poles were excited.

This is not necessary with most modern synchronous motors which are properly adapted to their load; because it is possible, by properly proportioning the squirrel-cage damper winding, to design synchronous motors with good starting torque.

When a synchronous motor has been brought up to nearly synchronous speed and is operating as an induction motor because of the damper winding, then the DC field poles are excited and the powerful flux of these poles causes them to be drawn into step or full synchronous speed with the poles of the rotating magnetic field of the stator.

During normal operation the rotor continues to revolve at synchronous speed, as though the DC poles were locked to the poles of the revolving magnetic field of the stator.

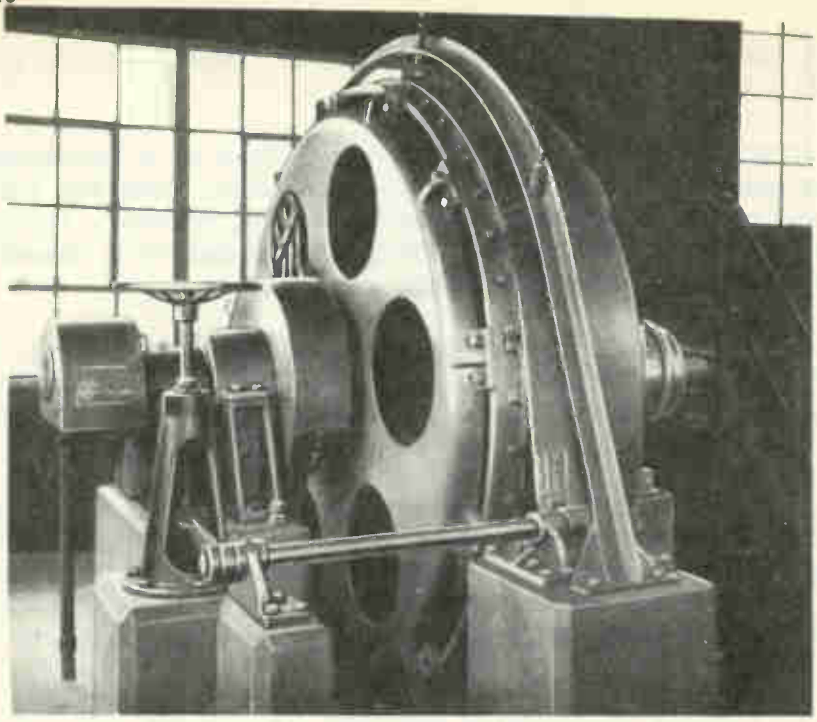
As a synchronous motor has no slip after the rotor is up to full speed, no secondary current is induced in the bars of the damper winding during normal operation, that winding is entirely inactive during synchronous operation.

F. Pull Out Torque

If a synchronous motor is overloaded to the extent where the d-c rotor poles are made to lag or pull out of step with the poles of the rotating stator field, the slip which results will again cause current to be induced in the damper winding and to develop torque by induction, as during starting.

If the overload is not too great or doesn't last for more than an instant, this torque developed by induction in the damper winding may enable the rotor to pull back into step; but if the overload is too great and lasts too long, the rotor will be

Fig. 7 300 HP super-synchronous motor



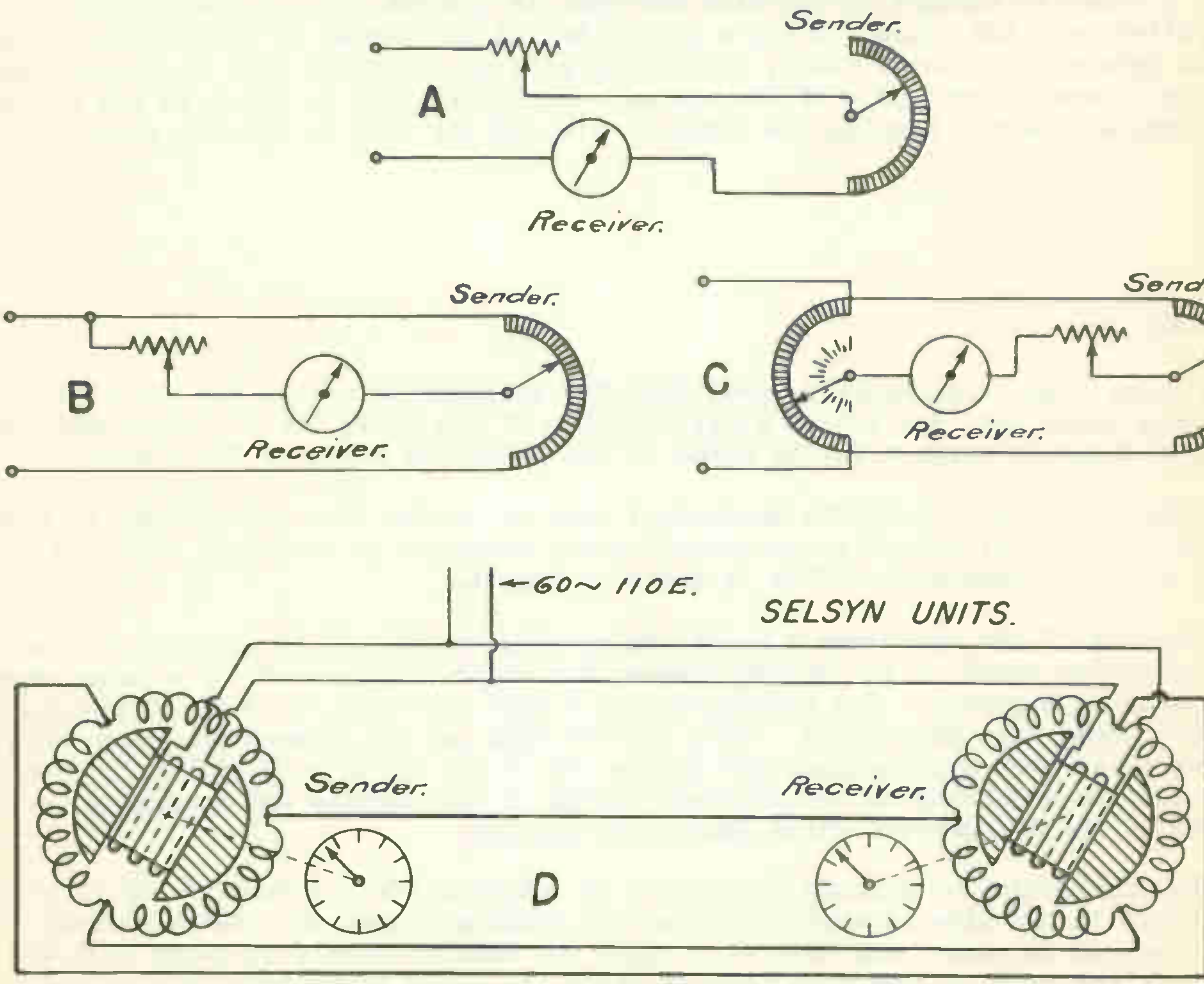


Fig. 8 Position indicator

pulled out of step with the revolving magnetic field, and the motor will lose its torque and will stall.

If the d-c current supplied to the revolving field of a synchronous motor is interrupted during operation, the motor will, of course, lose its torque and will stop if there is any appreciable load connected to it, however, torque developed by induction in some later types may be sufficient to maintain operation and permit motor to re-synchronize when d-c excitation is restored.

We have found that a synchronous motor developes its torque by the attraction between the poles of the revolving magnetic field set up by the stator and the poles of the rotor, which are maintained at constant polarity by direct current through their coils.

We know that magnetic lines of force are more or less elastic, so we can readily see that it is possible for the poles of the rotor to be pulled back a little or caused to lag slightly behind the center of the revolving poles of the stator, without actually being pulled out of step far enough to lose the attraction between the poles and thereby lose the torque. This might be caused by sudden surges of load of very short duration.

With a moment's thought we can also see that if a north pole of the revolving field is pulled back and caused to lag a little behind the center of an unlike pole or south pole of the stator field, this north pole of the rotor will be drawn closer to the adjacent north pole of the stator, which will tend to repel it and add to the torque, thereby keeping the rotor in step if the load is not too great.

G. Hunting

If a heavy load is suddenly removed from the synchronous motor, the rotor will tend to surge ahead and, due to the elastic nature of the flux, the d-c poles may for an instant actually surge a little ahead of the revolving poles of the stator.

Sometimes fluctuations in the mechanical load or in the line voltage may in this manner cause the rotor of a synchronous motor to surge or oscillate back and forth more or less irregularly. This is known as hunting.

The hunting of the synchronous motor can usually be noticed by a change in the normal operating sound or the smooth, steady hum which is given off by a motor when it is operating properly. The hunting causes a rise and fall, or sort of throbbing note, to come into this sound. This audible note may be of very low frequency, even as low as several oscillations per minute, or it may be of much higher frequency. This will be according to the size and design of the machine and according to the nature of the disturbance which causes the hunting.

Another indication of hunting may be had by watching the pointers of any ammeters connected in the line circuit to the motor. Hunting causes the stator current to increase and decrease, and this will cause the ammeter needle to swing back and forth at the same frequency as that at which the sound or hunting note occurs. During normal operation, the ammter pointer should change only when the load is changed or when the field excitation is varied.

Hunting may be due to anyone of the following causes: (A) Fluctuations in mechanical load on the motor. (B) Surging of generators on the line (C) Switching surges. (D) high or low frequency surges. (E) irregular or pulsating electric loads on the line. (F) Hunting of other synchronous motors on the same line.

Hunting should not be allowed to continue, because it may set up very dangerous mechanical stresses within the motor, and it will also produce objectionable surges of current on the a-c line supplying the motor.

Damper windings play a large part in the prevention of hunting, because, as soon as the rotor attempts to fall behind or surge ahead of the poles of the rotating stator field, the slip at once causes secondary currents to be induced in the damper winding, and thereby developes inductive torque which tends to hold the rotor at constant speed.

In some cases a synchronous motor may have a tendency to hunt, even though it is equipped with damper windings. Changing the voltage applied to the field may cause the motor to stop hunting, and if this doesn't stop it, it may be necessary to shut the motor down and restart it. This will often eliminate the hunting.

Sometimes a slight increase or decrease of the mechanical load on the motor may help to stabilize its speed and prevent hunting.

If none of these things will stop it, it will then be necessary to definitely locate and eliminate the cause; which may be in the supply line, in the exciter-generator or in the mechanical load.

Fig. 4 shows a large synchronous motor of 2000 h.p., designed for operation on 2300 volts and at unity power factor. Note the exciter-generator, which in this case is mounted on a separate pedestal at the right of the motor. The armature of the exciter is mounted on the motor shaft and is directly driven at the same speed as the synchronous motor.

H. Motor Connections Synchronous

Fig. 5 shows a diagram of the connections for a synchronous motor and its exciter-generator. You will note that the wiring and connections for this machine are practically identical with those for an alternator, with the exception that a rheostat is not always used in the field circuit of the synchronous motor.

Regardless of the voltage at which the synchronous motor may be operated, the exciter voltage is seldom higher than 250 volts. The capacity of the exciter-generator in kw, usually ranges from 1 to 3 per cent of the kv-a, rating of the synchronous motor.

By adjusting the exciter field rheostat, f, the voltage applied to the field of the synchronous motor can be varied. This varies the current flow through the field coils and changes the magnetic strength of the poles. By means of this rheostat the strength of the motor field can be properly adjusted for the mechanical load which it is to drive, and for the amount of power-factor correction it is to perform.

The field discharge switch d, and resistance, E, are for the same purpose as when used with alternators; that is, to prevent high induced voltages in the field winding when the circuit is interrupted.

The damper winding of the rotor is shown in this diagram by the short-circuited bars in the pole faces.

I. Starting Synchronous Motors

When starting the motor, the stator is supplied with alternating current by closing the knife switch or oil switch at "b". Some form of compensator is generally used with large synchronous motors to reduce the voltage applied to the stator when starting, and in this manner keep down the heavy surges of starting current which would otherwise occur.

When starting a synchronous motor, there are a certain number of steps or operations which should be performed in the proper order. This is particularly important when starting large motors. The procedure is as follows:

First, open all switches and see that the field switch is in the discharge position; then apply about 50% of the rated voltage to the stator winding. It may be necessary to apply higher voltage if the motor is to start heavy loads.

As soon as the rotor has reached nearly full speed, see that the exciter rheostat is properly adjusted so that the generator produces a low voltage as indicated by the voltmeter V; and with this low voltage excite the field of the synchronous motor very weakly. Then apply full line voltage to the stator and gradually increase the field excitation until the motor pulls into step. Then adjust the field strength to the proper value to enable the motor to carry the mechanical load, in case it is driving any load of this nature, and for the proper power factor at which the motor is supposed to operate.

Large synchronous motors usually have ammeters connected in series with the line leads to the stator, and the current input to the motor should not exceed the name-plate current rating, except as per instructions furnished by the manufacturer in regard to the overload capacity of the motor.

Even though a synchronous motor is not driving any mechanical load, it is possible to overload the stator winding by over-exciting the field and thus causing the motor to draw a large leading current. This, of course, tends to correct the power factor of the system to which the motor is attached, but the synchronous motor should not be overloaded for this purpose any more than it should for driving mechanical load.

J. Adjusting Power Factor by Changing Field Excitation.

By adjusting the exciting current, the power factor of a synchronous motor may be varied in small steps from low lagging power factor to a low leading power factor. This makes it possible to vary the power factor of these machines over a wide range and places this characteristic of the motor under the control of the operator at all times.

If a synchronous motor which has normal field excitation were driven as a generator, it would develop the same armature voltage as that which is applied by the a-c line when the machine is operating as a motor. If the field current is increased above this normal value the motor will have a leading power factor; and if the field current is below normal value, the motor will have a lagging power factor.

When a synchronous motor is used to drive mechanical load and also to correct power factor, the field will require a small additional amount of exciting current.

K. Starting Compensators and Protective Devices

Fig. 6 shows a diagram of the connections for a large synchronous motor, including the starting compensator, ammeter, circuit-breaker, and protective devices.

When starting, the contracts B are opened and contacts C and D are closed, thus supplying reduced voltage to the motor armature J by means of the auto transformer E.

After the motor comes up to speed, the contacts C and D are opened and B is closed, thus supplying the armature or stator winding with full line-voltage.

If at any time during operation the motor is overloaded and the current to the stator winding becomes too great, the current in the secondaries of the current transformers H will be increased and will energize the overload trip coils G and G strongly enough so that they will open the circuit-breaker contacts B.

If the line-voltage should fail or become too low during operation of the motor, this would also reduce the voltage of the potential transformer secondary and weaken the under-voltage trip-coil F, allowing it to release its armature and open the circuit-breaker B. The d-c field of the synchronous motor is shown at K.

To stop a synchronous motor or condenser, first decrease the field excitation to normal and then open the line switch. Next open the field-discharge switch and leave it in the discharge position. This switch can be left closed until the machine stops if desired, but should always be opened then.

L. Characteristics and Advantages of Synchronous Motors

The efficiency of medium and large-sized synchronous motors ranges from 88% to 96%, depending upon the size, speed, design, etc. Some very large synchronous motors have been built with efficiencies of nearly 98%.

The starting torque of synchronous motors is usually slightly lower than that of induction motors, but many of the later type synchronous motors are designed with starting torques approximately equal to those of squirrel-cage motors.

These starting torque vary from 50% to 250%, according to the design of the machine.

The pull-out torques of synchronous motors varies from 150% to 200% or more of full-load torque.

Several of the outstanding advantages of synchronous motors are: (A) their constant speed; (B) ability to correct power factor, which in turn results in better voltage regulation; (C) higher efficiency at low speeds than induction motors.

The ability of synchronous motors to correct power factor is one of the most important of their advantages.

Synchronous motors have several features which may be considered as disadvantages and these are: (A) they are somewhat more complicated than induction motors; (B) lower starting torque of the older types; (C) tendency to hunt and therefore to fall out of step and stall; (D) they require more skilled attention than induction motors; (E) they require a supply of both a-c and d-c; (F) in case of shorts on the line, synchronous motors act as generators and supply current to the short as long as the inertia keeps the rotor moving at a fair speed. This latter disadvantage can, however, be eliminated with proper protective relays.

M. Applications or Synchronous Motors

The advantages of synchronous motors for certain classes of service much more than make up for the disadvantages which have been just mentioned.

Synchronous motors have a very wide field of application and their use is being rapidly extended to other classes of power drives each year. A large number of power generating and public utility companies insist that all motors of 50 h.p. and larger which are connected to the lines must be of the synchronous type. This is done in order to improve the power factor of the system and thereby permit better utilization of the generator line and transformer capacities.

With lower power factors, a large portion of the generator, line and transformer capacities must be used for the circulation of lagging wattless currents.

A number of the more common uses or applications for synchronous motors are as follows:

Operation of compressors and pumps; operation of fans and blowers, motor-generator; and frequency changers; steel mill drives; paper mill drives, crushers and grinders; line-shaft drives; and as synchronous condensers for power-factor correction only.

N. Super-Synchronous Motors

It has previously been mentioned that, in order to start with loads, synchronous motors are sometimes connected to the load by means of friction or magnetic clutches. A variation of this principle is used on a special synchronous motor which has been designed for starting heavy loads and is known as a super-synchronous motor.

This type of motor has the stator frame arranged so that during starting the entire frame and core can revolve on auxiliary bearings, on the motor shaft. This allows the rotor, which is attached to the load, to remain stationary until the stator is revolving around it at full synchronous speed.

The field is then excited with D C and a brake is gradually applied to the stator frame, causing it to reduce speed and finally bringing it to a complete stop. This gradually exerts upon the rotor poles the full running torque of the synchronous motor, and as soon as the brake is applied the rotor begins to turn and drive the load, coming up to full synchronous speed by the time the stator frame is completely stopped.

This method permits the use of the full running torque to start the load and allows the starting to be accomplished at much higher power factor.

Fig. 7 shows a 300 h.p. super-synchronous motor of the type just described. In this figure you will note that the stator frame is not attached to the bearing pedestals but is instead mounted on its own bearings on the motor shaft. You will also note the brake-band around the outside of the stator frame and the brake-link and wheel which are used to tighten the band and stop the rotation of the stator and thereby cause the rotor to start the load.

The slip-rings of this motor are mounted on the left end of the shaft inside of the protective screen.

O. Position Indicators

Position indicators are employed to transmit motion by electrical means between points which cannot be readily connected mechanically. In Fig. 8A rotation of the arm on the sender rheostat varies the current through the indictor which is used as a receiver. When properly calibrated, the meter needle motion will be proportional to the motion at the sender. Thus the amount of gasoline in the tank may be indicated on the instrument panel of a car.

Fig. 8-b shows a similar arrangement. Here too clockwise rotation of the sender increases the voltage applied to the receiver and the deflection is in proportion to it.

Fig. 8-c shows a bridge type circuit in which the meter needle is returned to zero by manipulating a rheostat at the receiving end. When balanced, both rheostat arms are in identical positions.

There are many other circuit arrangements but the basic operating principle is the same. The electrical method is particularly suited to most applications because the units may be any distance apart, and several receivers may be attached to one sender.

If two small motors are connected together and the rotors are energized from a single phase a-c source, the varying flux produced by the rotors, will induce voltages in the stator windings. If the rotors are in identical positions, the induced stator voltages will be in direct opposition and no current will flow in the leads connecting the stators together. Should one rotor be moved, this voltage balance is disturbed and current will flow through the other stator winding in such a direction as to cause its rotor to move to a corresponding position. This self synchronizing action which is characteristic of many types of a-c motors is utilized in the Selsyn position indicator.

With the indcators arranged as shown, movement of the sender rotor is duplicated by the receiver and, whether the sender is rotated through a small angle or several revolutions, the receiver follows the motion exactly. Where several indications are required, several receivers may be attached to the same sender. In this way motion of the sender may be reproduced at any number of remote points.

P. How the Polarized Field Frequency Relay Works

When starting the motor, an alternating current is induced in the d-c field winding of the synchronous motor. This current flows through the field discharge resistor (FD), the reactor (X), and the coil (B) of the polarized field frequency relay (FR). The magnetic core of the relay has a d-c coil on leg "C", an induced field current coil on leg "B", and a pivoted armature "A" with normally closed contact "S". Coil "C" connected to the source of d-c excitation establishes a constant magnetic flux in the relay core and polarizes the relay. Superimposed on this polarizing flux is the magnetic flux produced by the a-c induced field current flowing in the coil "B". When the motor is started relay armature "A" snaps to the closed position, thus, opening contact "S" as shown above. Up to the synchronous speed of the motor the flux through the armature of the relay is sufficient to keep it closed. The reactor "X" has a relatively high voltage drop, whereas the reactance of coil "B" is low, so that, except at very low frequencies of the induced field current, enough current will flow through coil "B" to hold the armature closed. As the motor accelerates the induced field current decreases in frequency, reducing the voltage drop across "X" and decreases the current of coil "B", permitting the relay armature to open at 95% to 96% of synchronous speed. Since the relay is polarized by coil "C" the armature opens only when the magnetic fluxes of coils "B" and "C" are of a certain relative strength. Closing contact "S" will energize relay (FS) and apply d-c excitation to the field when it is at the phase angle most favorable for synchronizing; and thus avoid a possible current surge in the a-c stator circuit. If the motor pulls out of step, the FR relay armature will close and remove excitation, allowing the motor to re-synchronize if normal conditions are existant.

Q. Summary Review.

The Synchronous Motor is so named because the rotor revolves at the same speed as the revolving magnetic field of the stator. Three windings are used in the synchronous motor:

1. The a-c stator or armature winding, which produces a revolving magnetic field when polyphase a-c is applied to it.
2. The d-c field or rotor winding, which produces a fixed polarity. This winding must be excited from an outside source of DC.
3. The damper or squirrel cage winding which consists of a few large copper bars imbedded in the d-c field pole faces and shorted together by end rings. This winding serves two purposes:

   a. It permits the motor to start as an induction motor at low torque but is inactive during normal synchronous operation.
   b. It tends to prevent hunting.

Hunting - is a periodical variation in the speed of the rotor with regard to the revolving magnetic field of the stator. It is caused by:

1. A sudden change in mechanical load.
2. A sudden change in a-c line voltage.
3. A sudden change in d-c field excitation.
4. Hunting on the same system of other rotating electrical equipment.

The field discharge switch and the field discharge resistor are arranged to protect the d-c field from high transformer voltages induced by the stator field during the starting period, and also from high self-induced voltages generated by collapsing d-c field flux when the field is disconnected from the source of excitation. The discharge resistor and switch form a closed circuit on the field when the switch is placed in the discharge position, and this greatly reduces the danger to the field insulation.

Advantages of the Synchronous Motor:

1. Constant speed.
2. Variable power factor. The power factor may be varied by controlling the excitation current of the d-c field. The PF will be unity or 100% at normal excitation. Lagging at under excitation, leading at over excitation.

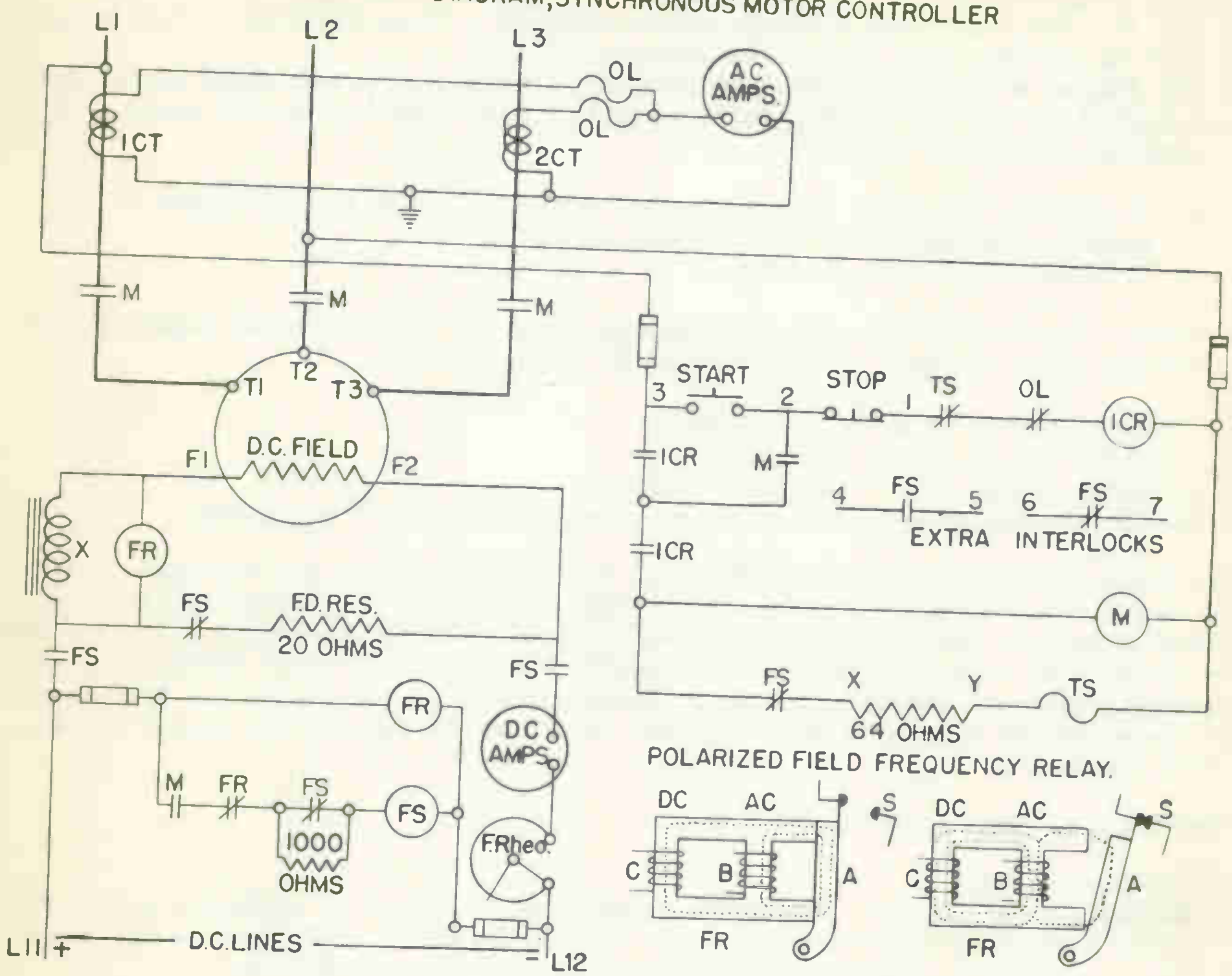
The motor will correct power factor because when the d-c field is over excited the a-c stator will draw a leading current which will neutralize a lagging current drawn by inductive apparatus connected to the same system. It will carry a mechanical load and correct PF of the system at the same time providing the full load current rating of the machine is not exceeded.

Disadvantages of Synchronous motor - Greater cost per HP, low starting torque, subject to hunting, requires outside source of excitation, more auxiliary apparatus for control and indication, more intelligent handling, and may require some form of clutch for connecting the load.

Applications: Driving compressors for air conditioning and refrigeration, also for compressed air. Driving textile mill looms, cement grinding and rubber processing machines, paper pulp grinders, also M.G. sets, frequency changers, or in general any load of 25 HP or more not requiring heavy starting torque and which may be operated at a constant speed.

Rotation may be reversed by changing any 2 of the 3 stator leads. The d-c field polarity does not determine the direction of rotation.

ELEMENTARY DIAGRAM, SYNCHRONOUS MOTOR CONTROLLER



R. Summary Questions

1. Name two advantages in using synchronous motors?

2. Briefly describe the construction of a synchronous motor?

3. For what purpose are "damper windings" used in synchronous motors?

4. Name three causes of "hunting" in a synchronous motor?

5. How is the field strength adjusted to cause leading power factor?

6. How does the starting torque of a synchronous motor compare to the starting torque of an induction motor?

7. For what purpose are Super-synchronous motors used?

SYNCHRONOUS GENERATORS

Objective

To learn about the common types of generators or alternators; their construction, operation, and care.

References

Lesson Content

A. General

Classification - The actual generation of voltages and currents have been fully discussed in previously studied chapters. Alternators are made in sizes ranging from the small belt driven or engine types of from 1 to 50 kva up to the mammoth turbine-driven units of several hundred thousand kva.

These alternators can be divided into the following classes:

1. Revolving armature or revolving field types
2. Vertical or horizontal types
3. Turbine or engine types

These classes of alternators will each be discussed in detail as the lesson progresses.

B. Revolving Field Alternators

Most a-c generators of over 50 kv-a capacity are of the revolving-field type, because this type of construction permits the generation of much higher voltages in the stationary armature windings, and also because it eliminates the necessity of taking high-voltage energy from a revolving member through sliding contacts. This greatly simplifies the construction of the machine and reduces insulation difficulties.

Revolving-field alternators are commonly made to generate voltages as high as 13,200, and some are in operation producing voltages of 22,000 directly from their stator windings. Alternators can now be constructed to produce voltage as high as 36,000. The generation of such high voltages makes possible very economical transmission of this energy, and also reduces the necessary winding ratio of transformers when the voltage is to be stepped up still higher for long distance transmission.

At the left in Fig. 1 is shown the stator, or stationary armature, of an alternator. The rotor, or revolving field, which has been removed from the stator is shown at the right. Note the stator coils or windings which are practically the same for alernators as for a-c induction motors.

Note the construction of the revolving field element and the manner in which the poles are mounted on the spider. The collector rings through which the low-voltage direct current is passed to the field coil, can be seen at the end of the rotor.

Some of the small a-c generators have revolving armatures which are wound very similarly to those for d-c generators, and have connections brought out to slip rings so the generator energy can be transferred from the revolving armature to the line by means of these slip rings and brushes.

However, many of the smaller alternators are also built with revolving fields. Fig. 2 shows a belt-driven alternator of 125 kv-a capacity, with a revolving field and stationary armature. This generator is driven at 900 RPM and produces three-phase, sixty-cycle energy at 2300 volts. Note the three leads which are brought out from the stator for permanent connections to the switchboard or line when the machine is installed. In this manner the load current flows directly from the stationary armature to the line without any slip rings or sliding connections in the circuit. Note the d-c exciter-generator which is attached directly to the end of the shaft of this alternator.

Fig. 3 shows the revolving field for a small alternator of the type shown in Fig. 2. Note carefully the construction of the field poles on this rotor, and also the slip rings and d-c exciter-armature on the end of the shaft.

The direct current energy required to excite the field of an a-c generator is very small in comparison with the AC output of the machine. This energy for excitation varies from three-fourths of one per cent, to two and a half percent, of the total capacity of the alternator.

It is easy to see, therefore, that the revolving field will require much smaller and lighter conductors than a revolving armature would; and also that the handling of this smaller amount of energy through brushes and slip rings at low voltage, is a much simpler proposition than to handle the total load current of the machine at the high voltages used on modern alternators.

It makes no difference in the nature or amount of voltage generated by the machine whether the field poles revolve past the stationary armature conductors or the armature conductors revolve past the stationary field poles. As long as the same field strength and speed of motion are maintained, the cutting of the lines of force across the conductors will in either case produce the same voltage and the same frequency.

C. Vertical Type and Horizontal Type Alternators

The terms vertical and horizontal as applied to a-c generators refer to the position of the shaft. Belt-driven alternators, or generators that are connected directly to steam engines, are usually of the horizontal-shaft type. The generator shown in Fig. 2 is of the horizontal type.

Large steam-turbine-driven generators are also more commonly made in the horizontal types, although some of these are in operation which have vertical shafts.

Water-wheel generators are more commonly made in the vertical type, as this construction allows the generator to be placed on an upper floor, with the water-wheel on a lower level and attached to the generator by means of a vertical shaft.

This reduces the danger of moisture coming in contact with the generator windings due to any possible leakage or dampness around the water-wheel.

Fig. 4, shows a large, vertical type, water-wheel-driven generator. This machine has a capacity of 18,750 kv-a and produces 60-cycle alternating current at 6600 volts. Mahines of this type usually operate at quite low speeds, this particular one

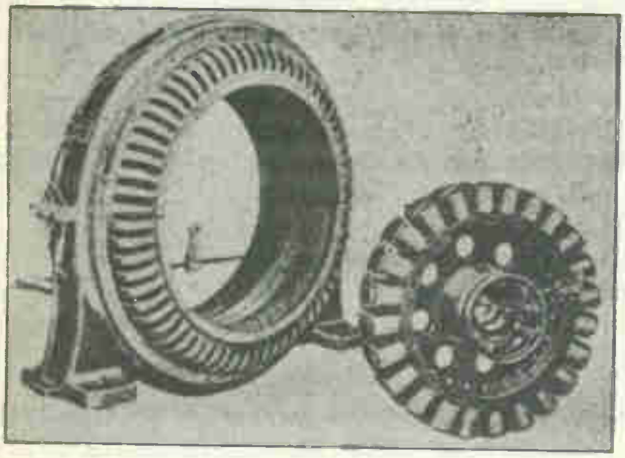


Fig. 1. Above are shown the complete stator of an A. C. generator on the left and the revolving field or rotor on the right. The field coils on the rotor are excited with direct current and revolved within the stator to generate alternating current in its windings.

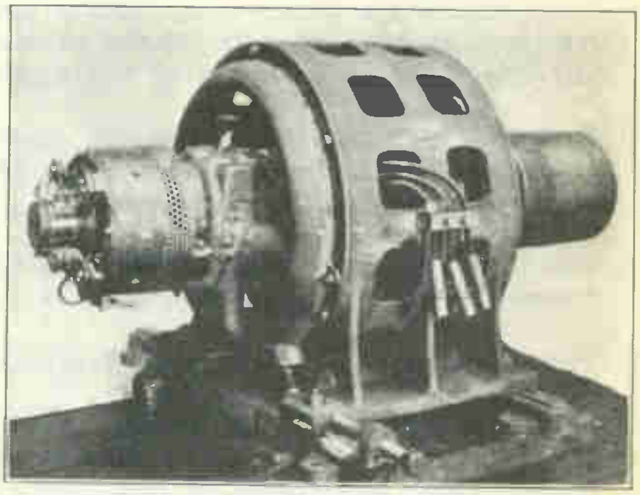


Fig. 2. This photo shows a 125 kv-a. alternator of the horizontal belt-driven type. Note the D. C. exciter-generator which is direct connected to the left end of the shaft.

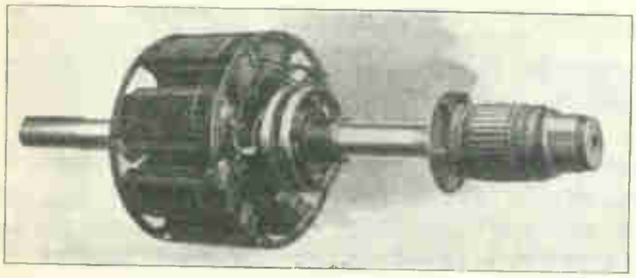


Fig. 3. This view shows the construction of the rotor or revolving field of an alternator similar to the one shown in Fig. 2. Examine its construction carefully and note the position of the collector rings and exciter-armature on the shaft.

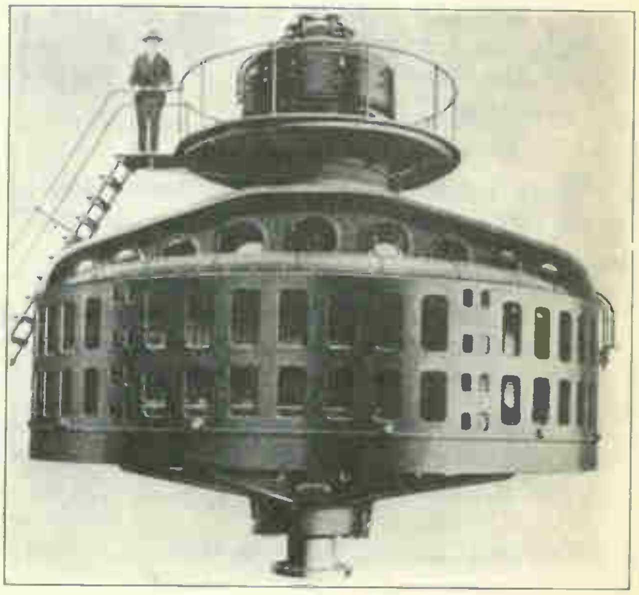


Fig. 4. Large vertical type alternator for water-wheel drive. The stator core and windings of this machine lay in a horizontal position just inside the lower frame work, and the field poles revolve on the vertical shaft within the stator.

having a normal speed of $112\frac{1}{2}$ RPM.

Note the d-c exciter-generator mounted on top of the shaft above the thrust bearing and main support members of the generator frame. The water-wheel attaches to this generator at the coupling which is shown on the lower end of the shaft.

Horizontal-type generators usually present a much simpler bearing problem, as the horizontal shaft lies in simple sleeve-bearings which support the weight of the revolving field at each end of the shaft.

Vertical-type generators require special thrust-bearings to support the weight of the shaft and rotor, and also a set of guide bearings to keep the rotor in proper alignment within the stator core.

Vertical-type machines require less floor space, which is one advantage in their favor where the power plant must be as small as possible.

D. Turbine Type and Engine Type Alternators

The terms "turbine" and "engine" type as applied to alternators refer to the type of prime mover by which the alternator is driven. As there is considerable difference between the speeds of ordinary reciprocating steam engines and those of steam turbines, the generators designed for engine drive are of considerably different shape and construction than those designed for high-speed turbine drive.

Engine-driven alternators are usually of quite large diameter and narrow in width from one side to the other of the stator core. The rotors for these machines usually have a rather large number of field poles in order to obtain the proper frequency at their low operating speeds.

Steam-turbine-driven generators or turbo-alternators as they are commonly called, are usually made with much smaller diameters and greater in length than the engine-type generators. The very high speeds at which steam turbines operate makes necessary the small diameter of the revolving field of the generator, in order to reduce centrifugal stresses.

These higher operating speeds also make possible the generation of ordinary 60 cycle energy with a very small number of field poles.

Turbine-driven generators are commonly made with two or four poles on the revolving field. Fig. 6 shows a large steam turbine-driven alternator of 50,000 kw, or 62,500 kv-a capacity. The generator is on the left in this view and the steam turbine on the right. The two are directly connected together on the same shaft.

This alternator is completely enclosed in an airtight casing to keep out all dirt and moisture from its windings, and to allow cooling by forced air circulation within this casing.

E. Construction of Alternators

Regardless of the type or construction of the alternator, the two principal parts to be considered are the armature and the field. The main winding, whether it is placed on the rotor or in the stator, is usually referred to as the armature; and as previously mentioned, these armature windings for ordinary a-c generators are practically the same as those for the stators of induction motors. In fact, the same winding can be used for either a motor or generator, if the squirrel cage is exchanged for a revolving field with the proper number of poles or vice versa.

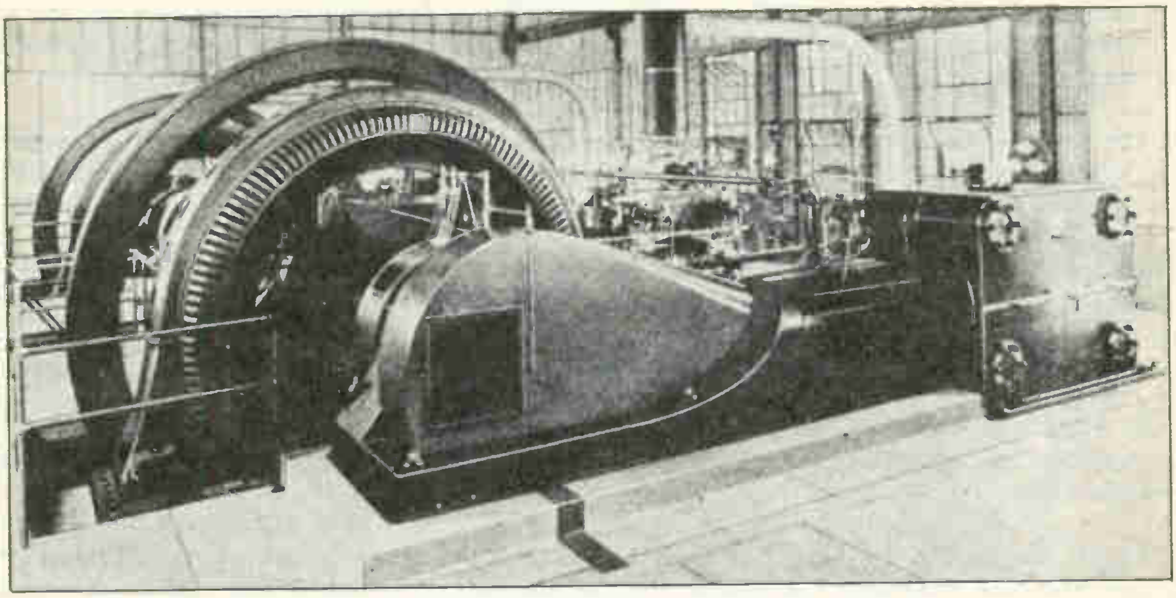


Fig. 5. This photo shows a view in a power plant equipped with horizontal type steam-engine-driven alternators. These alternators are made with large diameters because of the relatively low speed at which they are driven.

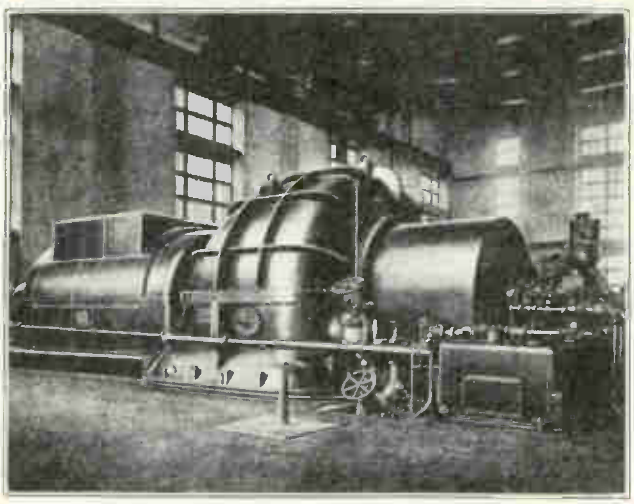


Fig. 6. Large steam-turbine-driven alternator. The turbine with its control mechanism is on the right. This alternator is enclosed in the air-tight casing at the left. This unit is typical of hundreds of great steam-driven generators in use in modern power plants throughout this country.

On large machines there are enormous magnetic stresses set up between the conductors of the winding when the generators are heavily loaded or during times of sudden surges due to overloads or short-circuits. For this reason, it is necessary to securely anchor or brace the coils, not only by slot wedges but also by using at the coil ends, special supports which are rigidly connected to the stator frame.

The coils are securely tied or wrapped to these braces or supports and in some cases are mechanically clamped down on the supports to prevent distortion or warping of the coils due to magnetic stresses set up by the flux around them.

The view on the left in Fig. 7 shows the frame of a turbine-driven alternator with one of the first stator punchings or core laminations in place. This view shows the manner in which these core laminations are fitted in the stator frame and held in place by the dovetail notches in the frame.

When the complete core is assembled, the laminations are also held more firmly together by the use of clamping rings and bolts which apply pressure at the ends of the stator core.

The view at the right in Fig. 7 shows the same stator with the core completely assembled and the windings in place. Note the heavy connections which are made between the phase and coils of the winding and also the manner in which these connections are rigidly secured to the end of the stator core.

Fig. 8 shows an excellent view of the end of the winding in a large turbine-driven generator, and shows clearly the method of bracing and tying the coils in place. Note the comparatively small diameter and great length of the stator openings on the machine shown in Figs. 7 and 8.

The armature coils on large alternators are usually made of heavy copper bars and consist of only a few turns in each coil. These coils are heavily insulated according to the voltage of the machine, and are securely wedged into the slots.

Spaces or air ducts are left at intervals throughout the stator when the laminations are assembled, to allow free circulation of the cooling air throughout the windings.

F. Field Construction

The field of a-c generator is constructed very much the same as the field of a d-c generator, except that the field of an alternator is usually the revolving element. Low-speed alternators of the large diameter engine-driven types usually have the field poles mounted on a spider or wheel-like construction of the rotor, as shown in Fig. 1.

Fig. 3 also shows the mounting of the field poles on a smaller rotor of the solid type which is used for a small diameter, medium-speed alternator.

The poles consist of a group of laminations tightly clamped together and equipped with a pole-shoe, or face, of soft iron. They are attached to the rotor core or spider either by means of dovetail ends and slots, or by means of bolts.

Fig. 9 shows several views of field poles of the dovetail type. These views also show the pole shoes and the rivets which hold the laminations together. The coils for field poles of this type may be wound with either round or square wire, or thin, flat, copper ribbon of the type shown in Fig. 11.

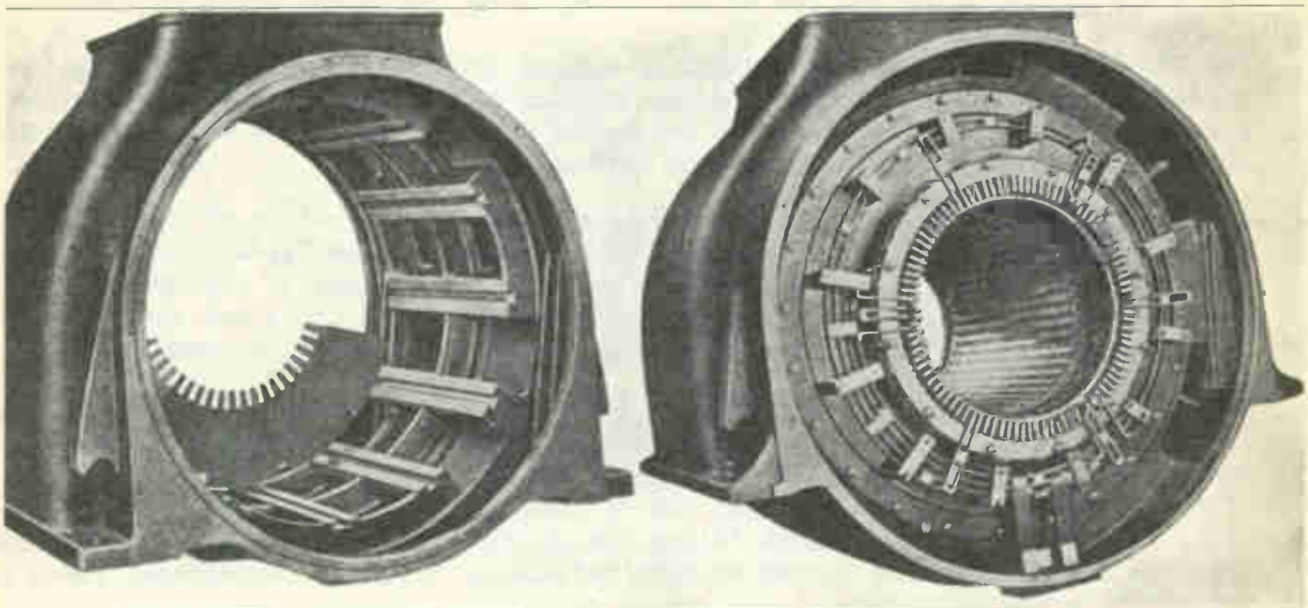


Fig. 7 The above two viewss show very clearly the method of construction of the stator core and windings of high speed steam-turbine-driven alternators.

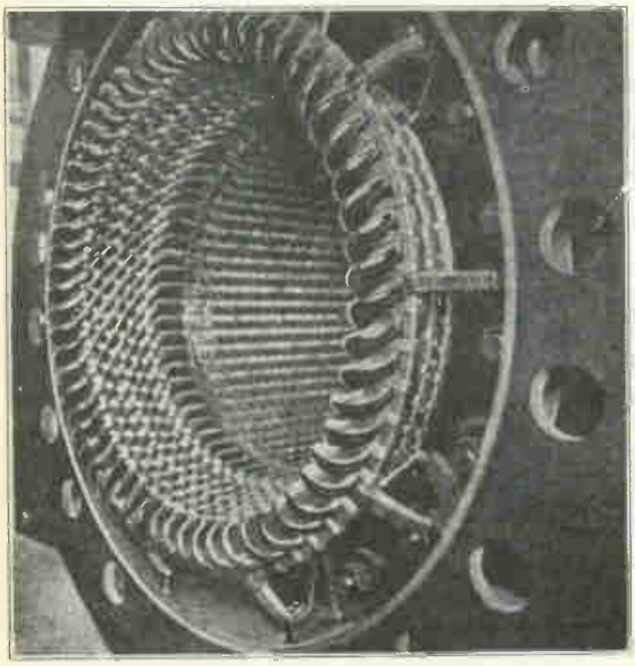


Fig. 8. This photo shows the end of a stator winding for a high speed turbo-alternator. Note the rigid bracing of the coil ends.

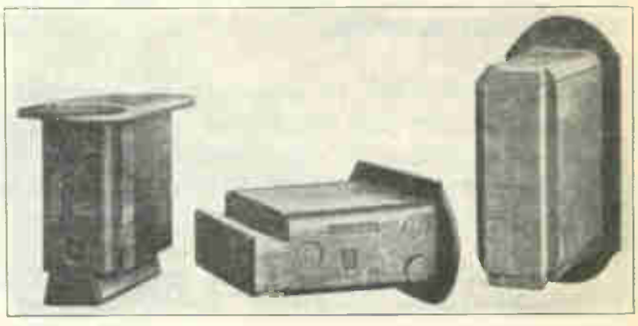


Fig. 9. Several views of laminated field poles such as commonly used in revolving field alternators.

Field poles and coils of this type are sometimes called "spool wound", because of the shape of the poles and the manner in which the coils are wound on them.

The field coils are connected either in series or in series-parallel groups, according to the size of the machine and the exciter voltage which is applied. They are always connected to give alternate north and south poles around the entire field. Alternator fields always have an even number of poles.

On high-speed turbine-driven alternators which have long rotors of small diameter, it would be very difficult to construct field poles of the "spool wound" type, and also extremely difficult to hold the coils in place because of the great centrifugal force at these high speeds. For such machines the field coils are usually wound in the slots cut in the surface of a long, solid field rotor or core.

Fig. 12 shows a two-pole rotor of this type, in which the field coils can be plainly seen at the left end of the slots. These coils are wound with strap or bar copper. When the rotor is completed, a metal casing or sleeve is placed over both ends of the coils as shown at the right end of this rotor. This sleeve protects the coils from damage or mechanical injury and also holds them securely in place and prevents them from being thrown or bent outward by the high centrifugal force exerted upon them during operation.

Fig. 13 shows a closer view of the end of a rotor of this type, in which the slip rings and ventilating blades can be clearly seen. This type of rotor construction provides a very rugged field element and very secure mounting of the coils and is therefore, ideally suited to the very high speeds at which steam-turbine alternators are operated.

G. Cooling of Generators

All electrical equipment produces a certain amount of heat in proportion to the losses which take place within the windings. Large a-c generators produce considerable heat, even though their efficiencies often approach 98%. In the enormous sizes in which generators are built today the cooling of these machines becomes a serious problem.

The heat must be removed or carried away from the windings as rapidly as it is created or the windings would soon overheat to a point where the insulation would be damaged. As the resistance of copper conductors increases with any increase in temperature, the efficiency of the machine would also be reduced by allowing it to operate at temperatures higher than normal.

Natural air circulation is not sufficient for effective cooling of the windings of these large machines, as it is with small d-c and a-c generators. Therefore, it is necessary to use one of the several forms of arificial cooling or forced ventilation.

One very common method of cooling is to completely enclose the generator in a housing, such as shown on the machine in Fig. 6, and force a blast of air under low pressure through this housing and the machine windings. The air used for this purpose is first washed with a spray of water to cool it and clean it of all dust and dirt, and then the air is dried before being passed through the generator windings.

This clean air is then kept dry and is recirculated through the generator over and over again, being cooled each time it leaves the machine, by being passed over a set of cold water pipes.

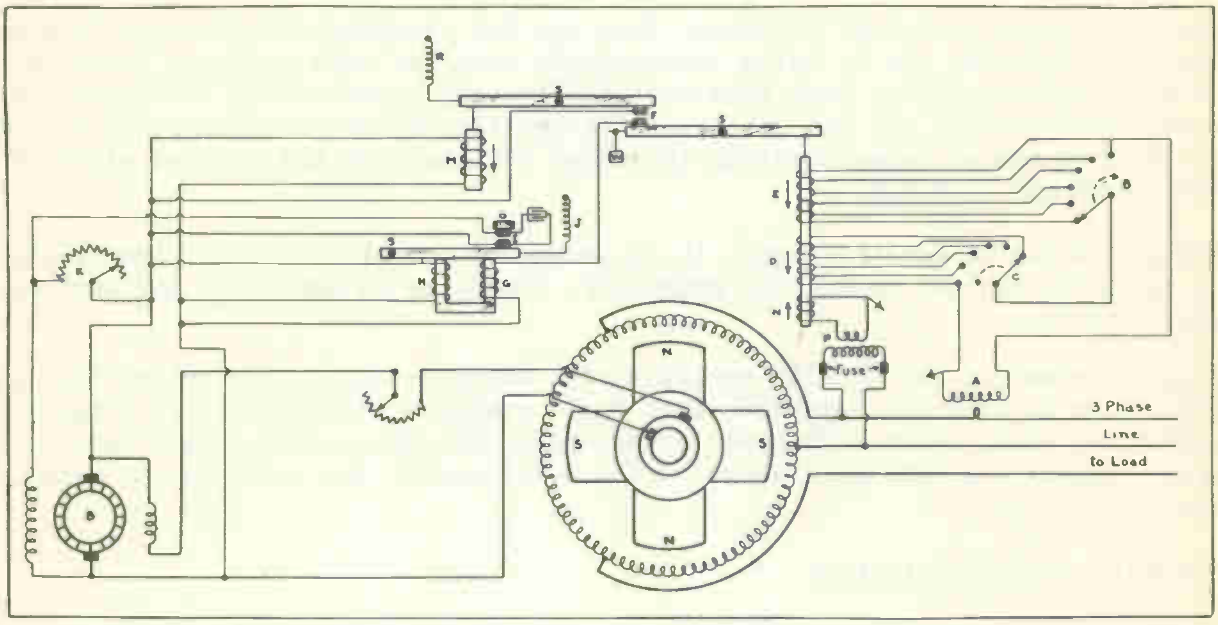


Fig. 10. The above diagram shows the wiring and illustrates the principles of a Tirrill automatic voltage regulator, properly connected to the exciter and line leads of a three-phase alternator.

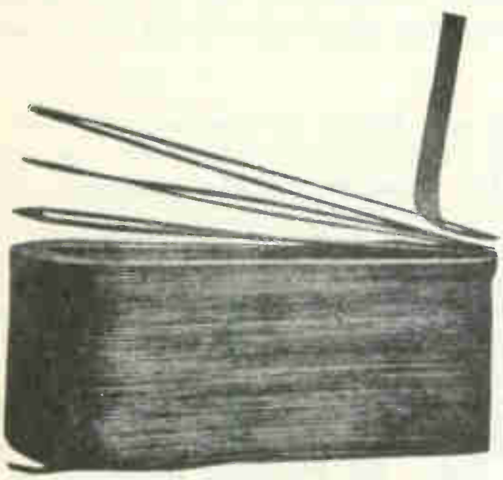


Fig. 11. Field coil which is wound with thin copper strip, making a coil which is very compact and easily wound.

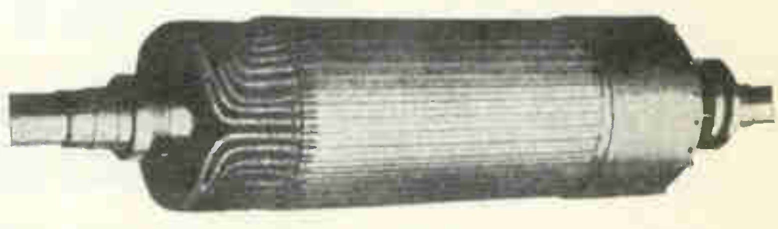


Fig. 12. This photo gives an excellent view of a high speed field rotor such as commonly used in turbine-driven alternators. Note how the field coils are placed in slots in the solid rotor so that when they are excited with D. C. they will create two field poles on opposite sides of the rotor. (Photo Courtesy Allis Chalmers Mfg. Co.)

It is of the greatest importance that this ventilating air be kept circulating constantly through large alternators during every moment of their operation, and also that the air be kept clean and dry.

Some other gases are more efficient than air for carrying off the heat from machine windings. Hydrogen gas is being successfully used for this purpose. Because of its efficiency in absorbing heat from the windings and transferring it to the cooling pipes through which the gas is circulated outside of the generator, the use of hydrogen in this manner makes possible increased efficiencies and reduced sizes of alternating current machines.

Hydrogen being an explosive gas, it is necessary to eliminate all possibility of its becoming ignited around the generator, otherwise an explosion and serious damage would result.

Large alternators are usually equipped with thermometers or electrical temperature indicators to show the temperature of their armature windings at all times during operation. Many large high-speed alternators have water-cooled bearings, with water circulating through passage in the metal around the bearings, to carry away the heat.

H. Alternator Field Excitation

The field of an alternating current generator is always excited or energized with direct current and in this manner constant polarity is maintained at each pole. As alternators do not produce any direct current themselves, they cannot be self-exciting, as many d-c generators are.

The direct current for excitation of alternator fields is produced by a separate d-c generator, known as the exciter generator. The exciter machine may be belt-driven from a pulley placed on the shaft of the main alternator, or it may be directly connected and driven by the end of the alternator shaft as on the machines in Figs. 2 and 4.

In some cases in large power plants, the exciters are driven by separate primer movers. Sometimes one large exciter-generator is used to furnish direct-current field energy for several alternators, each of which obtains its field current from the exciter bus.

In other cases, there may be a number of exciter generators which are all operated in parallel to supply the exciter bus with direct current: and any or all of the alternators can obtain their field current from this bus.

Exciter-generators are usually of the compound type and of a voltage ranging from 110 to 250 volts. It is not necessary to use high voltage for field excitation, as this current is only used to produce magnetic flux, the strength of which is determined by the number of ampere-turns on the field poles.

The direct current from the exciter generator or busses is conducted to the revolving field poles of the alternator through brushes and slip rings, as previously explained. These slip rings can be plainly seen on the revolving field units shown in Figs. 3 and 12.

F. Connections for Exciter and Alternator Field Circuit.

Fig. 14 shows the connection diagram and circuit of an exciter-generator connected to a three-phase alternator. This alternator has four poles on its revolving field and in this case all of the poles are connected in series.

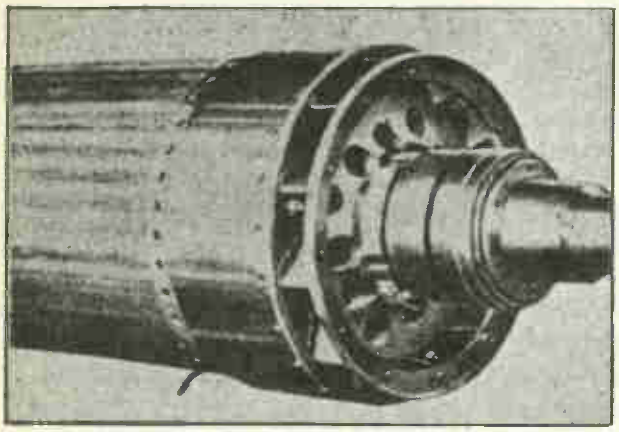


Fig. 13. End-view of high speed field rotor showing shield ring over the coil ends and also showing ventilating blades and slip rings.

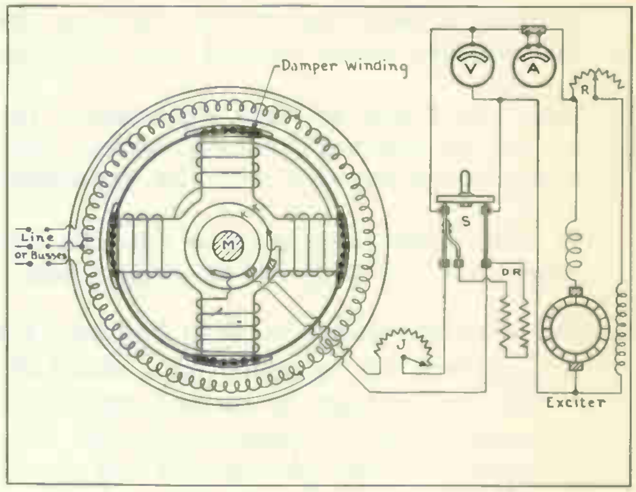


Fig. 14. This diagram shows the connections of the stator and rotor of a three-phase alternator with the exciter-generator, rheostats, meters, and field discharge switch.

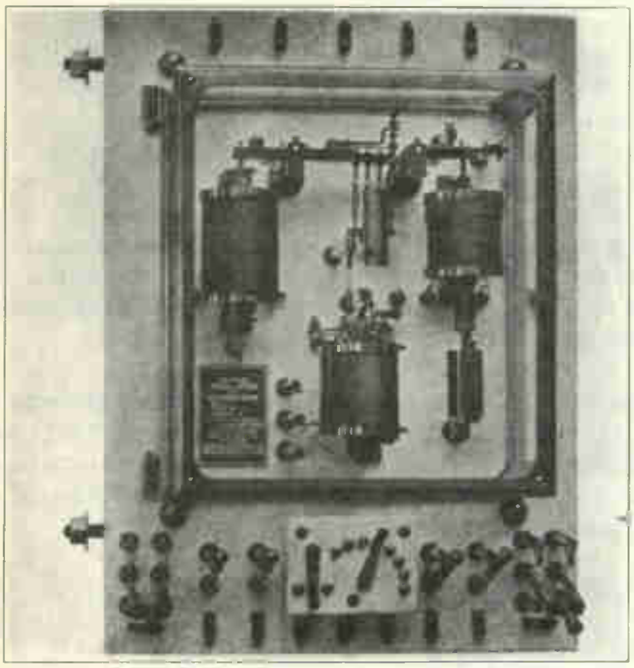


Fig. 15. This photo shows an automatic voltage regulator of a type similar to the one for which the wiring was shown in Fig. 10, and shows the arrangement of the solenoids and relays on the panel.

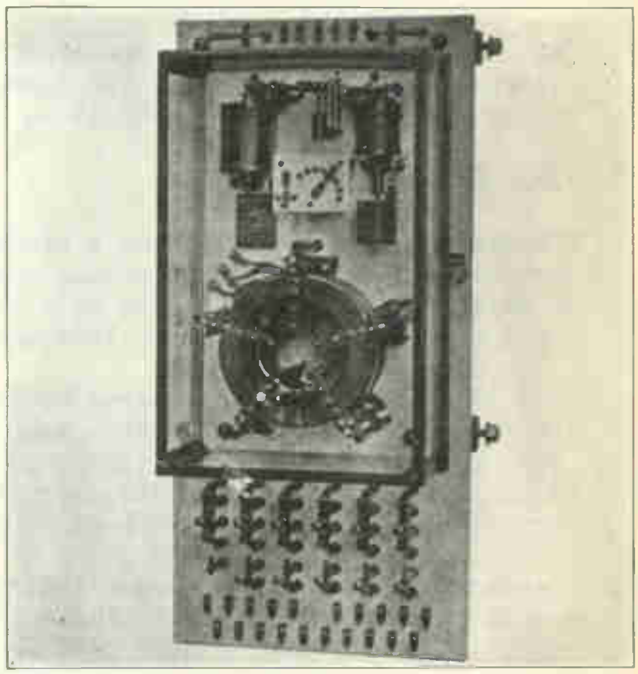


Fig. 16. Automatic voltage regulator for controlling the voltage of several alternators in parallel.

The stator winding is of the ordinary type which has been previously described in the lesson on a-c windings, and in this diagram it is simply shown as a continuous winding around the stator, having three line leads which are connected to points 120 degrees apart around the winding.

When the field of this alternator is excited with direct current and the poles revolved so their flux cuts across the conductors of the stator winding, three-phase alternating current will be generated and supplied to the line or busses.

If this four-pole machine has its field revolving at 1800 RPM, the frequency of the generated a-c will be 60 cycles per second.

The exciter shown in this Figure is a compound-wound d-c generator and has its voltage controlled by means of a shunt-field rheostat, R. The exciter voltage can be controlled either by manual operation of the field rheostat or by an automatic voltage regulator in connection with the field rheostat. This regulator will be explained in later paragraphs and in this figure we shall consider the rheostat to be manually operated.

A voltmeter and ammeter are shown connected to the exciter circuit between the d-c generator and the field discharge switch, S, of the alternator. They are connected at this point because it is desirable to know the exciter voltage before the field switch is closed, and also because of the high voltages which may be induced in the alternator field, if the field discharge switch should accidently be opened while the alternator is operating in parallel with others.

The ammeter indicates the amount of field current which is being supplied to the alternator at any time, and furnishes an indication of the field strength and normal or unusual operating conditions in the alternator.

J. Field Discharge Switch

The field discharge switch is a special type of switch which has a third or auxiliary blade attached to one of the main blades and is arranged to make contact with an extra clip just before the main blades of the switch are opened, and also during the time that this switch is left with the main blades open.

This places the field discharge resistance, D.R., across the collector rings and field winding of the alternator when its circuit to the exciter is open. The purpose of this discharge resistance is to prevent the induction of very high voltages in the field winding when its circuit is interrupted and the flux allowed to collapse across the large number of turns of the field winding.

Placing this resistance across the field winding allows the induced voltage to maintain a current through this closed circuit for a short period after the switch is open. This uses up the self-induced voltage and magnetic energy of the field, and allows the current to die down, somewhat gradually.

If the flux of the alternator field were allowed to collapse suddenly by completely opening the circuit, the induced voltage might be sufficiently high to puncture the insulation of the field windings and cause short-circuits or grounds between the winding and the core.

K. Exciter and Alternator Rheostats

Between the field discharge switch and the slip rings is an alternator field rheostat, "J". This rheostat is used to obtain very fine and accurate adjustment of the alternator voltage, and its resistance is usually so proportioned that its full range of voltage operation is just equal to the change in voltage obtained by moving the arm of the exciter rheostat one point.

It is easy to see that the voltage of the main alternator can also be conveniently controlled by adjusting the voltage of the exciter generator. As the exciter voltage is varied, more or less current will be forced through the field winding. By the proper use of both the exciter field rheostat, R, and the alternator field rheostat J, a wide range of voltage adjustment in very small steps can be obtained on the alternator.

For example, suppose that the exciter shunt field rheostat has 100 points, which will make it possible to obtain 10 voltages changes, on both the exciter output and the alternating output. If the alternator field rheostat has 20 points we can obtain 20 steps or variatioms in the alternator voltage between each two adjacent points of the ten-point exciter rheostat.

With this combination it is, therefore, possible to obtain 200 voltage variations, which will permit very accurate voltage adjustment of the alternator.

L. Factors Governing Voltage and Frequency of Alternators

From the alternator field rheostat we follow the exciter circuit to the brushes which rest on the slip rings, K-K. The slip rings are mounted on the rotor shaft but are well insulated from the shaft, and from each other. Leads are taken from these rings to the field coils. The slip rings and brushes form the sliding connection between the stationary part of the exciting circuit and the revolving alternator field.

Regardless of whether the alternator field is constructed with spool type coils or projecting poles as shown in Fig. 14, or with coils imbedded in the slots of the solid rotor as used on high-speed turbine generators, as long as direct current is passed through these coils a powerful magnetic field will be set up at each pole of the electro-magnets formed by the coils.

When the alternator field is thus excited or energized and is then revolved within the armature or stator core, it is evident that the lines of force from the field poles will cut the stationary armature conductors. In this manner, a voltage is induced in the armature conductors and, as we have already learned, this voltage will be proportional to the number of lines of force in the field, and to the speed in which the field poles are rotated, as well as the number of conductors in series in the armature winding.

As the frequency of the alternator depends upon its speed and the number of field poles, we cannot vary the speed of the alternator to vary its voltage, as we can with direct current generators.

The frequency must be kept constant in order to maintain constant speed of the motors attached to the system, and if the speed of the alternator were to be varied it would, of course, change the frequency. For this reason, the voltage of an alternator must be adjusted by means of the alternator field rheostat or the exciter field rheostat.

The voltmeter in Fig. 14 is across the armature leads of the exciter generator and will show any variations in the voltage produced by the exciter when its rheostat is adjusted.

When once the setting of the alternator rheostat, J, has been established, the voltmeter will give somewhat of an indication of the variations brought about in the alternator field strength when varying the exciter voltage.

The ammeter provides a more accurate indication, because its readings will show the amount of current flowing through the alternator field with any adjustment or change in either the exciter or alternator rheostats.

M. Control and Adjustment of Alternator Voltage

It is often necessary to change the voltage produced by the armature of an a-c generator while it is in operation, in order to compensate for voltage drop in the lines with increasing load on the system. In other words, when the load is increased, the added current flowing through the line will cause a greater voltage drop; and, in order to maintain constant voltage at the load, the alternator voltage should be increased.

We have already mentioned that the alternator voltage can be controlled either by manual operation of the rheostats by the plant operator, or by an automatic regulating device.

Manual or hand regulation is generally used only in small power plants which are not operating as a part of a large system.

The accuracy and uniformity of hand regulation depend upon the faithfulness and skill of the operator. This method is not usually satisfactory in large plants or on systems where they are frequent variations of considerable amounts in the load, because it requires almost constant attention on the part of the operators and even then doesn't prevent some voltage variation at the load.

It is very important to have constant voltage on most electrical machines and devices, in order to maintain their rated torque and speed. This is particularly true where any lighting equipment is connected to the system, because if the voltage is allowed to vary to any extent, it causes noticeable fluctuations in the billiancy of incandescent lamps.

N. Automatic Voltage Regulations

To obtain more accurate and immediate voltage adjustment for all variations in load, automatic voltage-regulators are generally used in connection with the exciter field rheostat. One of the most common types of these devices is known as the Tirrill voltage regulator. This device automatically regulates the alternator voltage within very close limits by means of a set of relays which cut resistance in or out of the field rheostat of the exciter-generator.

The relays are operated by variations in the voltage and current load on the lines leading from the main alternator.

Fig. 10 shows the connection diagram of a Tirrill automatic voltage-regulator. If you will trace out each part of this diagram very carefully, you will be able to easily understand the operating principle of this device.

Whenever the load on the alternator is increased, this will increase the amount of current flowing in each wire of the three-phase line, and the current transformer, A, will have an increased current flow in its secondary winding.

The secondary of this transformer is connected through a set of multiple point switches, B and C, to the solenoid coils; D and E. When these two coils have their current increased, they tend to pull the plunger downward and operate the lever arm to close the contacts at F.

When the contact F is closed it completes a circuit through coil G of the differential relay which is energized by direct current from the exciter-generator. Coil H of this relay is connected directly across the exciter-armature and is normally energized at all times.

Coil G is so wound that when it becomes energized it neutralizes the magnetism set up in the core by coil H, and this allows the armature to release and be drawn upward by the spring, J, thus closing the contacts at I.

These contacts are connected across the exciter field rheostat, K, and can be arranged to short-circuit all or part of this resistance. When the resistance of this rheostat is cut out of the shunt field of the exciter it allows the exciter voltage to increase, thereby, increasing the field strength and the voltage of the main a-c generator.

If the a-c generator voltage rises above normal, it will increase the voltage induced in the secondary coil of the potential transformer, P, thereby strengthening the solenoid coil, M, which will raise the plunger and open the contacts, F.

When the contact opens at F this de-energizes coil G of the differential relay, allowing the magnetism of coil H to draw the armature down and open contacts at I.

This removes the short-circuit from the exciter throestat and places the resistance back in series with the shunt field. The contacts at F can also be opened by the coil M if the exciter voltage rises too high.

When using a regulator of this type, the exciter field rheostat K should be set at a point so, that if it were used alone, it would maintain a voltage slightly lower than that required by the system.

The automatic regulator will then short out the resistance of the rheostat often enough to maintain the voltage at its proper value. The arm which operates the lower contact at F continually vibrates or oscillates, and opens and closes the contacts at frequent intervals during the operation of this device.

These contact arms are accurately balanced and adjusted by means of adjusting screws on the counter-weight, W, and the tension of the spring, R.

A condenser, O, is connected across the contacts I to reduce arcing and prevent burning and pitting of these contacts when they open and close the short-circuit on field rheostat K.

The relay armatures which operate the various contacts are pivoted at the points marked S. The switches, B and C, are used to vary the strength of the solenoid coils, E and B, and thereby adjust the regulator to operate at the proper amount of increased load current.

O. Summary Questions

1. Into what three classes may alternators be divided?

2. How much d-c energy is required to excite the field of an alternator, in terms of percent of alternator capacity?

3. Which of the two elements, the field or the armature of an alternator, is usually the revolving element? Why?

4. Describe one method by which large alternators are cooled.

5. How is the field excitation current produced?

6. Why are field discharge switches used on large alternators?

OPERATION AND PARALLELING OF ALTERNATORS

Objective

To learn the operation and paralleling procedures of alternators. To study the processes of phasing, synchronizing, load transfering, etc., of alternators.

References

Lesson Content

A. General

It is only in very few cases, such as in small isolated power plants, that a single a-c generator is operated alone. Usually several a-c generators are operated in parallel in the same plant, and in a great many cases a number of power plants generating a-c are all tied together in parallel.

In order to operate alternators in parallel we must have their voltages equal and in addition to this, the machines must be properly phased out and synchronized.

These three conditions are the principal ones which must be observed before connecting any alternator in parallel with another.

You have already learned how to adjust the voltage of a-c generators. Voltage adjustment, of course, can only be used to vary the voltage within a limited range above and below that of the normal voltage of the machine. Therefore, alternators must all be designed for the same voltage in order to operate successfully in parallel. Then the final adjustments can be made with the rheostats to exactly equalize the voltage.

B. Phasing Out Alternators

"Phasing Out" consists of identifying the phases of polyphase generators, in order to get the corresponding phase of two or more machines connected together. For example, the three-phase alternator, which is by far the most common, usually has the phases marked or designated A, B, and C. When connecting an alternator to one or more others, or to the buses in a power plant in which other generators are operating, each phase must connect to the corresponding phase of the busses or other alternator: A to A, B to B, and C to C.

Phasing out is usually necessary only when a machine is first installed or after some changes have been made in the connections of the windings of the machine. Once the generator has been properly phased out and the connections permanently made to the busses on the switchboard, it is not necessary to test the phases again unless changes are made in the generator or in the plant.

If a generator is disconnected even temporarily, the phases should be plainly and accurately marked, so that they can be connected back in the same manner when the machine is again attached to the busses or leads to the other alternator.

If an armature of an alternator has been rewound or if the connections have been changed in any way, the machine should always be phased out before reconnecting it to the busses or line.

Synchronizing is an operation which must be performed every time an AC generator is paralleled with other running machines. This will be explained in later paragraphs.

There are several methods that can be used for phasing out AC generators. Two of the most common are known as the lamp-bank method and the motor method.

Equally good results can be obtained with either method, and the choice of one, or the other will usually depend upon the convenience or the adaptability of the available equipment.

C. Lamp-bank Method of Phasing Out.

Fig. 1 shows the connections and illustrates the principle of the lamp-bank method of phasing out alternators. In this diagram two alternators are shown properly connected and furnishing power to the busses and outgoing line. A third similar generator is shown suitably located and ready to be phased out and connected to the live busses. The lamps to be used in the phasing-out operation are shown connected around the oil switch.

A sufficient number of lamps must be connected in series in each phase to withstand double the voltage of the alternator. It can readily be seen, therefore, that if the voltage of the machine is higher than 440 volts, it would require a considerable number of lamps in order to use this method, that is if the lamps only were used.

So, with higher voltage machines step-down transformers are often used to reduce the voltage to the lamps. Small power transformers or instrument transformers can be used.

In phasing out a new generator by this method it is necessary to bring it up to its rated speed and voltage. The lamps connected as shown in Fig. 1 will then alternately light up and go dark, due to the generator voltages being out of phase and in phase at different periods.

If all three sets of lamps become bright and dark together or at the same time, it indicates that the proper phases of the new generator are connected to corresponding phases on the opposite side of the oil switch. If the lights do not burn bright and dim together it is then necessary to intercharge or reverse any two leads of the generator which is being phased out.

While this interchange can be made anywhere between the generator and the oil switch or between the oil switch and the busses, it is usually best to reverse the leads right at the generator terminals. We should never reverse the leads of any other machine to make the phases match with the new generator, as this would reverse the rotation of all of the three-phase motors operating on the system.

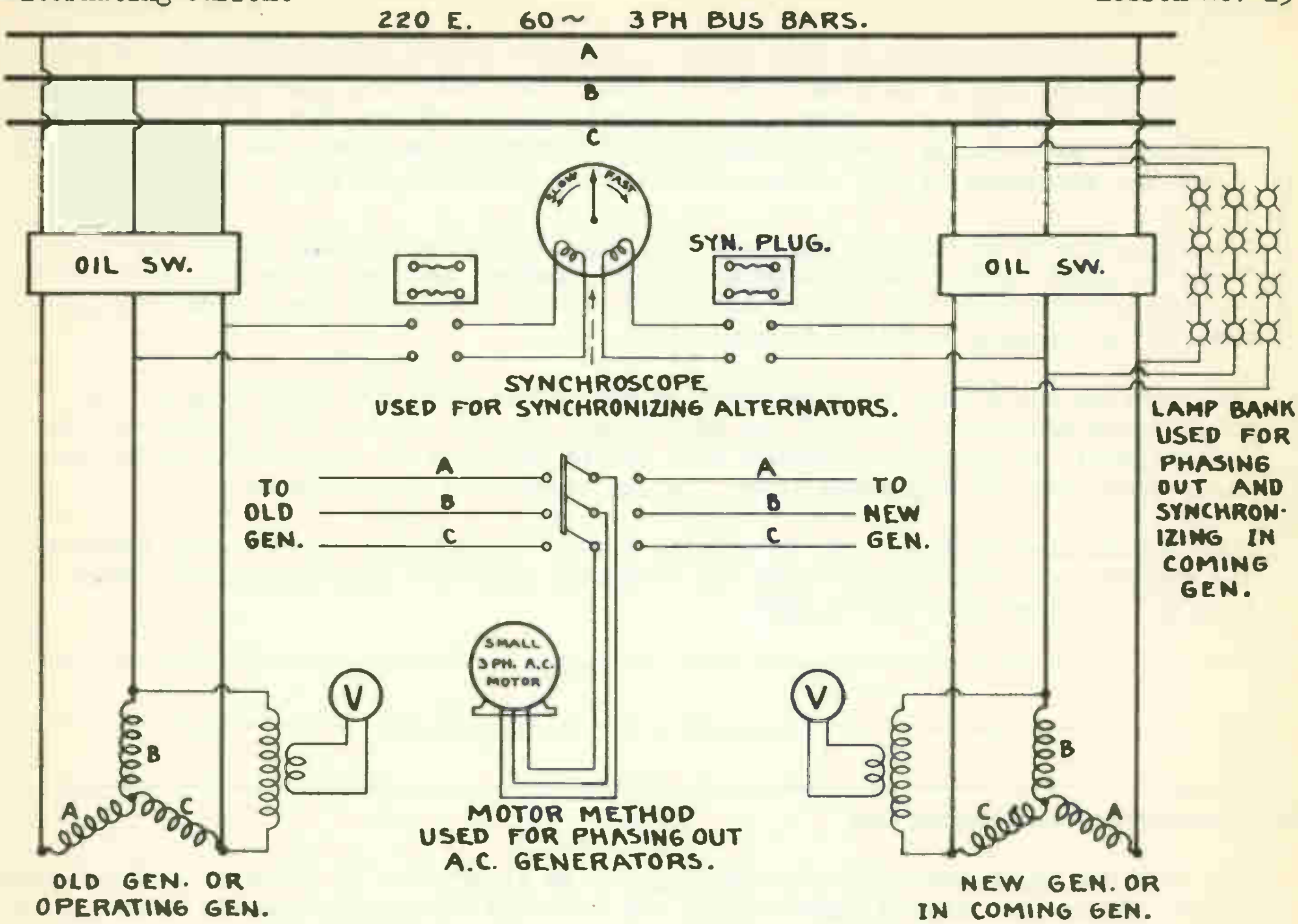


Fig. 1

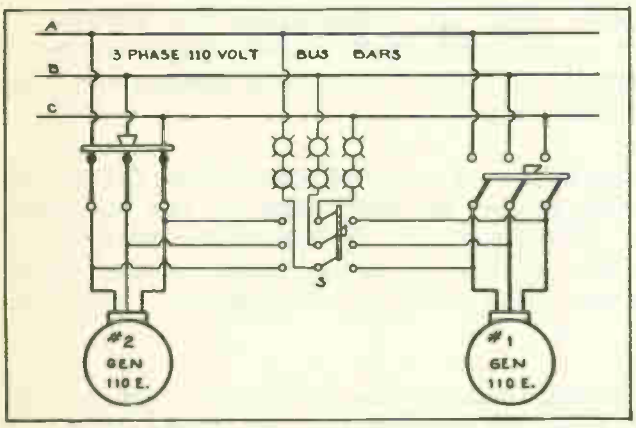


Fig. 2. Connection diagram for synchronizing either of two alternators with the bus bars by means of a lamp bank and double-throw switch.

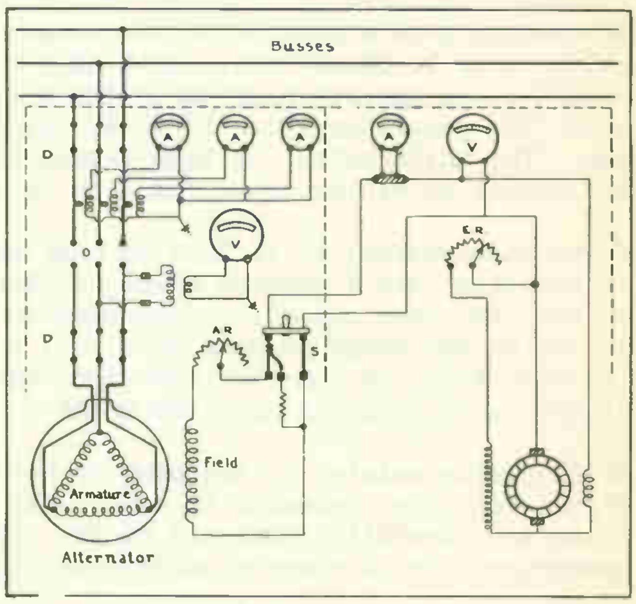


Fig. 3. This diagram shows the wiring and arrangement of a three-phase alternator, and the meters and equipment commonly used on the switchboard panels.

Extreme caution should be used never to connect even a small generator in parallel with another one or to live busses without first carefully phasing it out; because if one a-c generator is connected in parallel with others when out of phase, it results in practically a short-circuit on the running machines, the same as though one d-c generator of the wrong polarity were connected in parallel with others.

Care should also be used to see that the lamps are of sufficient number and resistance to stand double the voltage of the alternator, because at certain periods during the alternations they may be subjected to the voltage of the new machine plus that of the running machines in series.

When phasing out higher voltage machines and using lamps and transformers, the primary and secondary leads of the transformer should be carefully marked and tested if necessary, to determine whether they are of additive or subtractive polarity. These terms will be explained later, in the section on transformers.

Care should also be taken not to reverse either the primary or secondary leads of the transformer, but to have them all connected with the same respective leads both to the alternator and busses.

D. Motor Method of Phasing Out

Fig. 1 shows the connections for phasing out an alternator by means of a three-phase motor. To us this method conveniently and to avoid making mistakes in connections, it is usually best to connect the leads of the three-phase motor in uniform order to the blades of a double-throw, three-pole, knife switch.

The outer contacts or clips of the switch on one side are connected to the busses or running generators, while the clips on the other side are connected to the machine which is to be phased out. With this connection the motor can be operated either from the new generator or the running machines. When the connections are properly made, the generator which is to be phased out is brought up to rated speed and voltage. The knife switch is then closed to operate the motor from this generator, and the direction of the motor rotation is carefully noted.

To avoid mistakes, it is best to mark this clockwise or counter-clockwise direction of rotation with a checked arrow, either on the pulley or the frame of the machine on the side from which you are observing it. Then open the double-throw switch and allow the motor to come to a full stop. The switch is then closed in the opposite direction, to run the motor from the bus bars and running alternators, and the direction of rotation is again noted.

If the motor rotates in the same direction in both cases, the generators, have like phases connected opposite to each other on the switch terminals. If these same leads are carefully connected to the oil switch in the same respective manner, the generators should operate satisfactorily in parallel after having been synchronized.

If the motor rotates in the reverse direction when the switch is in the second position, it will be necessary to interchange or reverse any two leads of the generator which is being phased out. The connections should then be tested again by running the motor from each side of the switch, and it should run in the same direction in both positions of the switch blades.

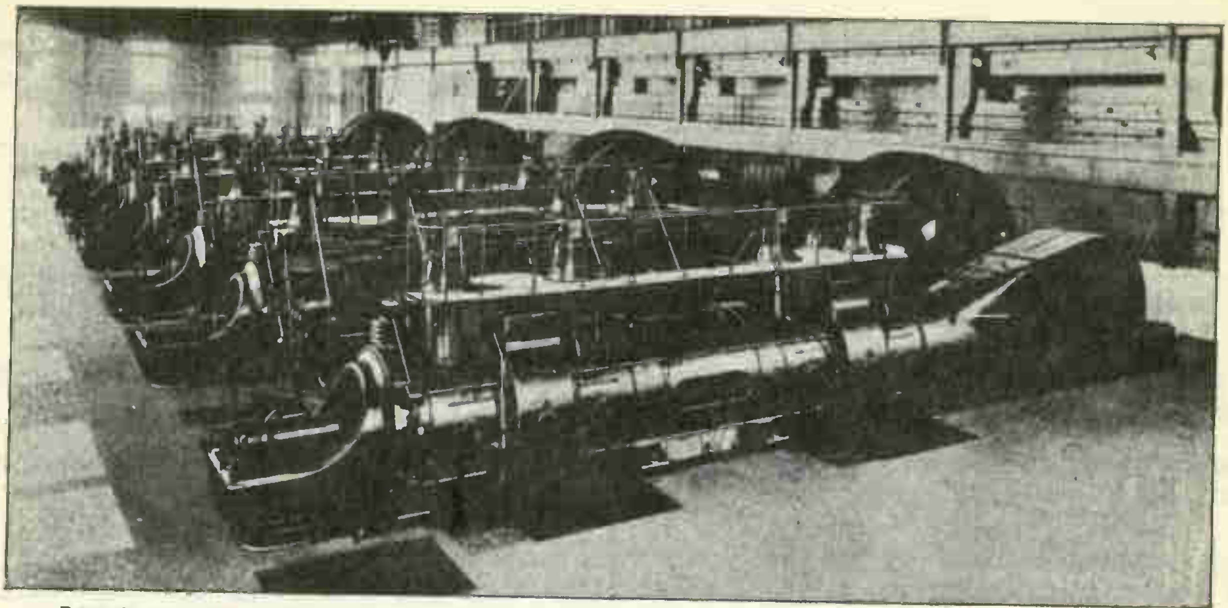


Fig. 4 Privately owned power plant producing alternating current for use in steel mill operations. These alternators are driven by gas engines which burn waste gases as a fuel.

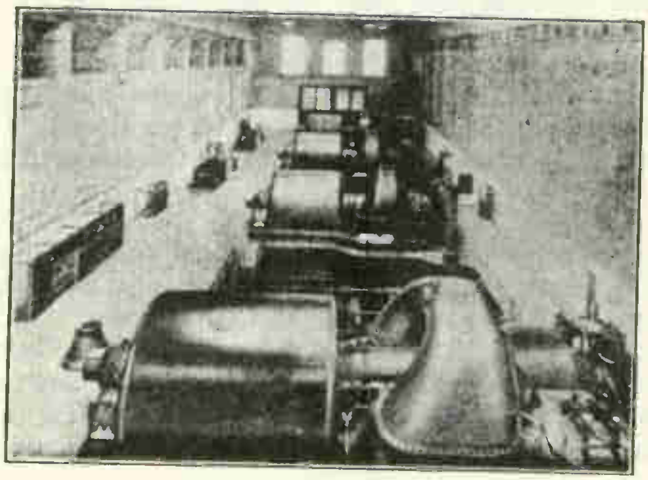


Fig. 5

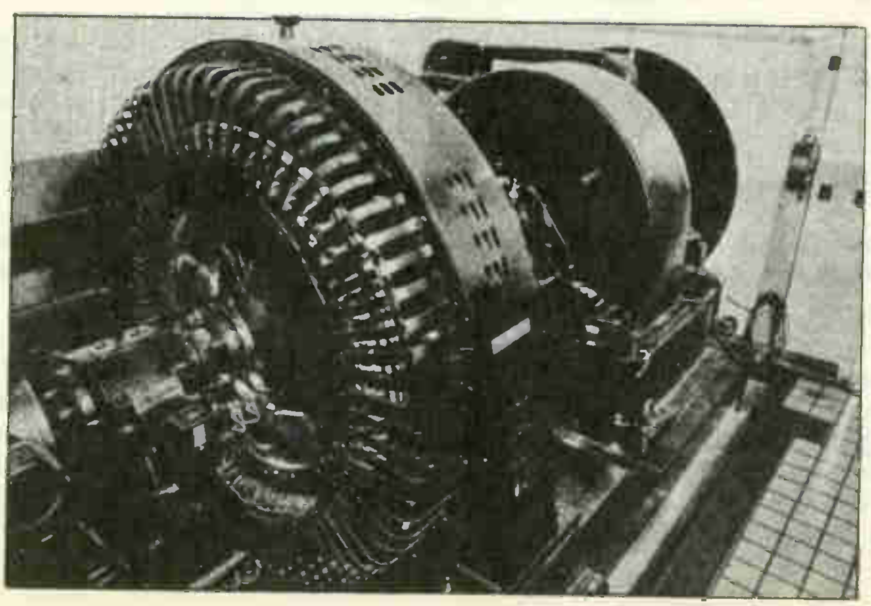


Fig. 6 This Westinghouse generator is driven by an airplane engine on break-in run.

If the voltage of the alternator is too high for any available motor, small power transformers can be used to reduce the voltage for making this test of the phases.

E. Synchronizing of Alternators

As previously mentioned, any a-c generator must be carefully and accurately synchronized before being connected in parallel with other running generators.

Synchronizing is one of the most critical operations to be performed in a power plant, and should be given careful study.

Synchronizing means to bring the generators into step or so that their positive and negative alternations occur at exactly the same time. On large machines this must be accurate to within a few degrees, that is, the same alternations of each machine must have their maximum and zero values occurring at the same instant in each phase.

By referring back to the sine curves which were shown for alternations in an earlier lesson, and also by drawing a few curves for yourself, if necessary, you will soon see what is meant by having the alternations occur in phase or in step with each other.

If alternators were connected together when out of phase more than a very few degrees, it would result in very heavy surges of current between the two machines, because of the difference in their voltages at any instant. If two machines were connected together when they were 180° out of phase, this would mean that one generator would be producing positive voltage while the other was producing negative voltage, and it would result in a double voltage short-circuit, the same as though two DC generators were connected together with wrong polarity.

The nearer the two machines are to being in phase, the less will be the difference in their instantaneous voltages at any point of the cycle.

By careful adjustment of the speed of the "incoming" alternator, we can, by means of a synchronizing device get the two machines exactly in phase with each other. A skillful operator can then close the oil switch at just the right instant and connect the machines in parallel with practically no resulting surge or current flow between the "incoming" and running generators.

If large generators are connected together when they are very much out of phase, it is likely to wreck the machine windings and possibly cause serious damage to the generators and other plant equipment.

The two most common methods for determining, when alternators are in synchronism are by the use of either a synchronscope or lamp-bank. A voltmeter is sometimes used for this purpose also. A synchronscope is by far the more reliable and convenient, as it shows whether the incoming generator is running too slowly or too fast and indicates which way the governor or throttle of the prime mover should be adjusted in order to bring this machine to the same frequency as the running machines.

The pointer of the synchroscope also indicates more accurately when the generators are exactly in synchronism with each other.

When voltmeters are used, they are connected the same as the lamp-bank, which will be explained in the following paragraphs.

Voltmeters to be used for synchronizing should be of the "dead-beat" type, or well damped so that their pointers do not oscillate or swing too far beyond the actual voltages. Voltmeters are seldom used for this purpose because of their cost and the fact that the synchroscope, costing very little more, is much more convenient and reliable.

F. Synchronizing Methods

1. Lamp-bank method - The lamp-bank method of synchronizing is used quite extensively in small plants, where the generators are not large and the cost of the synchronscope is considered prohibitive.

Fig. 2 shows the connections for using lamps to synchronize two alternators. You will note that these connections are practically the same as when lamps are used to phase out an alternator, except that the lamps are arranged with a double-throw, three-pole switch, so they can be used to synchronize either alternator with the busses, according to whichever machine may be running at the time.

The incoming generator, which in this case is NO. 1 in the Figure, is started and brought up to speed and voltage. The synchronizing switch, S is then closed to the right and the lamps will alternately become bright and dark, the same as in phasing out an alternator, except that in this case the alternators are presumed to have been phased out and the three sets of lamps should all go bright and dark together.

When the generators are 180° aout of phase, or one machine positive and the other negative, their voltages will add together through the lamps and cause the two lamps in series in each phase to burn brightly.

When the generators are exactly in phase-- that is, phase A of generator No. 1 reaches its maximum voltage at the same time phase A of generator No. 2 does - these voltages are then opposing each other on the busses and no current will flow through the lamps.

If the frequency of the incoming machine is only slightly different from that of the running machine, the lamps will brighten and darken very slowly; but if the frequency of the incoming machine is considereably different from that of the running machine, the lamps will flicker on and off very rapidly.

So, by adjusting the governor or throttle of the prime mover which drives the incoming generator and watching the operating of the synchronizing lamps we can tell whether we are approaching the frequency of the running generator or if we are getting farther away from it.

When the speed of the incoming generator is properly adjusted and the frequencies are almost exactly the same,the lamps should go on and off very slowly, actually remaining dark for a second or two, and requiring several seconds to change from bright to dark each time.

During the middle of this dark period, the switch which connects the incoming generator to the busses should be closed. By watching the speed with which the lamps brighten and go dark throughout several of these periods, one can approximately time the length of the dark period so that the switch can be closed about the middle of this period.

This requires good judgment and skill, which can be obtained only by practice.

One of the disadvantages of using lamps for synchronizing is the fact that an incandescent lamp requires a considerable proportion of its rated voltage to cause the filament to light even enough to be noticeable. Therefore, there may be some small difference in voltage between the two alternators even when the lamps are dark. This is the reason for closing the switch at the middle of the dark period, when the voltage difference between the two machines should be zero.

Alternators should never be paralleled as long as the lamps are burning at all; or, in case a synchroscope is used, as long as it indicates any phase difference between the two machines. If the phase difference is small when the machines are paralleled, they may pull in step; and while there may not be any serious damage the first time this is done, if it is done a number of times the severe shock to the windings will sooner or later damage their insulation or the coil bracing.

The very heavy surges of current which result through the generator windings when they are paralleled slightly out of phase, set up enormous magnetic stresses which tend to distort the conductors at the end of the coils and also apply very heavy pressures against the insulation in the slots. This also results in severe mechanical shock to the entire machine.

2. Synchroscopes

The lamp-bank method will probably be encountered in a number of small plants and may often be very handy to you in synchronizing small generators when no synchroscope is available. The synchroscope is, however, by far the most commonly used in modern plants of any size, and because of its extreme accuracy this instrument should be used whenever possible. Refer back to Fig. 1.

Another of the decided advantages of the synchroscope over the lamp-bank is that its pointer indicates whether the incoming generator is running too fast or too slow.

When the synchroscope is used, the governor of throttle of the prime mover is adjusted according to the indication of the synchroscope pointer and whether it is revolving in the direction showing that the incoming generator is running too fast, or in the opposite direction showing that it is running too slow.

When the speed of the incoming generator has been adjusted to a point where the synchroscope is revolving very slowly in the "fast" direction the knife switch or oil switch which connects the incoming machine to the busses can then be closed, just as the pointer reaches the mark on the center of the scale.

By connecting the alternators together when the incoming machine is running slightly faster than the running machines, it enables the incoming generator to pick up its share of the load more readily and smoothly.

When paralleling alternators by means of remote controlled oil switches it is often necessary to allow a fraction of a second for the actual closing of the oil switch. This is done by closing the remote control switch just before the synchroscope pointer reaches the mark on the scale, so that the oil switch will close and parallel the alternators just at the time the pointer is on the mark and the machines are in exact synchronism.

G. Starting Alternators

The procedure to be followed when starting an alternator and preparing to bring it on to the busses in parallel with others may vary in certain details with the operating policies of different plants, but there are certain general methods and precautions to be followed.

The following material on this subject applies only to alternators which are already installed and in operating condition. The procedure for starting new alternators which are to be operated for the first time will be covered in a later lesson on the installation and operation of electrical machinery.

When starting an alternator in a small plant, the electrician or switchboard operator may also have to start the prime mover. In large power plants the prime movers are usually started and controlled by the turbine engineers or men of the steam crew.

In either case, a certain amount of time must be allowed for the routine and preparations necessary in starting the prime movers.

Before starting an alternator we should make sure that the armature and field switches are open. The field switch should be set in the discharge position.

If the exciter is separately driven, it should be started and brought up to full rated speed before the alternator is started. If the exciter is driven from the alternator shaft it will, of course, come up to speed at the same time the main alternator does.

In either case the exciter voltage should be kept low, usually at about 50% of its rated voltage, until after the field circuit to the alternator has been closed. This allows the voltage to be built up more gradually in the armature of the alternator.

The alternator field switch can next be closed, to energize the field poles. Then adjust the exciter voltage until the alternator armature develops it full rated voltage. If the generator is to operate alone and supply power to a line, the armature switch may then be closed. If the generator is to operate in parallel with others, it must first be properly synchronized before closing the armature switch.

In some cases, when starting a single alternator that is to be operated alone, it is desirable to close its armature switch to the line with the alternator voltage at about one-half its full rated value. This allows the generator to pick up any load which may have been left connected to the system, without such heavy current surges through the machine. The voltage can then be brought up to normal by means of the field rheostats, after the armature switch is closed.

Always remember that the three most important requirements before paralleling AC generators are: 1. They must be of equal voltage; 2. Generators must have been phased out and have like phases ready to connect together; 3. The generators must be in synchronism.

When these conditions have been obtained the armature switch may be closed and the incoming generator connected in parallel with the bus bars and running switches. The alternators should then operate satisfactorily in parallel, if they are of the proper design and characteristics.

H. Adjusting and Transferring Load on Alternations

The next step is to make the alternator which has just been connected pick up its share of the load on the system. This cannot be done by increasing the armature voltage, as is done with direct current generators.

Alternating current generators are caused to take more of the load by slightly increasing the power applied by the prime mover. This is done by adjusting the governor or throttle of the prime mover so it will deliver slightly more power to the alternator.

This momentarily tends to make that alternator, on which the power is increased, run slightly faster than the others but, the tendency of two or more alternators, to hold together in synchronism after they are once paralleled, prevents the machine from actually running any faster than the others.

Instead, the additional power applied by the prime mover merely causes this generator armature to advance a few degrees in phase ahead of the others, and this will cause it to pick up its share of the load.

The field rheostat can then be adjusted to reduce any cross currents or wattless currents between the armatures of the alternators in parallel. This is very important, and the field current should be adjusted until the armature current of each alternator is at the minimum for the load they are carrying at that time.

In other words, by having wrong field adjustment on alternators, it is possible to have the sum of the currents from the separate machines equal considerably more than the total load current being taken from the busses. These cross currents between the alternators may result in heating, if they are not kept at a minimum.

When the proper load distribution has been obtained between the generators operating in parallel they should maintain this division of load, provided the governor of the prime movers is properly adjusted so that all machines respond alike to variations in the load.

I. Shutting Down an Alternator

When the load on a certain power plant or group of alternators is reduced to such an extent that it is not economical to keep all of the alternators operating, one of the machines can be disconnected from the bus and shut down until such time as increased load may again require its operation.

Shutting down an alternator is a simple operation, but there are several important steps to be followed in order to perform this operation properly.

In some small plants a-c generators are taken off the busses, by merely opening their armature switches. This, however, results in a very sudden dropping of the load of the disconnected machine and may result in heavy current surges and fluctuations in the voltage of the other machines.

For this reason many power companies object to this practice, and require that the load be gradually dropped from the machine which is to be disconnected. This can be done in the following manner.

The throttle valve on the prime mover of the generator to be shut down is first closed little by little until the generator drops practically all of its load and the ammeter or wattmeter in its circuit shows its current output to be at a very low value. In up-to-date plants of medium or large size, wattmeters or watthour meters give the most reliable indication when the load is reduced to zero, as an ammeter might still show some flow of wattless current.

This load is, of course, automatically picked up by the other generators, or is in reality simply transferred by reducing the power applied to the alternator which is being shut down.

When by adjustment of field excitation the load on the machine is shown by the ammeter has been reduced to zero or a very low value, the armature switch is then opened, disconnecting the generator from the busses. The throttle valve of the prime mover is then closed all the way and the generator is allowed to drift to a stop.

After the armature switch has been opened, the field switch may be opened if desired, or the field can be left energized temporarily, in order to bring the generator to a stop in a little shorter time. Brakes are used for this purpose on larger machines. The field switch should never be opened before the armature switch has been opened.

When the generator comes to a complete stop and is standing idle, the field switch should always be open. It is also a very good precaution to open any disconnect switches which are between the generator, oil switch, and the bus bars. This will prevent any power flow from the busses to the generator armature if the oil switch should accidentally be closed when the machine is standing idle.

Different generating companies have various special rules to meet the operating conditions in their various plants, and any operator should make a careful study of these rules as well as the general rules and principles which are covered in this lesson. All such rules are made to provide safety for operators and machines as well as to provide satisfactory service to the customers to whom the power is supplied.

J. Instrument and Connection Arrangements for Alternators

Fig. 3 shows a diagram of the connections for an alternator and its exciter. This diagram also shows the meters to measure the voltage and current of each machine.

The three a-c ammeters are connected, by means of current transformers, to measure the current in each line wire of the alternator.

The a-c voltmeter is connected by means of a potential transformer to indicate the voltage of the alternator. This voltage, of course, should be the same on all three phases; so it is only necessary to measure it on one phase.

You will note that the voltmeter connections are made between the alternator and the oil switch, O; so that the voltage of the alternator can be read before the oil switch is closed to parallel this machine with any others which may be connected to the busses.

Two disconnecting switches, D, are provided, one on each side of the oil switch. After the oil switch is open and the alternator shut down, these disconnecting switches can be opened with a switch pole, or by hand in the case of low voltage circuits, and thus the oil switch and instrument transformers are separated from the live busses.

This permits any necessary repair work to be done on these devices with safety. The alternator rheostat, A.R., and the field discharge switch, S are mounted on the alternator panel of the switchboard. The alternator panel is also very often provided with a wattmeter and a watthour meter. The wattmeter is to indicate the power output of the machine at any instant and the watthour meter shows the power in kw. hours which is produced by the machine during any certain time period.

The alternator panel are usually provided with switches or plugs for connecting. the synchronscope or synchronizing lamps to any machine that is being started. These auxiliary devices are not shown in the diagram in Fig. 3.

The exciter panel at the right in Fig. 3 contains the d-c ammeter and voltmeter, for measuring the current to the field of the alternator and the voltage generated by the exciter. The exciter field rheostat, E.R., is also on this panel.

In some power plants the exciter panel is located adjacent to the alternator panels in this manner. In other large plants the direct current from the exciters may be metered and controlled from an entirely separate switchboard.

Among the more important features to be checked and watched in the care of alternators are the following. The temperature of both the windings and bearings should be frequently checked, and the meters watched to see that the machines are not overloaded. The speed and frequency of alternators should be accurately maintained and the fields properly adjusted to keep cross currents at a minimum between parallel alternators. Tests should be made periodically on the insulation of alternator windings to note any weakness before it results in a complete failure of the machine.

Always see that there is plenty of cool clean, dry air available for cooling the machines. All parts of the generators should be kept clean, and the windings should be cleaned with compressed air to keep dust or dirt from blocking ventilating passages and causing excessive heating.

Fig. 4 shows a section of a large industrial power plant in a steel mill. Waste gases from blast furnaces are used to operate twin tandem gas engines, and these engines in turn drive the alternators, which are operated in parallel to supply electricity used in the mill.

A great many of the larger factories and industrial plants have their own private power plants to generate the vast amount of electrical energy which they use. See Figs. 4, 5, and 6.

Operation of electrical equipment in plants of this type as well as in the mammoth generating stations which are owned and operated by public utility companies, provides fascinating and profitable work for thousands of trained men.

K. Summary Questions

1. What three important requirements are necessary in order to operate alternators in parallel?
2. When using the lamp-bank method of "phasing out" an alternator, what changes would be necessary when the lamps do not all burn at the same brilliancy at any one time?
3. Referring to Fig. 1 what would be the indication on the motor when the incoming gen. No. 2 is properly phased out?
4. What is meant by the term synchronizing when used in connection with alternators?
5. Draw a sketch showing how lamps may be used to indicate synchronism when paralleling alternators.
6. What will happen if alternators are paralleled without synchronizing?
7. What advantage does the synchronscope method have over the lamp-bank method of synchronizing alternators?
8. How are alternators caused to take more of the total load?
9. What procedure should be followed when shutting down an alternator where it is desired to prevent heavy current surges and voltage fluctuations on the line?
10. Name at least three important things to watch when operating alternators.

MAINTENANCE AND TROUBLESHOOTING AC EQUIPMENT

Objective

To learn the main troubles and their remedies in regards to a-c motors, alternators, and their respective control equipment.

References:

Lesson Content

A. General

Troubles in a-c equipment may be due to such things as overloads, improper "preventative maintenance", worn bearings, etc.

Motors and generators ordinarily found in manufacturing plants, however, do not demand extra ordinary care to keep them operating efficiently. A regular well planned system or schedule of inspection, adjusting and servicing will make continuous operation a certainty.

B. Efficient "Preventative Maintenance"

To be effective and efficient and to minimize breakdowns and shorten breakdown periods, requires careful consideration. A good plan of procedure is as follows:

1. Schedule shut-down time of machines with maintenance crews, so electrical and mechanical work can be done without delay.

2. Keep a supply of spare parts, units, and sub-assemblies, so quick changes may be made. (These parts, etc., must be kept dry and clean).

3. Keep accurate records of troubles and cures of each machine, as a means for running down chronic cases, and finding the cause.

NOTE: A general data card file should be kept on each motor in service. An example of the type of information card is shown below.

4. Be regular with the thorough inspections, if possible.

5. Keep motors and generators well lubricated and clean.

DATA CARD

MAKE			
HP	RPM	VOLTS	AMPS
CYCLE	TYPE	FRAME	STYLE
TEMP.	MODEL	SERIAL #	PHASE
NO. COILS	SLOTS	CONNECTION	
SIZE WIRE	TURNS	NO. OF GROUPS	
COIL GROUP	POLES	PITCH OF COIL	

C. After Breakdown - various steps should be followed in order to efficiently replace motor in service:

1. Consult card file for data card on motor needing work.
2. Strip winding
3. Re-insulate stator
4. Wind coils in stator
5. Connect coils
6. Test winding and mark leads
7. Re-varnish and bake the windings

D. Trouble Shooting the Motor

1. If motor will not start, check:

   a. Fuses
   b. Incorrect voltage or frequency
   c. Bearings and end play
   d. Grounded winding
   e. Open phase
   f. Reversed Phase
   g. Shorted coils
   h. Loose rotor bars

2. If motor does not operate properly, check:

   a. Fuses
   b. Incorrect voltage or frequency
   c. Bearings and end bell play
   d. Grounded winding
   e. Open phase
   f. Reversed phase
   g. Shorted coils
   h. Loose rotor bars

3. If motor will not come up to full speed, check:

   a. Overloading
   b. Reversed phase
   c. Shorted coil or coil group
   d. Worn bearings
   e. Reversed coils or groups

4. When motor overheats, check:

   a. Overload
   b. Tight or worn bearings
   c. Motor single-phasing
   d. Shorted internally
   e. Loose rotor bars

E. Troubleshooting the Controller

1. If controller contacts close but motor does not start, check:

    a. Poor connections in overload equipment.
    b. Main contactors for burn, grit, or dirt
    c. Terminal connections broken, loose or dirty.
    d. Timer equipment damaged or out of adjustment.
    e. Open autotransformer or resistance unit.
    f. Mechanical troubles (springs, pivots, interlocks, etc.)
    g. Magnet core with an obstruction which prevents line contactors from "making" properly.

2. If contacts do not close when "start" button is pressed, check:

    a. Holding coil
    b. Forward-reverse interlock
    c. Loose connections and dirty contactors
    d. Open overload equipment
    e. Low voltage
    f. Shorted coil
    g. Mechanical trouble.

3. If contacts do not hold when "start" button is released, check:

    a. Holding contactors for make.
    b. Pitted, loose or dirty contactors.
    c. Wrong connections between station and controller
    d. Defective stop button

4. If fuse blows when start button is pressed, check:

    a. Grounded contactors
    b. Shorted contactors
    c. Shorted coils
    d. Shorted contacts or contactors
    e. Line voltage too high

5. If the holding magnet chatters, check:

    a. Alignment of core and moving armature
    b. Broken shading coil
    c. Dirty core face.

6. For a burned or shorted holding coil, check:

    a. Overvoltage on holding coil
    b. Too frequent operation
    c. Excessive current due to magnetic gap
    d. Undervoltage, allowing gap at relay core and armature
    e. Excessive spring tension making a gap at relay core and armature.

F. Tools for Maintenance Work

1. Minimum necessary test equipment (vary as to application)

   a. Portable indicating voltmeter and ammeter
   b. Megohmmeter or "megger"
   c. Hand RPM counter
   d. Centigrade thermometer
   e. Spring balance
   f. Necessary leads with insulated clips and points

2. Additional Test Equipment Which can be Used:

   a. Portable recording voltmeters and ammeters
   b. Indicating tachometer
   c. Phase rotation indicator
   d. Hook-on voltmeter - ammeter
   e. Growler
   f. Millivoltmeter

G. Summary Questions

1. What is meant by the term "preventative maintenance"?

2. What steps would you take if a motor needed rewinding?

3. Name three motor troubles and at least 4 logical places to look for the cause of that trouble.

4. What is a likely cause of relay chattering?

5. What would you consider as a minimum of test instruments for a "preventative maintenance" electrician?

TRANSMISSION OF ELECTRICAL ENERGY

Objective

To learn about transmission and distribution systems which are used in the transfer of power from the public service company to customers.

References

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Lesson Content

A. General

Large power plants generate most of their power at voltages ranging from 2300 to 16,500 volts, with some exceptions as high as 18,200 and 24,600 volts. These voltages are high enough for economical transmission and distribution over limited distances up to about 25 miles.

B. Long Distance Transmission

Long distance transmission may be accomplished more economically at higher voltages obtained from voltage step up power transformers which range as high as 305,000 volts. Experiments are now being conducted with voltages as high as 450,000 and 500,000 volts.

Long distance transmission voltages now in use are:

33,000 44,000 66,000 132,000 154,000 220,000 and 305,000 volts

A typical transmission and distribution system is shown in Figs. 1 and 2.

C. Line Voltage Drop

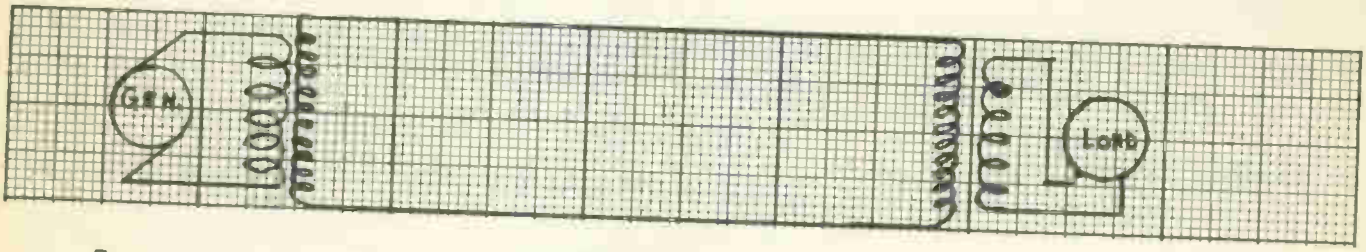
It is customary to supply approximately 1000 volts per mile-length of line. This general rule may vary, to accommodate economic conditions, which include cost of materials, such as structural, insulating, copper or aluminum conductors, and labor. The amortization period for the average transmission line is 15 years.

D. Area of Conductors

Area of conductor is determined by the current in amperes to be transmitted at any voltage. It is common practice to provide about 1000 CM per ampere of transmission current in copper conductors, and about 1400 CM in aluminum. (The conductivity of aluminum is about 60% that of copper).

Transmission at high voltage reduces the current required for a given amount of power, and permits the use of a smaller line conductor. Voltage regulation will be improved on high voltage transmission circuits.

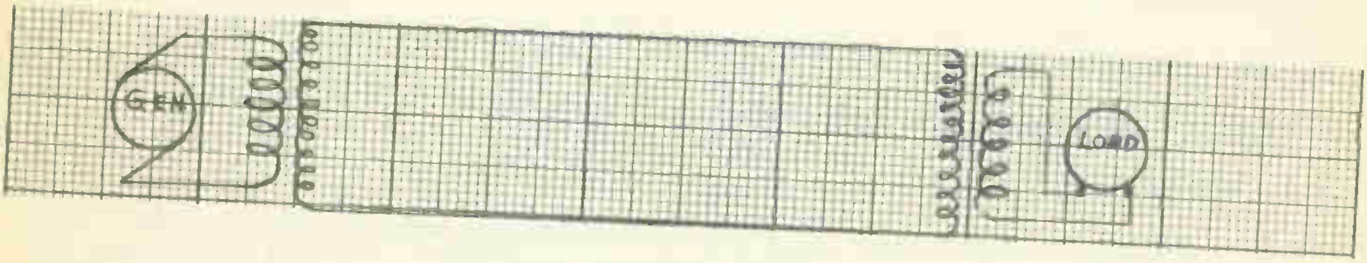
Advantages of high voltage transmission are illustrated in the following examples which will be worked in class.



Z per line =
Kw . . . . . =

R per line =
PF of line =

Line voltage =
Kva . . . . =

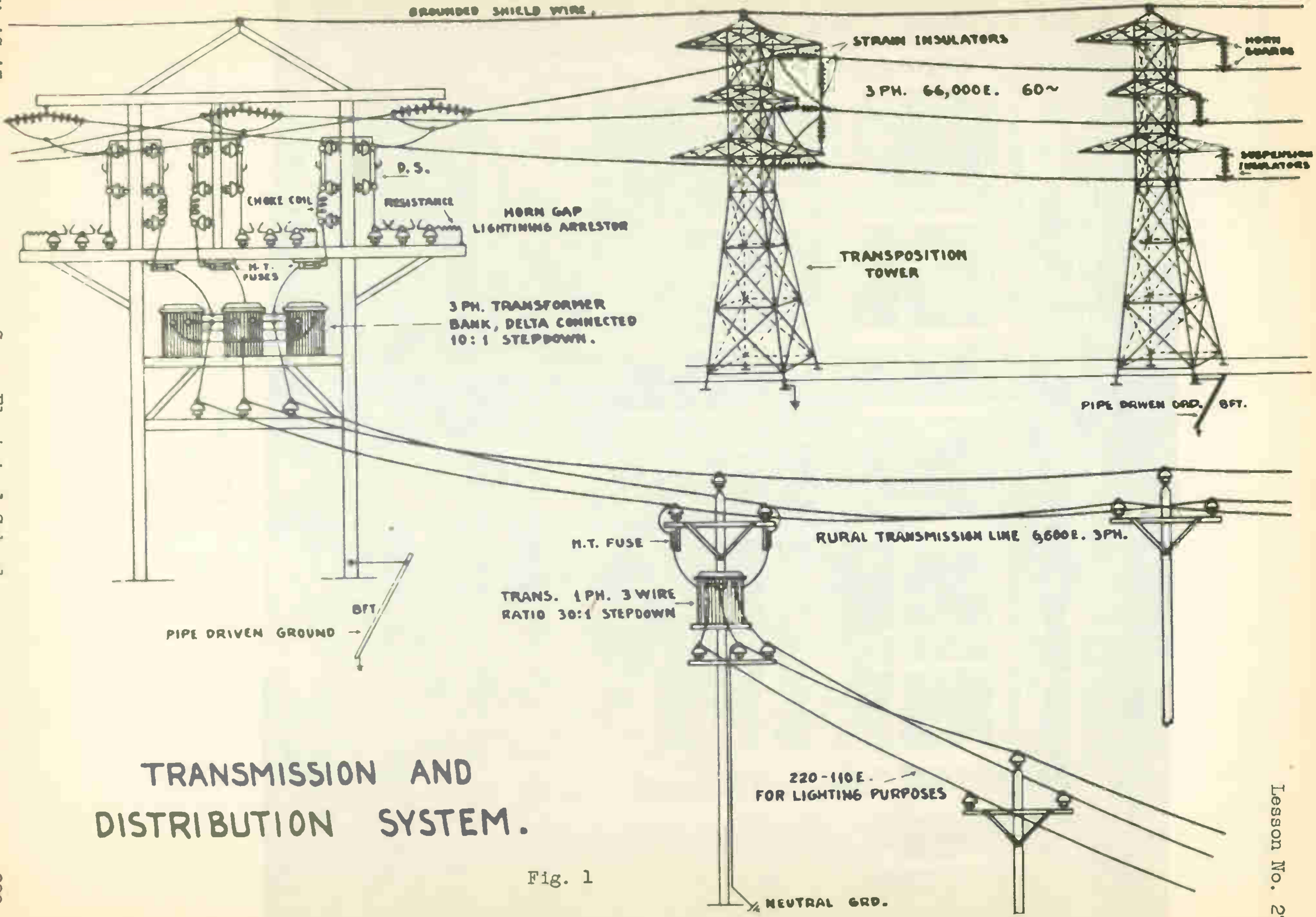


Z per line =
Kw . . . . =

R per line =
PF of line =

Line voltage =
Kva . . . . =

In the foregoing example it should be noted, the efficiency of the transformer units has been neglected, and will lower efficiency of transmission several percent below value calculated.



TRANSMISSION AND DISTRIBUTION SYSTEM.

Fig. 1

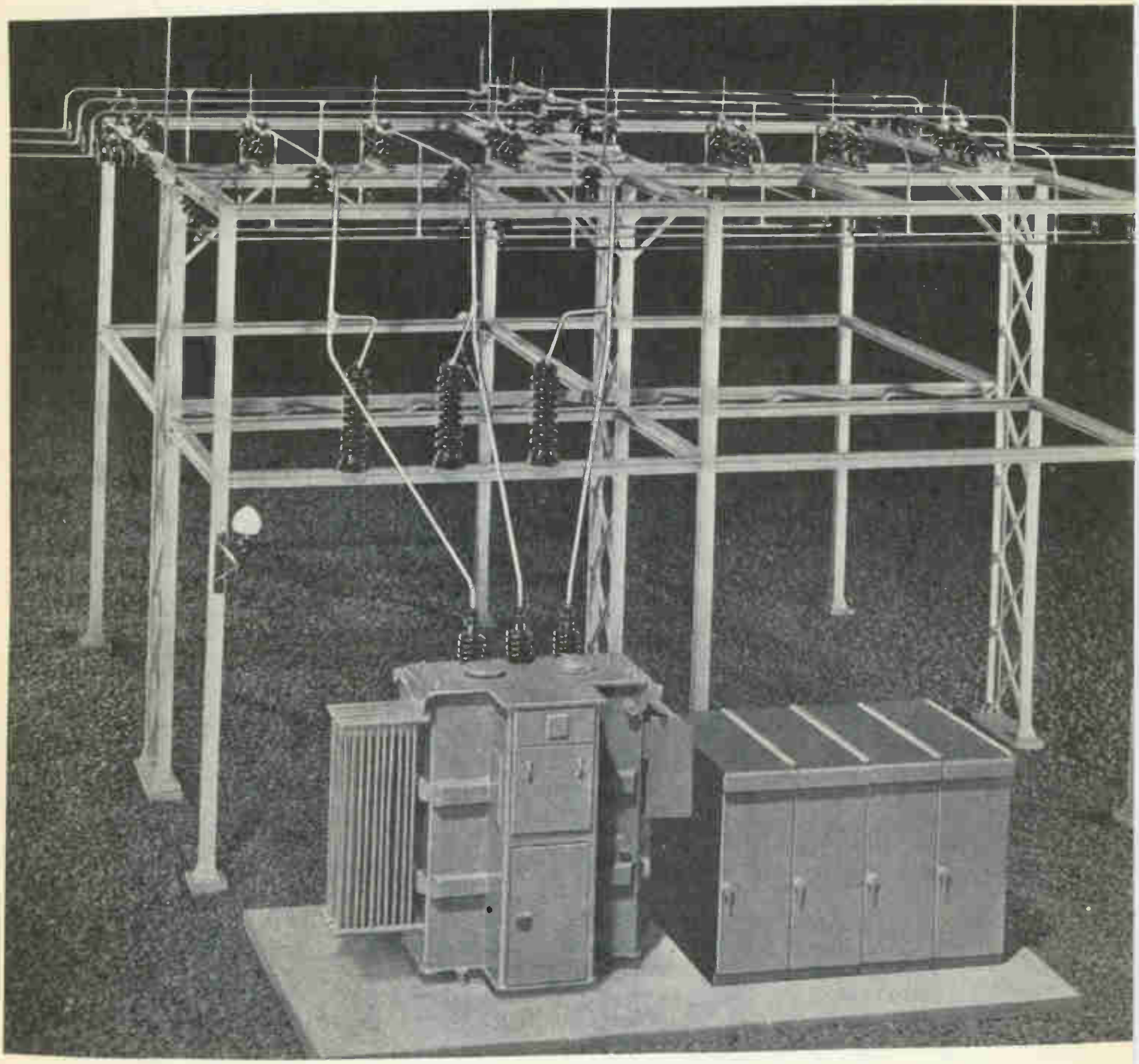


Fig. 2 A modern power sub-station

E. Insulators

1. Pin Type

This type designed for 60 cycle flashover up to about 200 KV, but use on circuits over 66 KV is rare. Fig. 3 illustrates this type.

2. Pillar or pedestal

This is a stacked pin type insulator used to support high voltage bus bars at central and switch stations where side strain is negligible, Fig. 2 and Fig. 4.

3. Suspension insulators

This type used extensively on lines over 66 KV, on long spans, and with heavy conductors. 4 or 5 units are used on 66 KV, 7 or 8 on 110 KV, 8 to 10 on 132 KV, 9 to 11 on 154 KV, 14 to 20 on 220 KV, and 24 on the Hoover Dam 287 KV line.

4. Strain insulators

This type is an assembly of suspension units arranged to "dead end" the conductor at a structure as illustrated in Fig. 5.

F. Insulator Protection

1. Insulator damage

Damage to insulators from heavy arcs resulting from High transient voltages can be very serious. Protection is provided by overhead ground wire, and arcing horns with a large spread. Proper contouring of the horn reduces the gap, and tends to spread the gap, and also tends to spread the arc away from the insulator.

2. Conductor to insulator ties

Fig. 6 illustrates several methods of tying line wires to insulators of the pin type. Clamps are provided to attach conductors to suspension insulators.

G. Lighting Arresters

1. Auto valve

This type consists of a series or stack of thin carbon composition discs which are separated a few thousandths of an inch by thin mica rings. It may be used on any voltage by providing the proper number of discs, and is connected in series with an adjustable arc gap to ground.

2. Oxide Film

This type consists of procelain rings over which two metal discs are crimped. The inner surfaces of the disks are coated with insulating varnish which punctures at about 300 volts. The space between discs is filled with lead perioxide, which is changed to red lead and litharge by the heat produced by the discharging current. When the voltage has returned to normal, these lead compounds seal the puncture in the varnish film.

3. Thyrite

This type consists of a nonporus ceramic material developed by General Electric and is an excellent insulator until a critical voltage is reached; the resistance then suddenly decreases, and the material becomes capable of discharging large currents with small increases in voltage. The current increases 12.6 times for each time the voltage is doubled.

H. Arrester Protection

1. Arrester Connections - Arresters should be connected as close as possible to the apparatus they are designed to protect. They are frequently mounted directly on the power and distribution transformers, Fig. 7.

2. Choke Coils - These coils consists of a few turns with an air core, and clamped by wooden strips. The connection of these coils is placed between the load circuit (transformer) and the transmission line. The impedance offered to the flow of transmitted energy is negligible, but lightning surges of high frequency encounter high reactance ($X_L = 2\pi FL$) which tends to choke back that energy, and it seeks a path of lower impedance through the lightning arresters to ground.

3. Overload Protection

Overload protection for transmission and distribution circuits is provided in the form of oil immersed switches or high tension fuses, Fig. 8. This fluid filled fuse of popular type, has a fuse element which melts due to overload and the current is shunted through a strain wire, causing it (fuse element) to melt and release the spring. The arc, thus drawn, is very rapidly extinguished by compressed liquid directed by the arcing terminals.

NOTE: An example of a power distribution switchboard is shown in Fig. 9

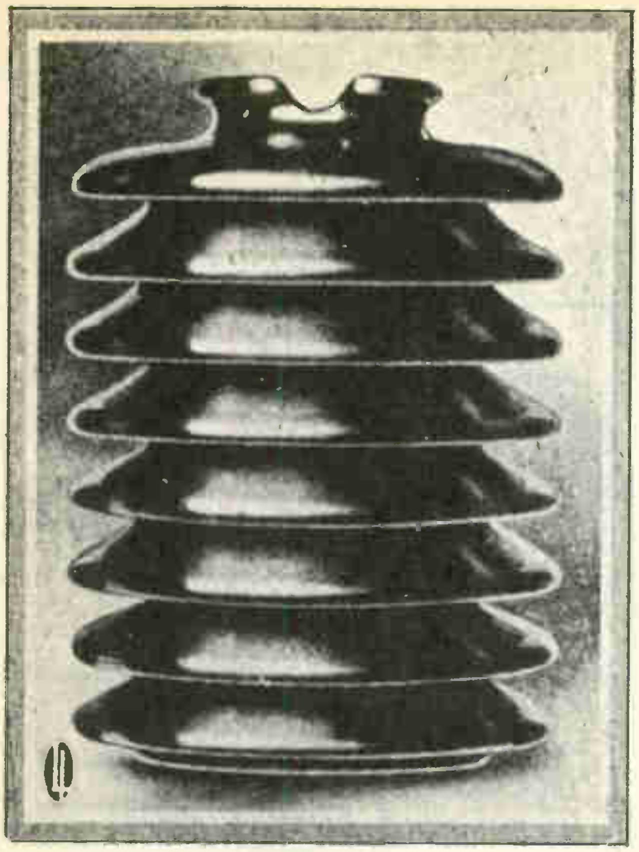


Fig. 3

Large special fog type pin insulator having a number of extra skirts to prevent flashover in districts subject to heavy salt fogs, mist, dirt, etc. Courtesy Lapp Insulator Company, Inc.

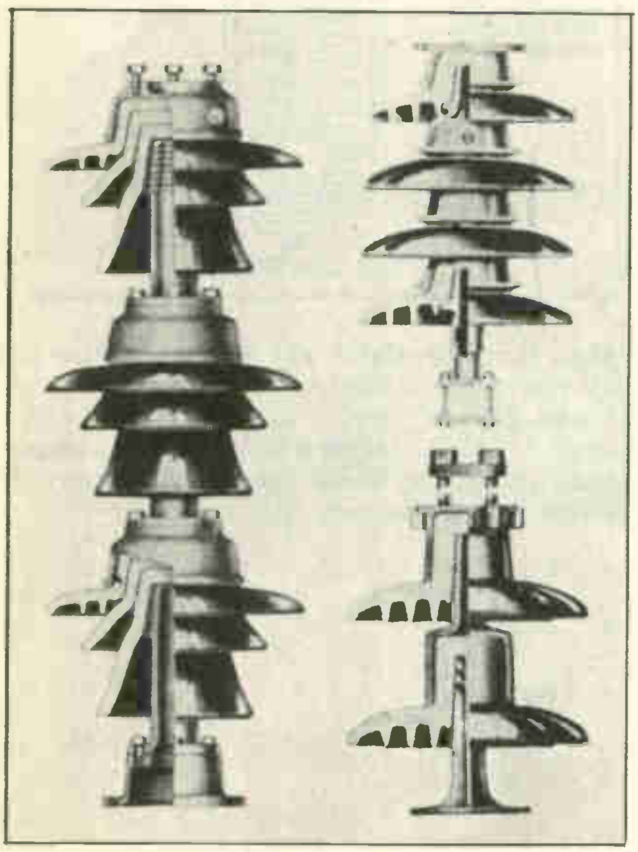


Fig. 4

Three styles of pedestal type insulators which can be built up in rigid pedestal or pillar form to support high-voltage bus bars and switching equipment.

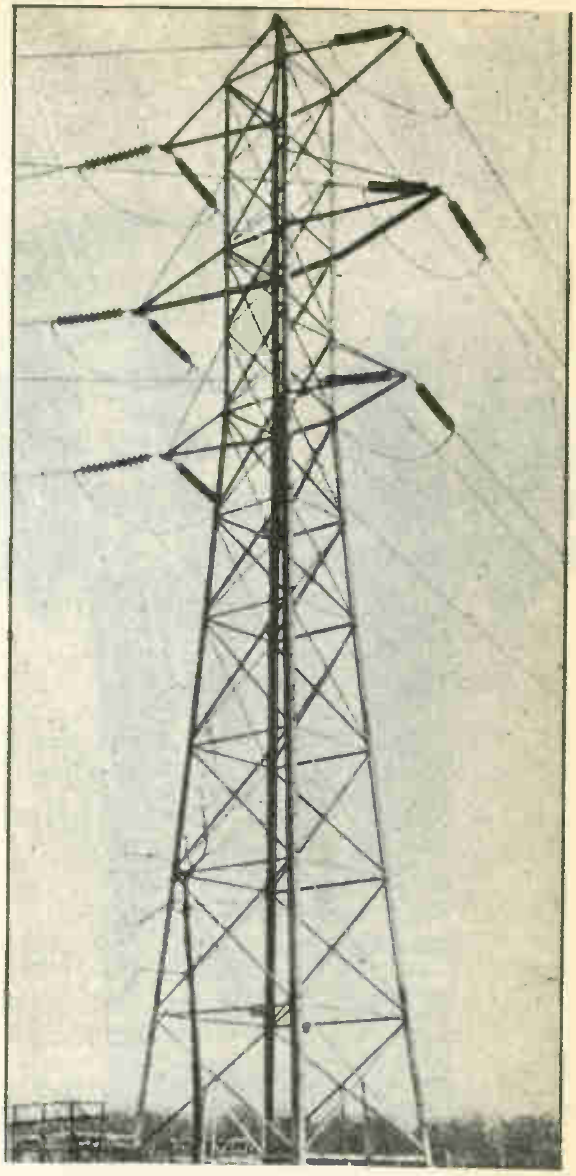


Fig. 5

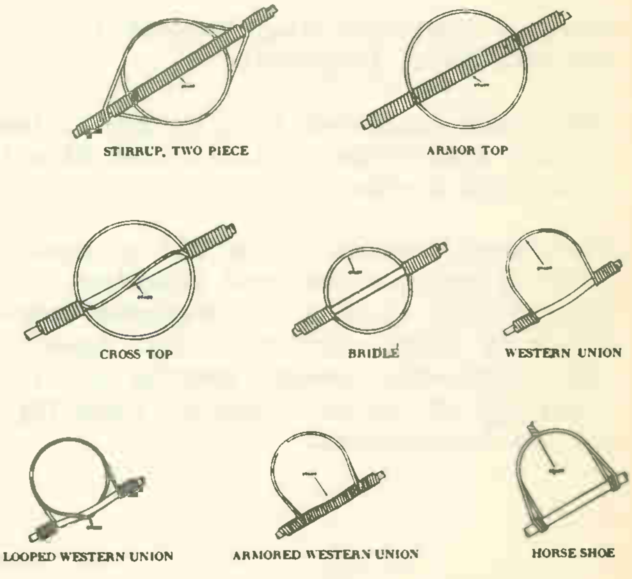


Fig. 6 METHODS OF TYING LINE WIRE TO INSULATORS

The above sketches show the methods of making some of the most common types of line ties. Note carefully how the tie wires are wrapped around the insulator cap and around the conductor. Courtesy Lapp Insulator Company, Inc.

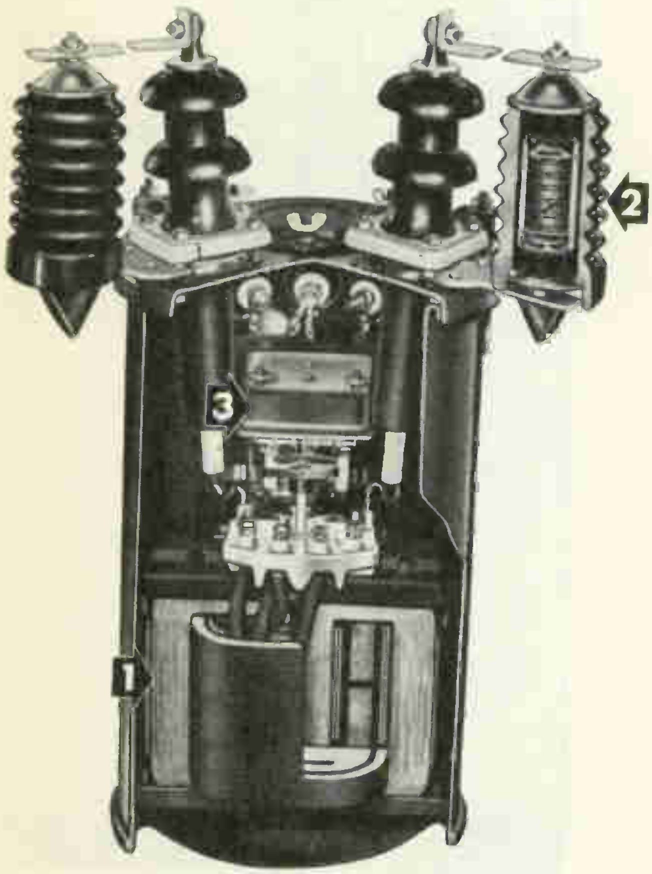


Fig. 7

1. Core of laminated High Permeability Silicon Steel (Hipersil).

2. Arresters connected to give protection to the transformer against even direct lightning strokes.

3. Secondary Breaker (FR or TR) automatically removes the load from the transformer in case of dangerous overloads or short circuits. Even more important--the breaker permits utilizing all of the safe thermal capacity of the transformer.

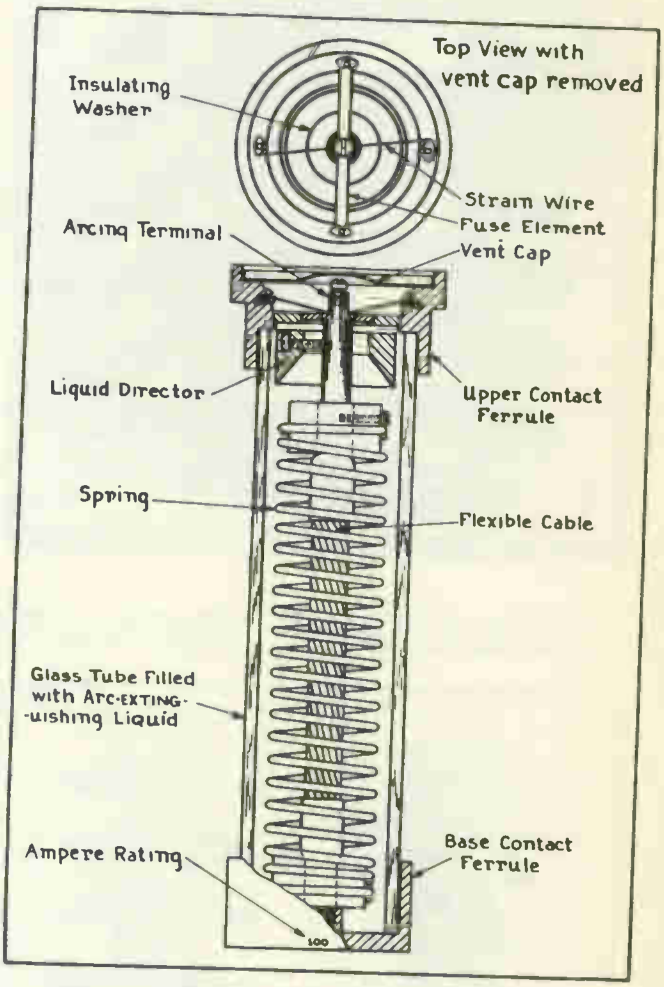
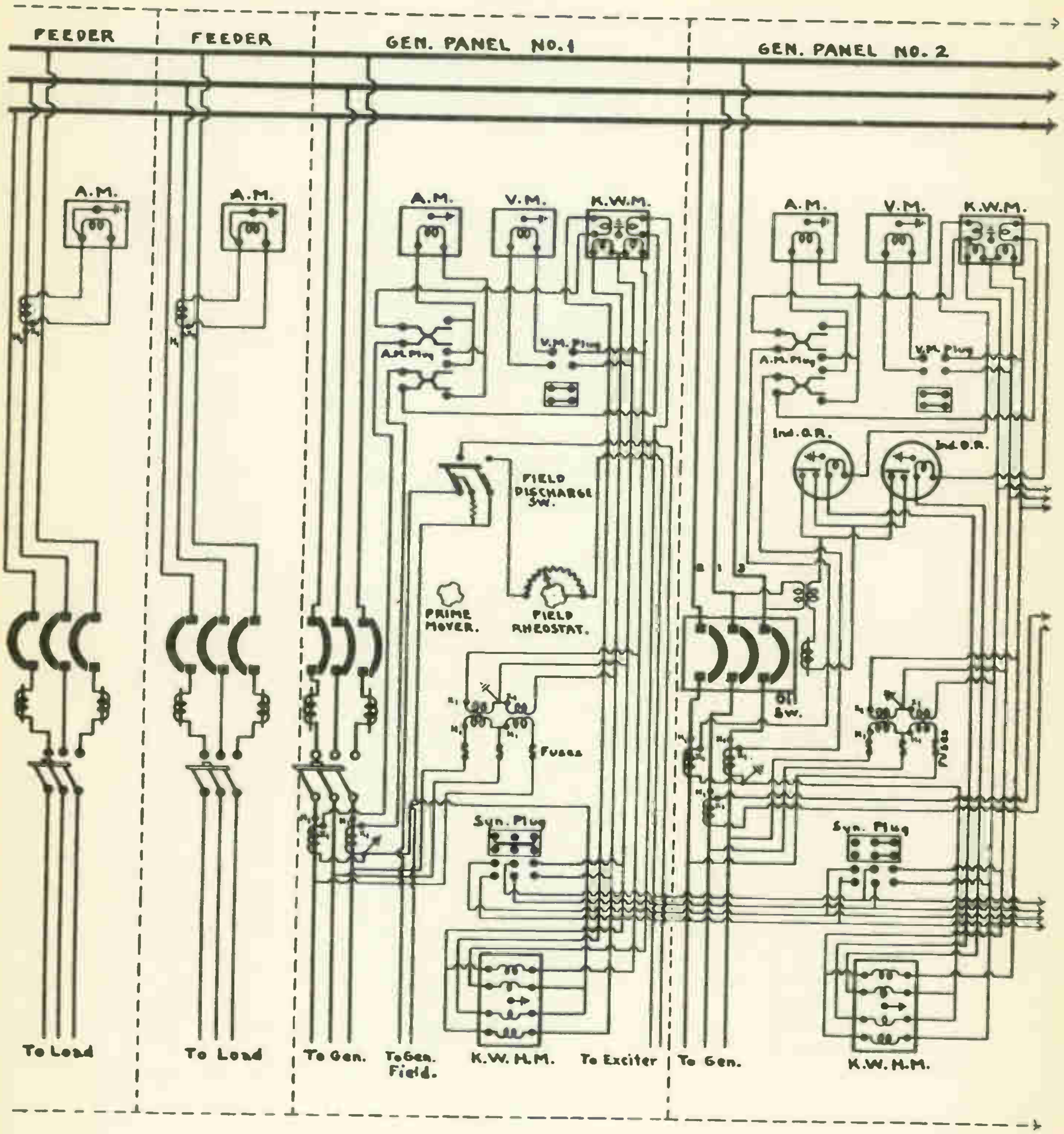
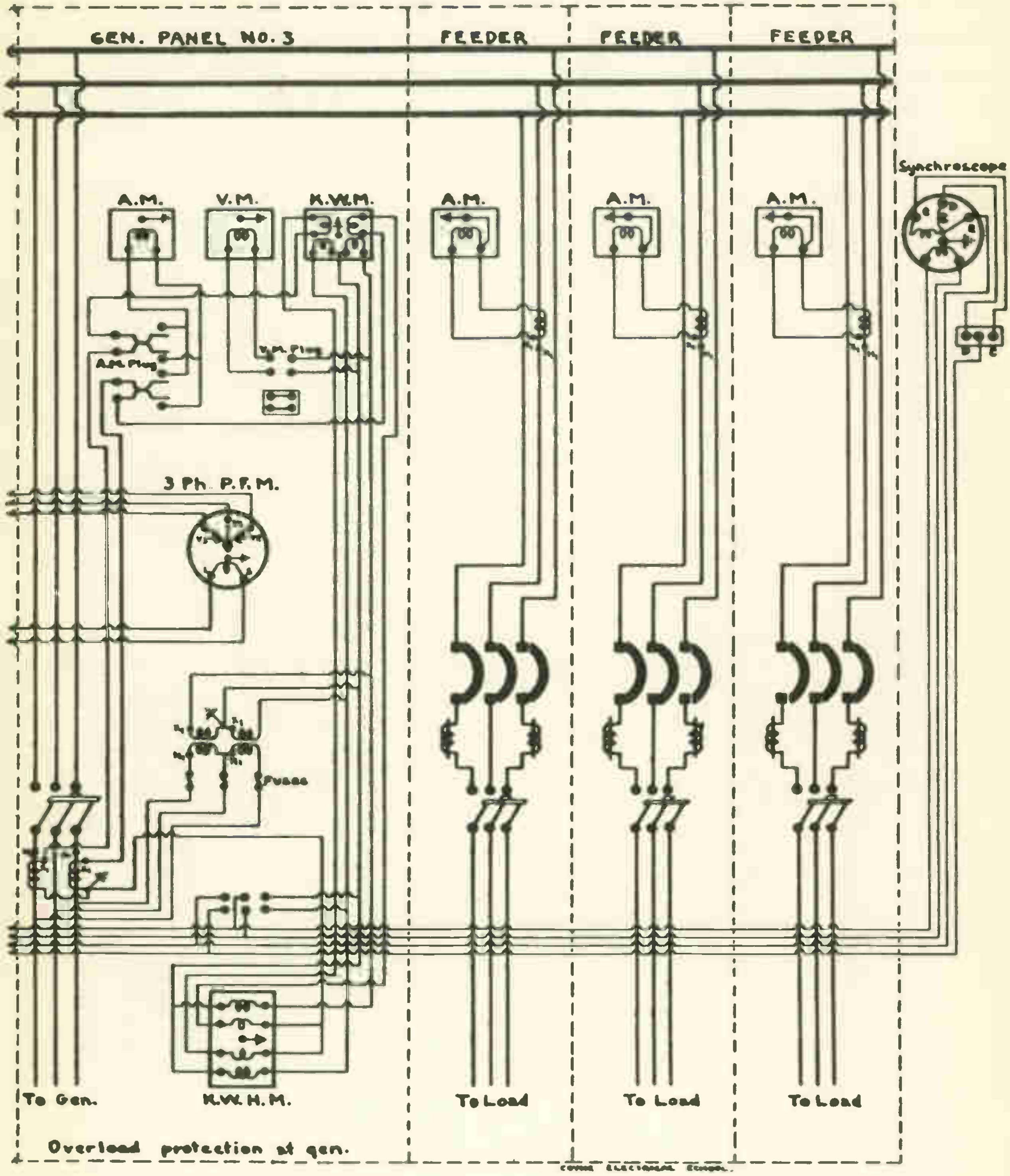


Fig. 8. The above sketch shows the principal parts of a high-voltage fuse of the liquid filled type. Examine each part carefully and compare with the explanations given on these pages. Courtesy of Schweitzer & Conrad, Inc.


FEEDER
FEEDER
GEN. PANEL NO. 1
GEN. PANEL NO. 2
A.M.
A.M.
A.M.
V.M.
K.W.M.
A.M.
V.M.
K.W.M.
A.M. Plug
V.M. Plug
A.M. Plug
V.M. Plug
Ind. O.R.
Ind. O.R.
FIELD DISCHARGE SW.
PRIME MOVER.
FIELD RHEOSTAT.
Fuses
Fuses
Oil Sw.
Syn. Plug
Syn. Plug
To Load
To Load
To Gen.
To Gen. Field.
K.W.H.M.
To Exciter
To Gen.
K.W.H.M.


GEN. PANEL NO. 3
FEEDER
FEEDER
FEEDER
Synchroscope
A.M.
V.M.
K.W.M.
A.M.
A.M.
A.M.
A.M. Plug
V.M. Plug
3 Ph. P.F.M.
Fuses
To Gen.
K.W.H.M.
To Load
To Load
To Load
Overload protection at gen.

CHANGING AC TO DC

Objective

To learn how to convert a-c to d-c for several applications where d-c is preferred for use.

References

Lesson Content

A. General

The greater percentage of generated power is a-c, but applications such as traction work, elevators, reducing aluminum to magnesium, battery charging, electro-plating heavy mill drives, etc., require d-c to accomplish satisfactory service.

B. Circuit Point of Conversion

The power, transmitted as a-c, is converted to d-c at the point of consumption. Some of the mechanical methods of conversion are:

1. A-c motor d-c generator sets - This unit is about 75 to 80% efficient and varies as the product of the separate motor and generator efficiencies. See a working example Fig. 1.

2. Rotary converter, (Fig. 2) Rotary converters are a combination motor and generator in one frame. The armature winding is regular d-c wound, but is tapped at equi-distant points through slip rings to the a-c supply. The machine is started as an induction motor by applying low voltage to the armature winding and it uses a stationary cage for a damper winding. As synchronous speed is approached, field excitation is applied and synchronous speed is obtained. The efficiency of this unit is approximately 92 to 94%. See Figures 3 and 4 for other comparisons.

C. Rectifiers

1. Definition - a rectifier is a device designed to permit passage of current in one direction only. Ripple frequencies are compared in Fig. 5.

2. Parts

   A tube rectifier consists of two elements:

a. Cathode - This is the electron emitting element from which electrons are liberated thermionically (heated cathodes) or sometimes by high voltage bombardment (cold Cathode type).

Two general cathode types are:

1) Mercury pool type (ignitrons)
2) Alkaline metal - barium, thorium, or other suitable metals which emit electrons at low temperatures.

b. Anode - This element or electrode is the "electron receiving" element, sometimes referred to as the tubes "plate". It will not emit electrons at normal voltages and temperatures. Usually composed of steel or graphite or a combination of the two.

3. Operation

A positive charge on the anode attracts the electronic emission of the cathode and so permits passage of current from anode to cathode. The electron stream consists of a flow of electrons from the cathode to the anode.

4. Tube rectifier types

Mercury arc See Figures 6, 7, 8, and 9.

Output voltage - The output voltage of mercury arc rectifiers with common connections, can be determined from the following ratios:

Single phase - 2 anodes - .636
Three phase - 3 anodes - .827
Quarter phase- 4 anodes - .900
Six phase - 6 anodes - .955

The figures given are the ratio of the average d-c pulsating voltage output to the maximum a-c voltage input. For example, if we apply 100 volts a-c to six-phase unit, the d-c voltage will be 100 x .955, or 95.5 volts. The greater the number of phases, the higher is the d-c output voltage.

Voltage regulation - Voltage regulation of mercury arc rectifiers is very good; it should not exceed 35 volts over normal load ranges. Its efficiency may run as high as 98.5%.

Advantages - There are several important advantages of mercury arc rectifiers over motor generator units:

1) no moving parts
2) no heavy foundations
3) easily installed
4) quiet operation
5) highly efficient

5. Tungar bulb, Fig. 12

Used for light duty jobs as battery charging, etc. Its efficiency is from approximately 65 - 70%.

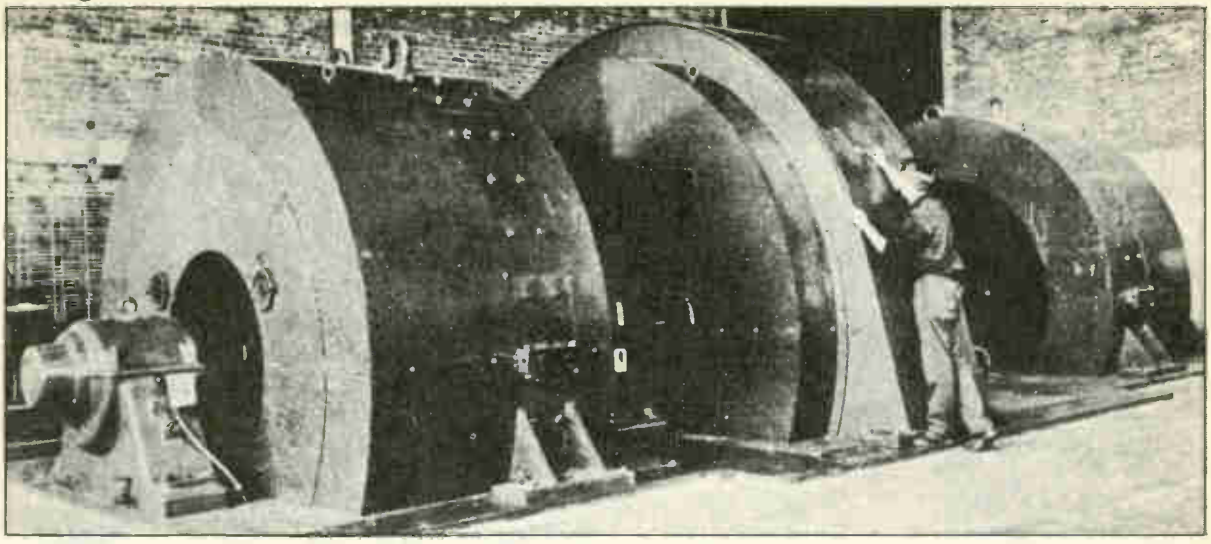


Fig. 1

This 8300-kw Westinghouse synchronous motor generator set, the largest ever built for such service, supplies power for the mill and reel motors of a new high speed 54-inch wide fourstand tandem cold reduction strip mill. It consists of two 4000-kw, 750 volt, direct current, main power generators; a 300-kw, 450 volt, reel booster generator; and 11,250 horsepower, 0.9 power factor, 11,000 volt, 3 phase, 60 cycle, 300 rpm, synchronous driving motor. The machines are ventilated by a downdraft air cooling and recirculating ventilation system.

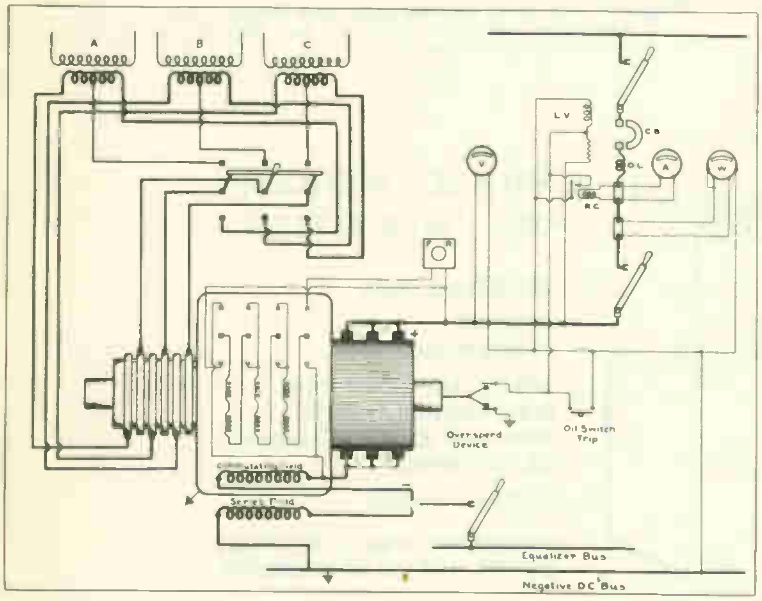


Fig. 2

This diagram shows the connections of the transformer secondaries to the A. C. slip rings of a six-phase, synchronous converter and also shows the starting switch used for obtaining half voltage to start the machine from the A. C. end. Note the connections of the shunt field windings to the field break up switch and rheostat, and also the connections of the commutating and series field windings to the equalizer bus and negative D. C. bus. The equalizer bus will be used only in case the machine is operating in parallel with other converters. Note the low voltage trip coil, L.V., which will open the circuit breaker in case of voltage failure, and the overload trip coil, O.L., which will open the breaker in case of D. C. overload. The reverse current relay, R.C., will short circuit the low voltage trip coil and open the breaker in case of a D. C. feed-back to the converter.

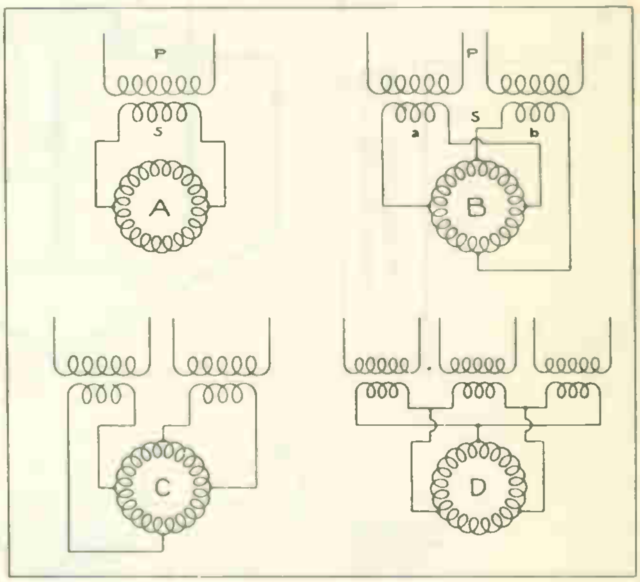


Fig. 4

A. Transformer connections for a single-phase converter. B. Transformer connections for a two-phase, diametric converter. C. Transformer connections for a two-phase, adjacent tap converter. D. Transformer connections for a three-phase converter. The armature connections in all of the above diagrams are for two-pole machines.

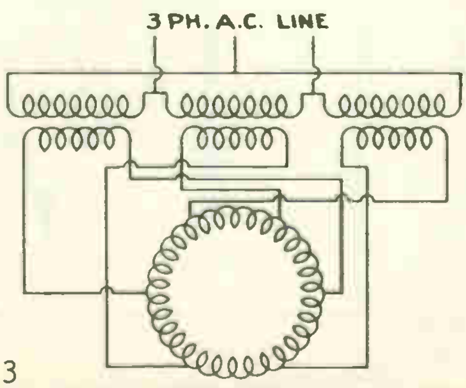
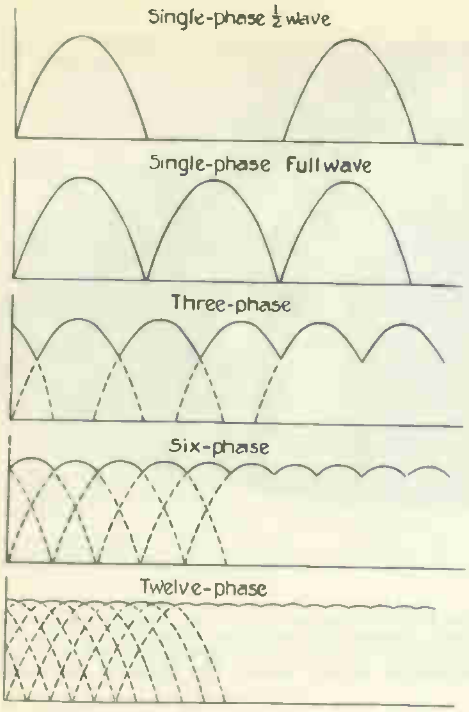


Fig. 3

6 PH. CONVERTER CONNECTION



COMPARISON OF RIPPLE IN D.C. OUTPUT FOR VARIOUS NUMBER OF PHASES

Fig. 5

These sine wave diagrams show the amount of pulsation or ripple in rectified D.C. from units operating on different numbers of phases. Note the much smoother voltage curve obtained with the six and twelve phases.

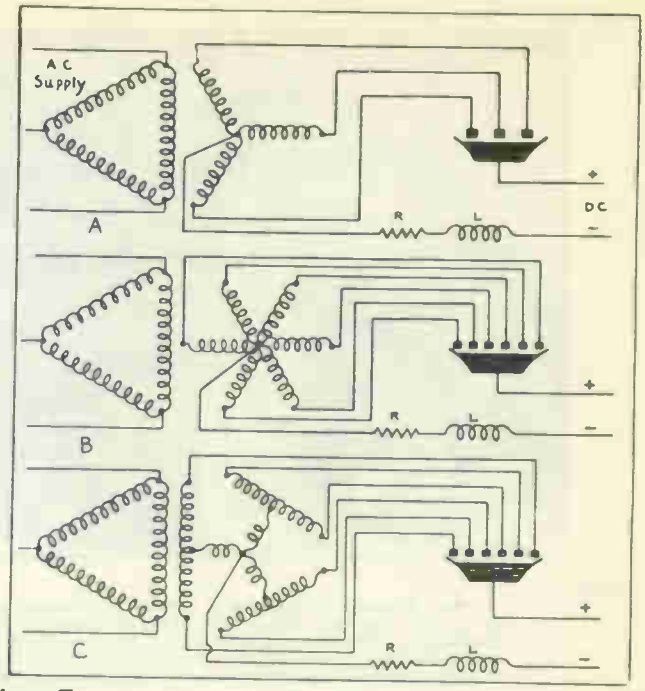


Fig. 7 The above diagrams show three different types of transformer connections which are commonly used with three-phase and six-phase mercury arc rectifiers.

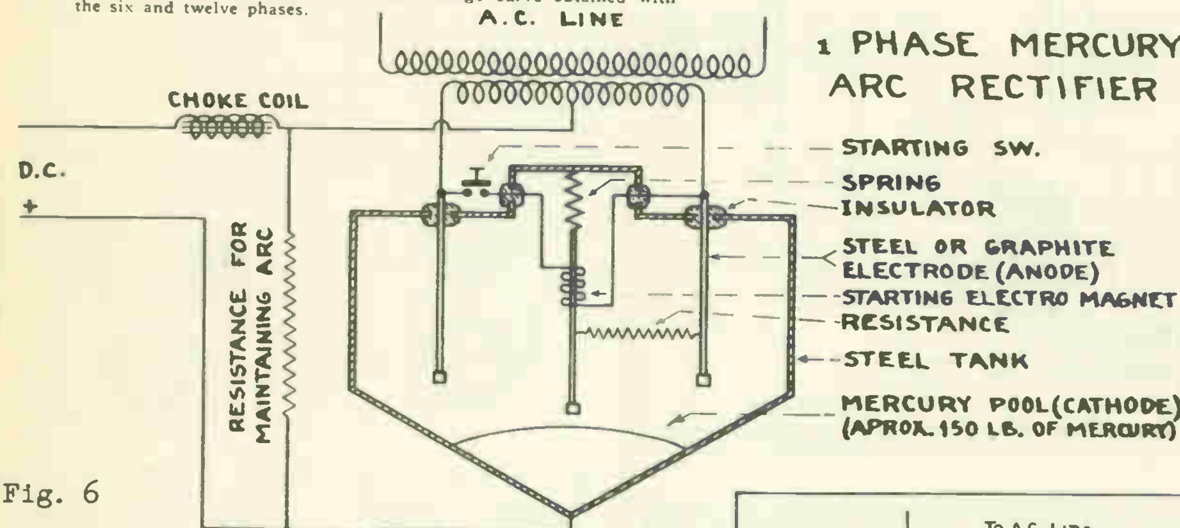


Fig. 6

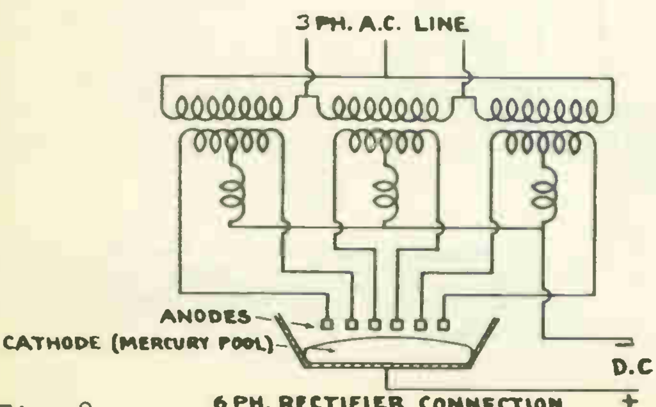


Fig. 8

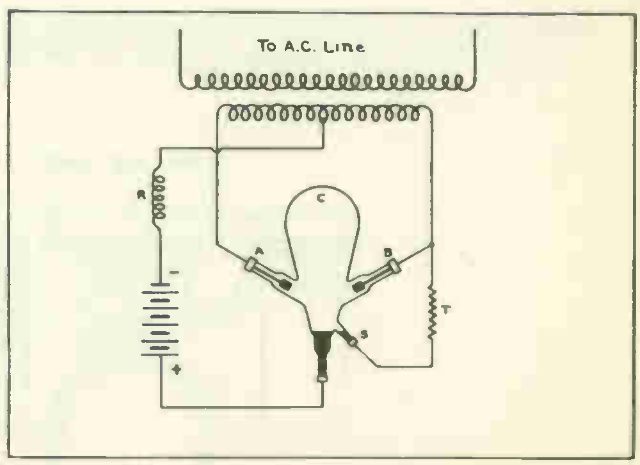


Fig. 9 Circuit diagram of a bulb type mercury arc rectifier used for battery charging purposes.

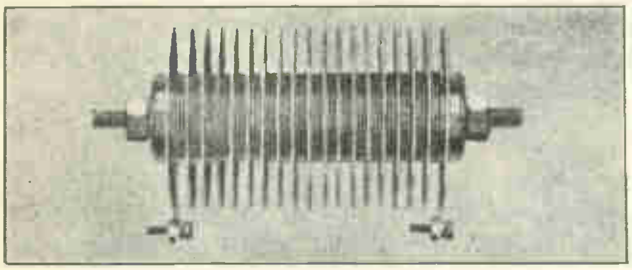


Fig. 10. Single unit of a copper oxide rectifier, consisting of a number of copper disks coated with copper oxide and clamped into one series group. Current can only pass through these devices in one direction.

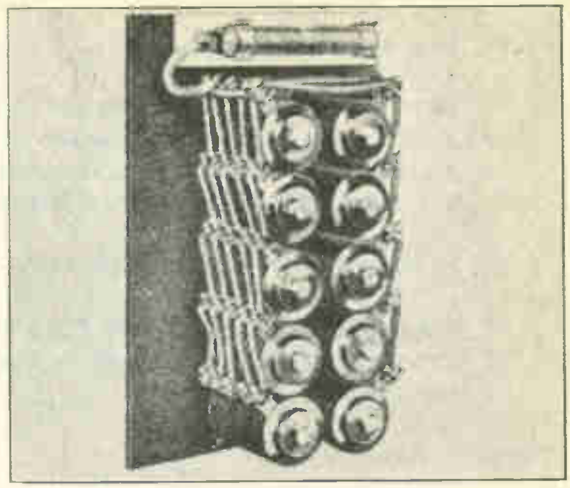


Fig. 11. Copper oxide rectifier consisting of a number of units connected in series and parallel to obtain increased voltage and current capacity.

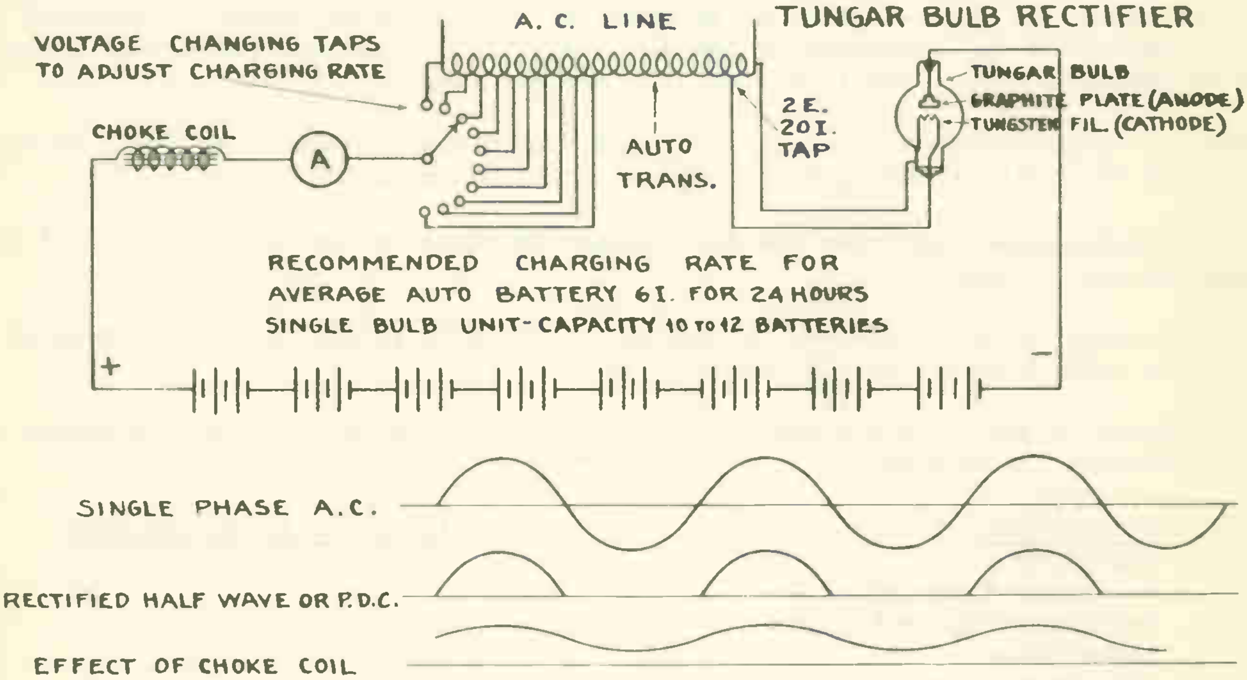


Fig. 12

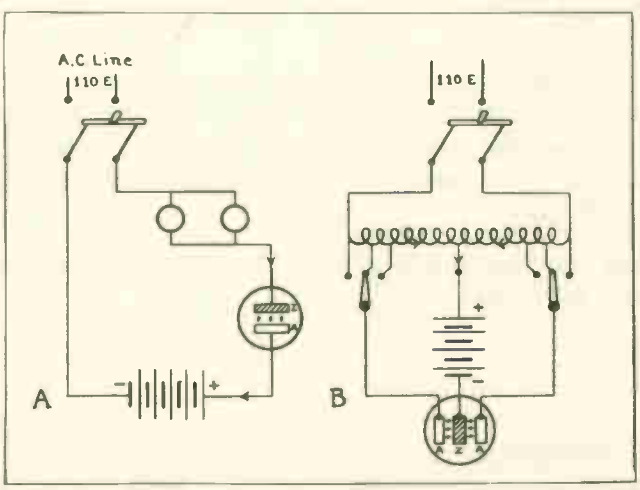


Fig. 13A shows a half-wave, electrolytic rectifier and B shows an electrolytic rectifier of the full-wave type. Current can only pass through these devices in one direction.

6. Dry disc rectifiers, Fig. 10 and 11.

   Two common dry disc rectifiers in use are the copper - oxide and the selenium-iron type. The efficiency of these two units is from 40 to 60%. For a full explanation as to application, description, and resistance analysis, refer to the next department (Industrial Electronics).

7. Electrolytic rectifiers

   Comparison of half and full wave rectifiers of this type is shown in Fig. 13. Trace current paths and notice flow is in one direction through this type of rectifier.

D. Voltage Ratios

The adjustment of the d-c output voltage of synchronous converters over any considerable range is generally accomplished by means of voltage regulators or tapped transformers on the a-c side, or by means of a d-c booster generator attached to the same shaft and connected in the d-c circuit. A-c booster converters or generators are also often used in series with the a-c supply.

The d-c output voltage of synchronous converters depends almost entirely on the applied a-c voltage and upon the type of armature connections used.

In a single-phase converter the d-c voltage is equal to the maximum value of the applied a-c voltage.

For example, if 100 volts a-c is applied to the slip rings, the d-c voltage at the brushes will be equal to $\frac{100}{.707}$, or 141.4 volts.

The ratios of a-c to d-c voltages which are obtained with different converter connections are as follows:

Connections	Ratio of a-c to d-c voltage
one-phase	.707
two-phase diametrical	.707
two-phase adjacent taps	.5
three-phase	.612
six-phase diametrical	.707
six-phase adjacent taps	.354

The three-phase and six-phase diametrical connections are the ones most commonly used in power converters. To determine the d-c voltage output of a three-phase machine we simply divide the a-c voltage applied to the slip rings by 0.612. For example, if 370 volts a-c is used to operate the converter, we will obtain $\frac{370}{.612}$, or approximately 604 V. d-c.

If we apply 440 volts a-c to a six-phase diametrical converter, we will obtain $\frac{440}{.707}$, or approximately 622 volts d-c.

E. Summary Questions

1. What is a rotary converter?
2. Why are some rotary converters designed for six-phase?
3. What is the relationship between a-c and d-c voltages on a single phase rotary converter?
4. What is meant by a "mercury pool" tube?

JOB SECTION
STUDENT MANUAL

COYNE ELECTRICAL SCHOOL

CHICAGO, ILLINOIS

TABLE OF CONTENTS

THREE PHASE STATOR WINDING

Objective

To learn rewinding and connecting for a 3-phase stator containing 36 slots, 6 poles with a coil span of 1 to 7.

References:

Tools, Equipment and Materials

1. An a-c stator tool kit
2. An a-c stator
3. Cotton sleeving, manning paper and replacement coils if required

PRECAUTION: Be sure to displace the phases 120°.

Procedure Steps

1. Obtain stator at desk area by signing the register.

2. Remove slot wedges; cut all stubs and jumpers.

3. Remove coils by lifting up top side of 6 coils, then remove coils, in turn, one at a time. Check each coil for number of turns and condition. If damaged, or the number of turns is less than 20, exchange for a new coil. Provide new leads six inches in length for each coil. Secure leads by wrapping 3 turns of each around end of coil.

4. Inspect all slot insulation; if damaged, replace with new material. Cuff each piece at both ends, and form to approximate shape of slot by bending it around some round object such as a pencil.

5. Install 1st coil group (2 coils, bottom side only) in any 2 adjacent slots. Make stub connection between 1st and 2nd coil, (finish lead of 1st to start lead of 2nd). Do not shorten leads for stub, leave full length. Identify top and bottom leads of 1st group with red sleeving. Tie a knot in top lead (start of group) and twist a loop in bottom lead (finish of group).

6. Proceed in a counter-clockwise direction, repeat the above procedure for 2nd and 3rd groups, with different color sleeving on each group. Be careful to connect coils of each group for the same polarity.

7. Install 4th group in slots 7 and 8, also place top coil sides in slots 1 and 2 on top of 1st group. Leave top coil side of 1st 6 coils (3 groups) up out of slots until all coils have been installed.

8. Check each group for continuity and accidental grounds as they are placed in slots. (use test lamp on 110 volt d-c supply at the table).

9. After 8 coils have been installed in stator, with group connections properly identified, have the stator checked by an instructor and receive job card credit for this step.

10. Complete installation of winding in stator, and arrange group connections with all top leads straight out from the stator core, all bottom leads bent around the edge of the frame. Have the stator checked by an instructor and receive the second job card credit.

11. Connect groups of "A" phase in series (bottom to bottom, top to top) as illustrated by the diagram given in lecture.

12. Check for continuity. Connect "start" and "finish" leads of the phase winding to d-c supply and test polarity with magnetic compass. (This test should show six alternate "N" and "S" poles). Have this connection checked by an instructor and receive third job card credit.

13. Connect groups of "B" and "C" phase in series, using top lead of group 3 for "B" start, top lead of group 5 for "C" start. Test polarity of each phase with magnetic compass.

14. Connect phases "star" and test on 3 phase circuit at test bench for operation with the rotating compass.

15. Answer the questions and have the instructor check your work.

Questions

1. T (X) F ( ) Each slot contains two coil sides in a double-layer winding.

2. T ( ) F (X) Electrical degrees per pole is always equal to 90.

3. T (X) F ( ) Full pitch coil span equals 180°.

4. T ( ) F (X) Magnetic effects produced by full pitch coil span will be negligible.

5. T ( ) F (X) The coils of each pole phase group must be connected in parallel with each other.

6. T ( ) F (X) In a 54 slot, 6 pole, 3 phase stator, the number of coils per pole phase group will be 9.

7. T (X) F ( ) A stub connection is formed by connecting the bottom coil side lead to the top coil side of the lead adjacent to it.

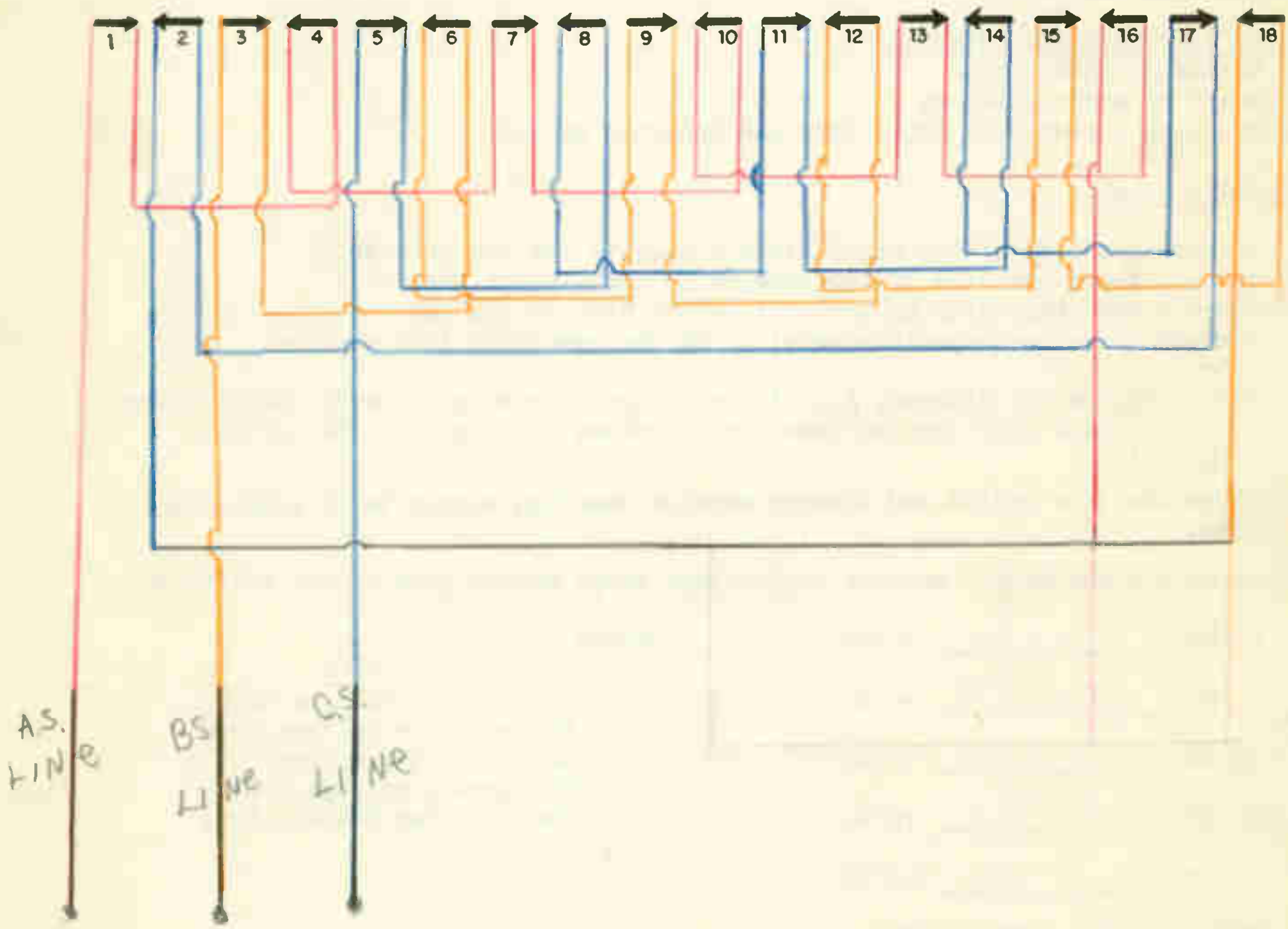
8. T (X) F ( ) Phase windings are displaced 120° by using the top coil side leads of groups 1-3-5 for start leads of A-B-C phases.

9. T ( ) F (X) Polarity tests are made by applying AC to the winding.

10. T (X) F ( ) Test for grounds may be made between the winding connections and the stator core.

11. T ( ) F (X) Tests for shorts between coils should be made after all connections have been completed.

12. T (X) F ( ) The stator just completed, may be used on any suitable transmission frequency, provided the voltages are not excessive.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BS LINe
C.S. LINe

IMPEDANCE TESTING

Objective

To gain knowledge concerning impedance, inductive and capacitive reactances.

References

Average Time Required:

Tools, Equipment and Materials

1. Necessary hookup wire
2. Board of mounted meters
3. One each - resistor, capacitor, and inductor or coil

Procedure Steps:

1. Connect one side of the available a-c line to the a-c ammeter.
2. Connect the other side of the ammeter to one side of the coil.
3. Connect the other side of the coil to one side of the capacitor.
4. Connect the other capacitor terminal to the remaining line terminal.

.NOTE: Follow the diagram, Fig. 1, very carefully so as to avoid meter damage. Recheck your work at least once, before closing the line switch.

5. Close the line switch and observe ammeter reading, should be 20 amperes or less.

6. Using the voltmeter, measure the voltage drops across each of the following:

a. ER= 200E volts.

b. EC= 145E volts.

c. EL= 220E volts.

d. ET= 240E volts.

e. Eam.= 0E volts.

where=

ER resistor voltage drop
Ec capacitor voltage drop
EL coil voltage drop
ET circuit voltage drop
Eam. Ammeter Voltage drop

7. Calculate the various ohmic values:

(a) Xc= $\frac{\text{voltage drop across Xc}}{\text{amperes}}$ = 145E or 9.6 ohms

(b) R = $\frac{\text{voltage drop across R}}{\text{amperes}}$ = 200E or 13.3 ohms

(c) XL= $\frac{\text{voltage drop across XL}}{\text{amperes}}$ = 220E or 14.6 ohms

NOTE: From the obtained values, it is now possible to obtain the total circuit's impedance (Z) as follows:

(1) $Z=\sqrt{R^2 + (XL - Xc)^2}$

(2) $Z=\sqrt{13.3^2 + (14.6 - 9.6)^2}$

(3) $Z=\sqrt{176.89^2 + 25^2}$

(4) $Z=\sqrt{176.89 + 25}$

(5) $Z=\sqrt{201.89}$

(6) Z= 14.15 ohms.

8. The value of Z obtained in the preceeding step, may now be checked by dividing the line voltage by the ammeter reading. Errors in the instruments and in meter readings will undoubtedly cause a little variation between the two Z values. Test by using the following:

$$Z = \frac{\text{Line voltage}}{\text{Amperes}} = \frac{220}{15} \text{ or } 14.6 \text{ ohms.}$$

9. Show impedance triangle on graph in Fig. 2, using a convenient scale. Be sure to label all values given.

10. Answer review questions and have your work checked by your instructor.

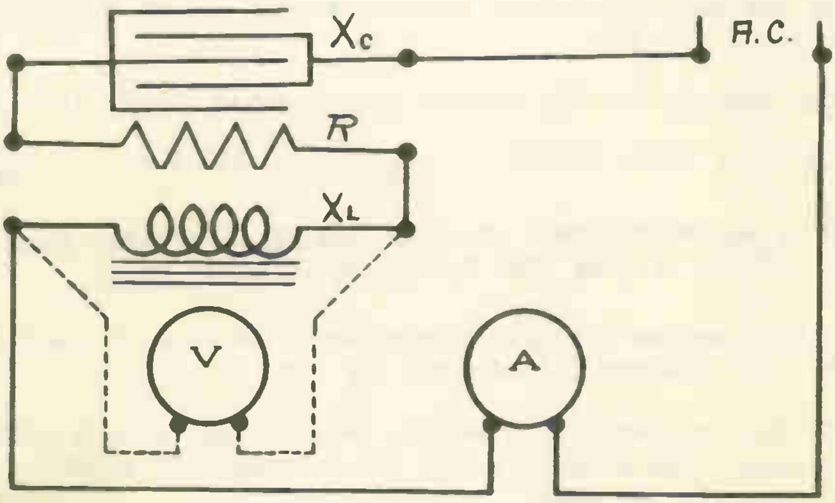


Fig.1

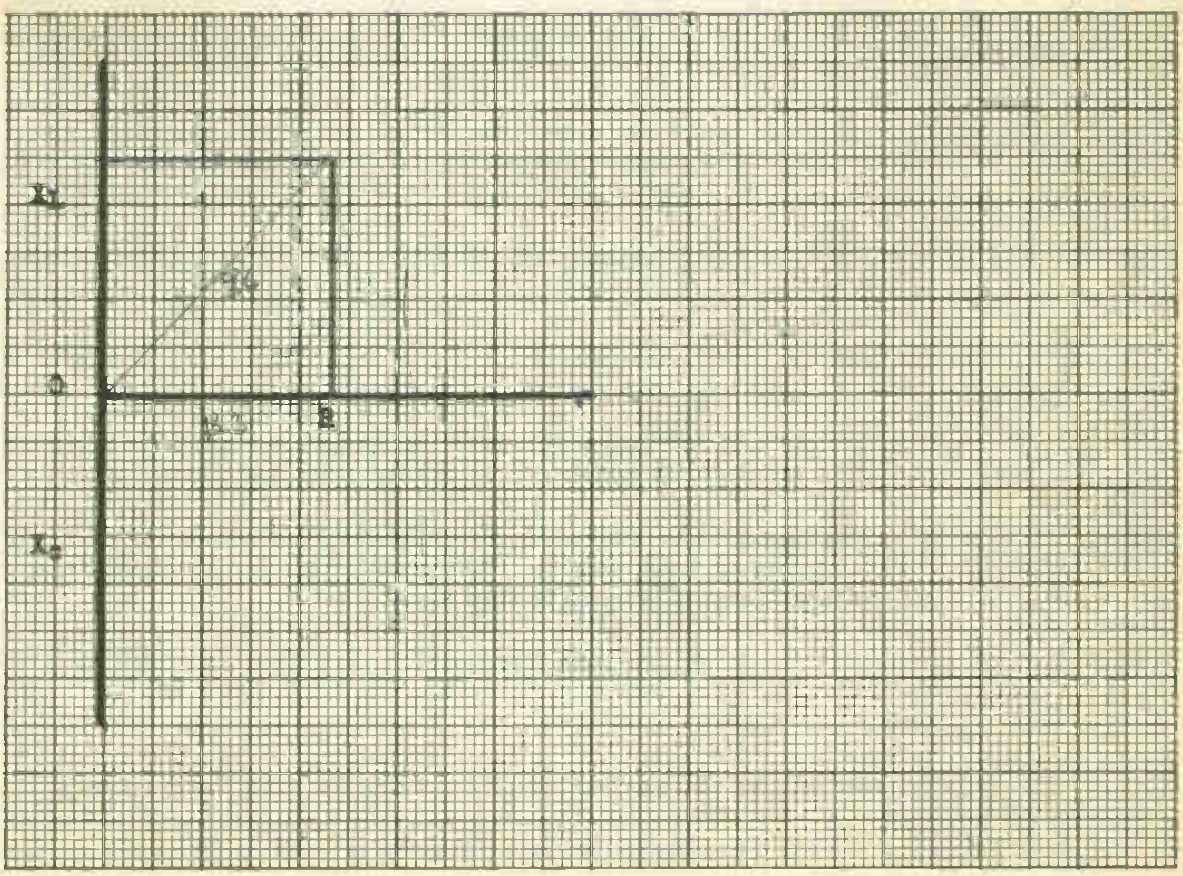


Fig. 2

1. A ( ) B ( ) C ( ) D (X) Total opposition to the flow of A C is called: (A) R (B) X_L (C) X_C (D) Z.

2. A ( ) B ( ) C (X) D ( ) The effect which causes I to lead E in the A C circuit is: (A) R (B) X_L (C) X_c (D) Z.

3. A ( ) B (X) C ( ) D ( ) The opposition of a totally inductive circuit to the flow of A C is: (A) R (B) X_L (C) X_C (D) Z.

4. A (X) B ( ) C ( ) D ( ) Which of the following causes no phase displacement in the a-c circuit? (A) R (B) X_L (C) X_C (D) Z.

5. A ( ) B ( ) C (X) D ( ) By how many electrical degrees are X_L and X_C displaced? (A) 90 (B) 120 (C) 180 (D) 360.

6. A ( ) B ( ) C (X) D ( ) The formula for X_C, when C is expressed in mf, is: (A) $X_C = \frac{1}{2\pi fc}$ (B) $X_C = 2\pi fC$, (C) $X_C = \frac{10^6}{2\pi fC}$ (D) $C = \frac{10^6}{2\pi fX_C}$

7. A ( ) B (X) C ( ) D ( ) In a series resonant circuit: (A) X_L is greater than X_C (B) X_L equals X_C (C) X_L is less than X_C (D) X_L is equal to R.

8. A (X) B ( ) C ( ) D ( ) When a series circuit is resonant, the flow of current in amperes will be: (A) maximum (B) minimum (C) zero.

9. A ( ) B (X) C ( ) D ( ) If the frequency of a series resonant circuit is either increased or decreased, the current will: (A) increase (B) decrease (C) become zero (D) remain the same.

10. A (X) B ( ) C ( ) D ( ) If the resistor of a series resonant circuit becomes short circuited, the current will: (A) increase (B) decrease (C) become zero (D) remain the same.

11. A ( ) B (X) C ( ) D ( ) If the inductance or capacitance of a series resonant circuit becomes short circuited, the current will: (A) increase (B) decrease (C) become zero (D) remain the same.

12. A ( ) B ( ) C (X) D ( ) The formula for finding the capacity of 3 capacitors connected in series is: (A) $C = C_1 + C_2 + C_3$ (B) $C = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$

(C) $C = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$ (D) $C = \frac{1}{C1 + C2 + C3}$

13. A ( ) B ( ) C (X) D ( ) The X_C of a 25 mf. capacitor on a 60 cycle circuit is approximately: (A) 81 ohms (B) 93 ohms (C) 106 ohms (D) 123 ohms.

14. A (X) B ( ) C ( ) D ( ) Decreasing the mf. capacity of a capacitor connected in series with R will cause the Ed across its terminals to: (A) increase (B) decrease (C) become zero (D) remain the same.

15. A ( ) B (X) C ( ) D ( ) When a coil with an inductance of .25 henry is used in a 50 cycle circuit the X_L will be: (A) 63 ohms (B) 78.5 ohms (C) 81.6 ohms (D) 87.5 ohms.

16. T ( ) F (X) Inductive reactance varies inversely as the frequency.

17. T (X) F ( ) Capacitive reactance varies inversely as the frequency.

THREE PHASE STATOR VOLTAGE CHANGES

Objective

To obtain practice in reconnecting a three phase stator for different operating voltages.

References

Average Time Required

Tools, Equipment, & Materials

1. Stator wound for job No. 1
2. AC stator tool kit.

PRECAUTION: Do not fail to place arrows on the "coil-groups" when making the straight - line diagrams.

Procedure Steps

1. Complete line diagram of the winding, (connected 2-circuit star).
2. Have an instructor check the diagram.
3. Connect the winding 2-circuit star.
4. Have the connection checked by an instructor.
5. Test the completed job at the lamp bank test table with a rotating compass.
6. Have an instructor check your work and questions for credit.

1. T ( ) F ( ) When reconnecting a 6 pole winding for 2 circuit, the finish of group 4 should be connected to the start of group 1 for each phase.

2. T ( ) F ( ) If designed for 440 volts, single circuit, the winding should have 220 volts applied to it.

3. T ( ) F ( ) A 660 volt single circuit delta connected stator is to be changed to two circuit star. The voltage that should be applied for normal operation is 660 volts.

4. T ( ) F ( ) If voltage requirements of the new connection are satisfied, the line current drawn will be decreased.

5. T ( ) F ( ) If the number of circuits is increased, the horsepower output will remain the same.

6. T ( ) F ( ) The speed of a motor reconnected to operate on a different voltage will remain the same.

STATOR POLE CHANGES

Objective

To learn that a different number of coils "make-up" a coil-group when winding any given stator for a different number of poles.

References:

Average Time Required:

Tools, Materials and Equipment

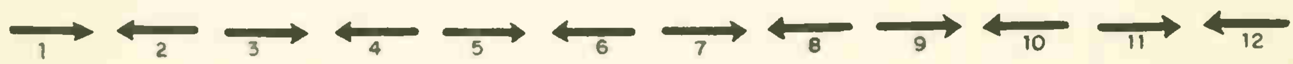
1. Stator wound for Job No. 1
2. AC stator tool kit

Precaution

After you have a good start with your "change over" (from 6 to 4 poles), check with an instructor to see that you have not misunderstood the technique.

Procedure Steps

1. Disconnect all jumper connections
2. Regroup the coils for a four-pole machine. (3 coils per group with short stubs)
3. Connect the proper coil-groups in series to form the first phase. Use short jumper connections.
4. Apply d-c to 1st phase and test polarities with magnetic compass.
5. Connect coil groups of 2nd phase in series. (Start of B 120° from start of A).
6. Test second phase by using method described in step "4".
7. Connect third phase (start of C 120° from start of B) and test.
8. Connect winding "one-circuit-delta".
9. Test the completed job, at the lamp bank test table, with a rotating compass.



10. Have an instructor check your work after you answer the following questions:

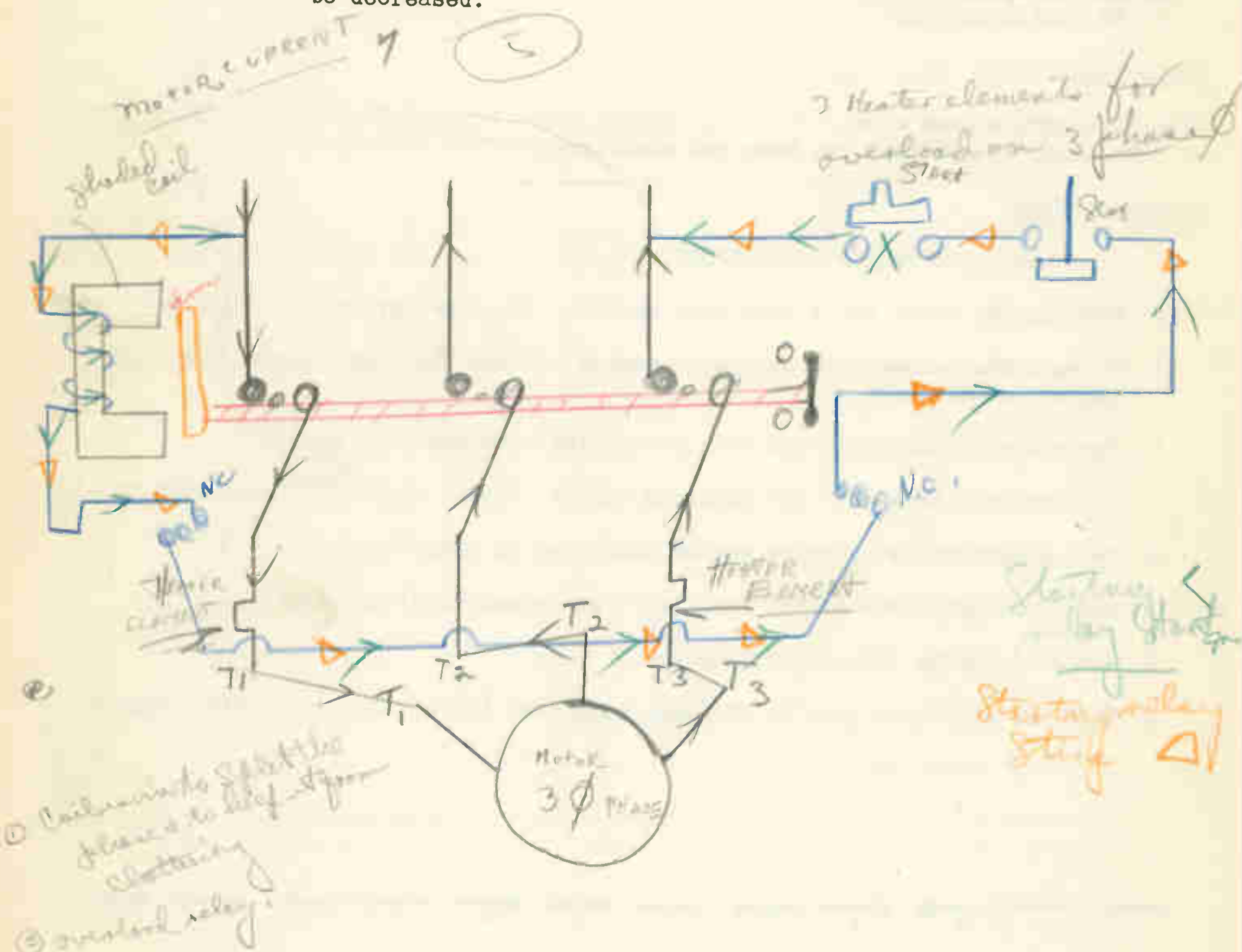
a. T ( ) F ( ) If the coil span (1:7) is full pitch for six poles, it will become fractional pitch when changed to 4 poles.

b. T ( ) F ( ) In this stator the coil spans 60° electrical in the four pole connection.

c. T ( ) F ( ) Magnetic effect equals 72% of that produced by full pitch coil span.

d. T ( ) F( ) RPM of the motor is decreased when changing from 6 to 4 poles.

e. T ( ) F ( ) The voltage applied to the reconnected 4 pole arrangement should be decreased.



ACROSS THE LINE STARTERS

Objective

To apply knowledge gained during the discussions on across the line starters. To understand the parts, purpose, and application of this popular starter for three phase motor equipment.

References

____

____

Average Time Required:

Tools, Equipment, and Material

1. Necessary hookup wire
2. Starter-motor stand with equipment mounted
3. Three fuses

NOTE: It might be well to explore all equipment used on this job, referring, when in question, to your lecture notes and the lesson on ACROSS THE LINE STARTERS.

Procedure Steps

1. Select a diagram found on succeeding pages of this job and find the corresponding starter-motor.

2. Trace all circuits on the diagram selected.

3. Check the equipment usually for possible faults, tripped overload protection, etc.

4. Wire the diagram one step at a time and complete each step begun.

5. Doublecheck your wiring and with the line switch open, insert the fuses.

6. Close line switch and operate the control.

7. Reverse the rotation of the motor.

8. Answer the questions pertaining to this job.

9. When completely finished with wiring, testing, and determining how the overload equipment works, as well as the questions, have your job checked by the instructor.

Start Relay start
Start Relay finish
Motor circuit

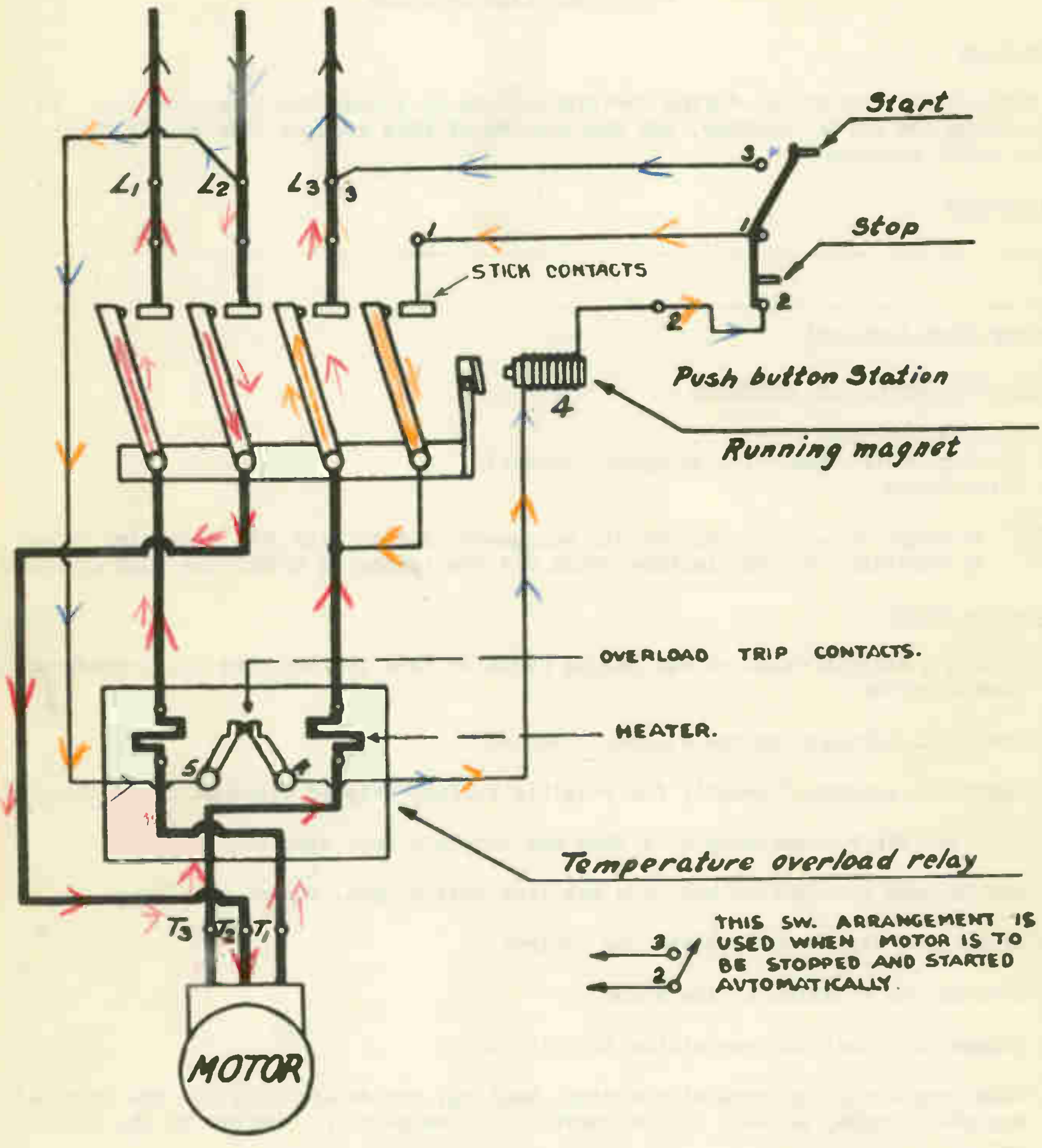


Fig. 1 Across the line starter
(General Electric)

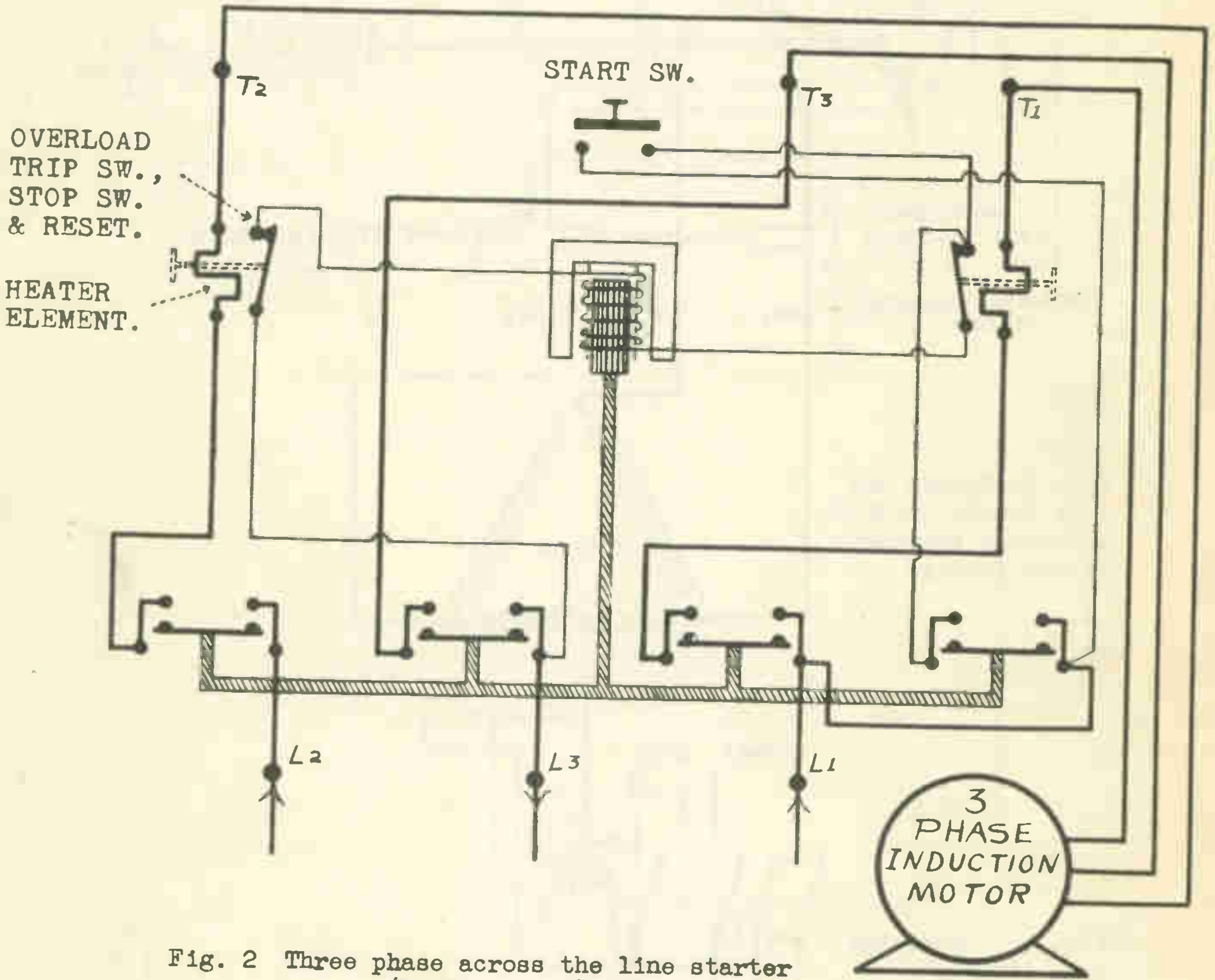


Fig. 2 Three phase across the line starter
(Westinghouse)

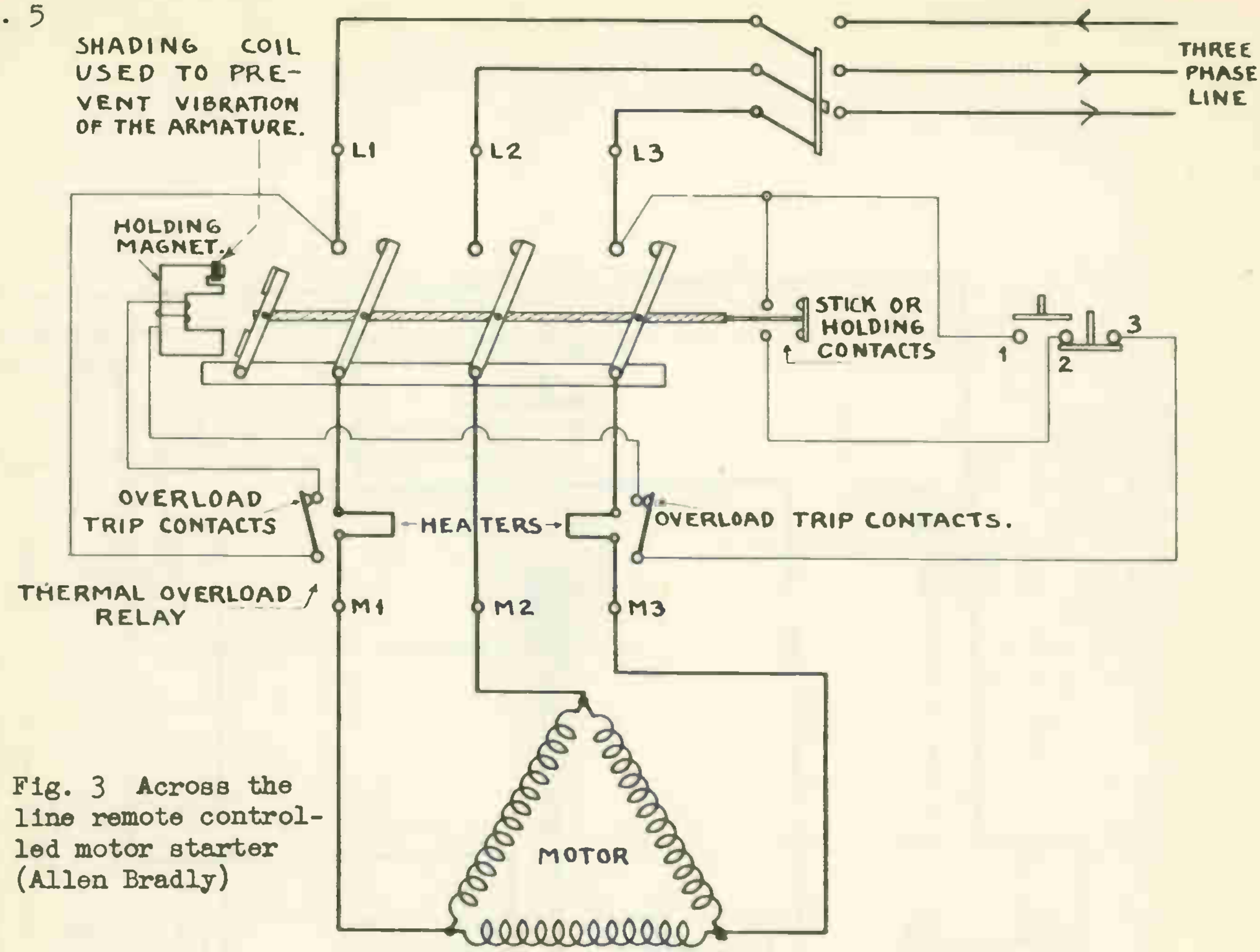


Fig. 3 Across the line remote controlled motor starter (Allen Bradly)

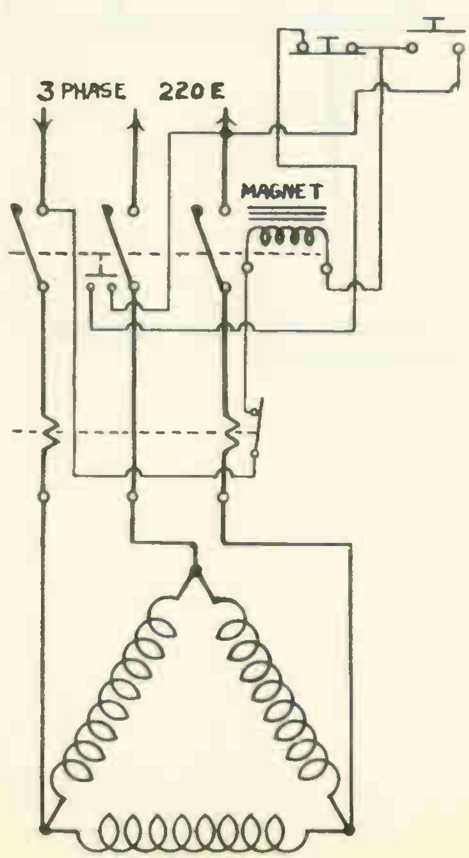


Fig. 4 Across the line starter (Westinghouse)

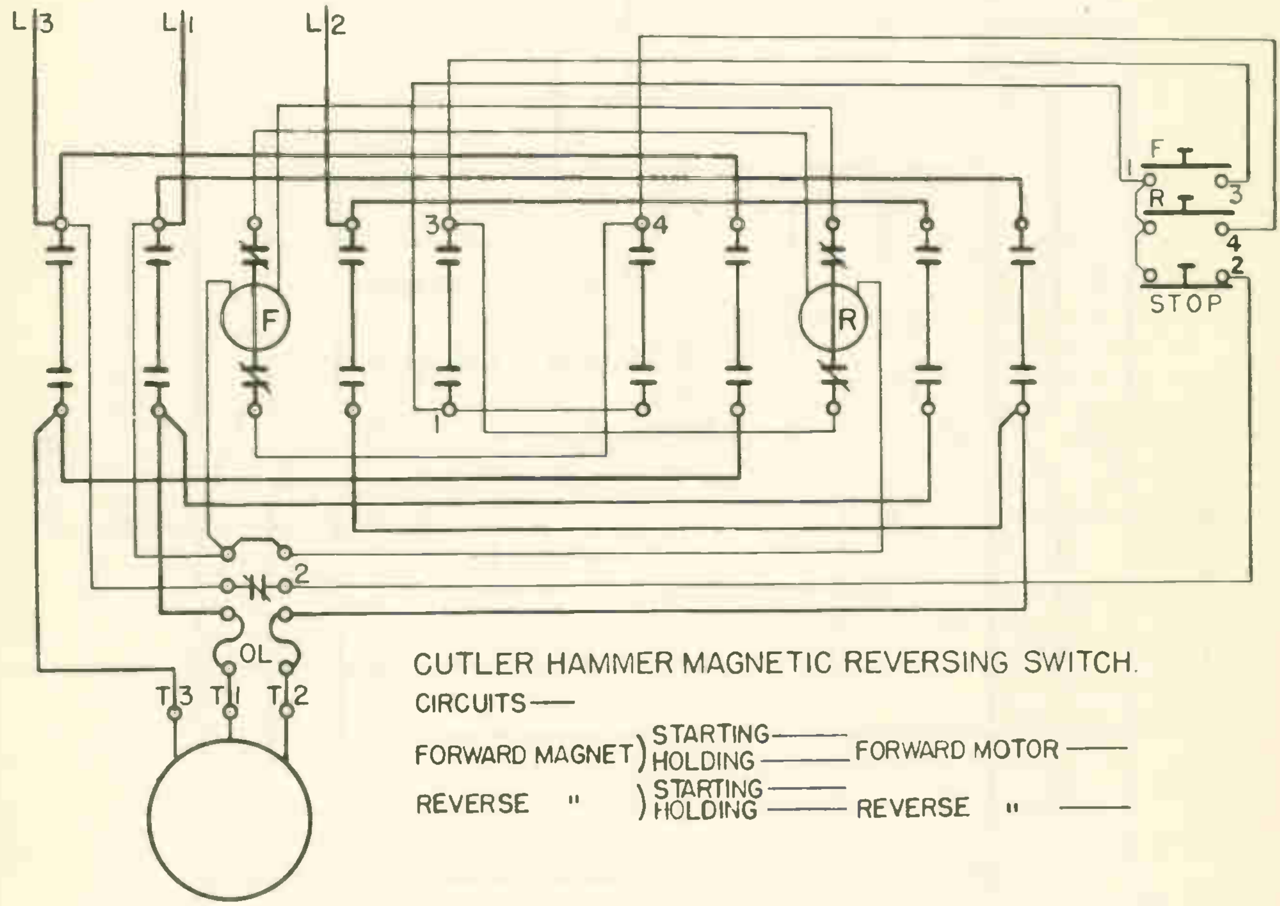

L3
L1
L2
F
R
1
3
4
2
STOP
OL
T3
T1
T2
CUTLER HAMMER MAGNETIC REVERSING SWITCH.
CIRCUITS
FORWARD MAGNET STARTING HOLDING
REVERSE " STARTING HOLDING
FORWARD MOTOR
REVERSE "

Fig. 5

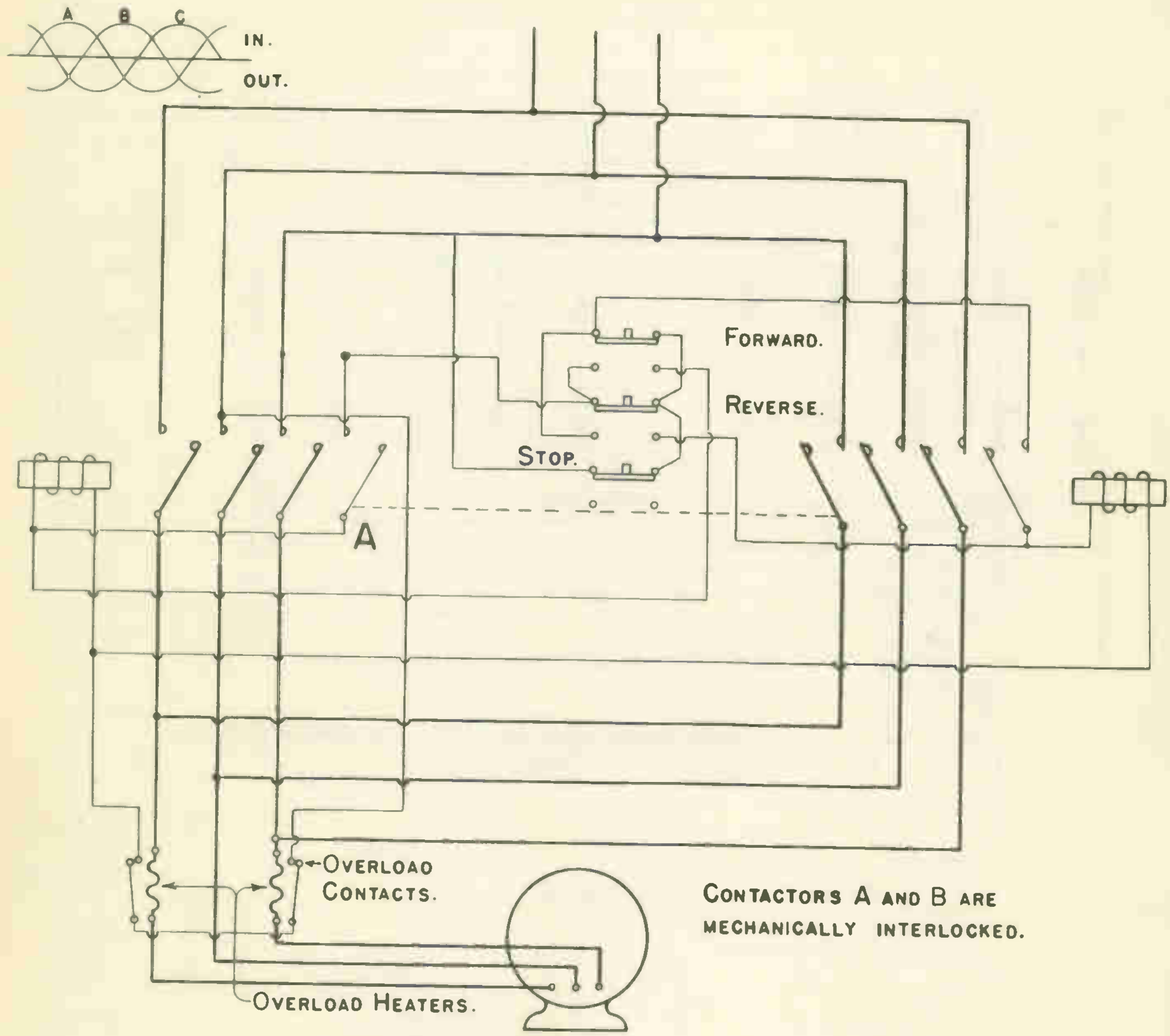

A
B
C
IN.
OUT.
FORWARD.
REVERSE.
STOP.
A
OVERLOAD
CONTACTS.
OVERLOAD HEATERS.
CONTACTORS A AND B ARE
MECHANICALLY INTERLOCKED.

Fig. 6

A ( ) B ( ) The "across the line" starter is so known because: (A) the holding
C (X) D ( ) circuit is across the line (B) the contactors are connected across the line (C) it connects the motor directly across the line (D) it reduces the voltage applied to the motor during the starting period.

A ( ) B (X) The minimum number of wires required by code rules in the remote con-
C ( ) D ( ) trol circuit is: (A) 2 (B) 3 (C) 4 (D) 5.

A ( ) B (X) Which type of overload relay is used on this starter? (A) Magnetic
C ( ) D ( ) (B) Thermal with bi-metal strip (C) Thermal with solder (D) thermal with bi-metal diaphram.

A ( ) B (X) Two overload relays provide full protection against overload in a 3-
C ( ) phase, 3 wire motor circuit because: (A) the 3rd line is neutral (B) the I of the 3rd line must pass through one of the other two (C) because they open 2 lines to the motor.

A (X) B ( ) The overload relays are connected: (A) series with the motor (B)
C ( ) series with the operating magnet (C) parallel with line.

A (X) B ( ) When an overload occurs the overload relay opens the overload trip
C ( ) contacts and interrupts the circuit for the (A) operating magnet (B) the motor circuit; (C) the line.

A ( ) B (X) The purpose of the holding circuit is to: (A) serve as an electrical
C ( ) interlocking switch (B) maintain magnet circuit independent of "start" switch; (C) reduce voltage applied to magnet.

A ( ) B (X) To reverse the rotation of a 3-phase induction motors: (A) shift the
C ( ) brushes (B) reverse any 2 motor or line leads (C) reverse or change all 3 leads.

T ( ) F (X) The holding contacts are connected parallel with the closed circuit switch of the remote control station.

T (X) F ( ) The purpose of the shading coil is to prevent vibration of magnet armature.

T (X) F ( ) Insufficient spring tension applied to main contactors will cause them to overheat when carrying normal current.

T (X) F ( ) Excessive spring tension applied to main contactors will cause vibration of magnet armature.

T (X) F ( ) A 440 volt E starter could be used on 220 volts by installing an operating magnet designed for the new voltage.

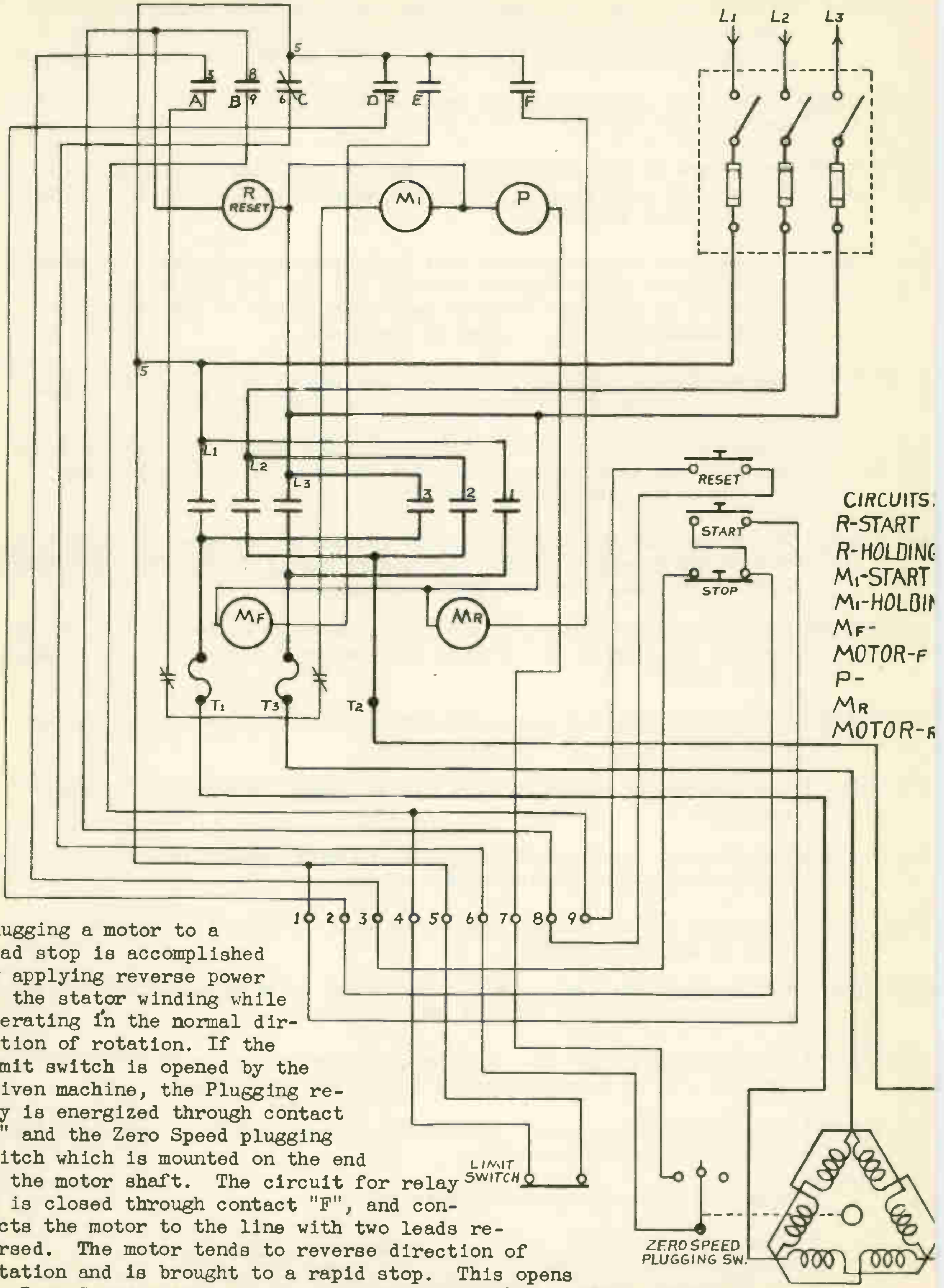
T (X) F ( ) The starting torque of a high torque induction motor with full voltage applied will be approximately 3 times full load torque.

T ( ) F (X) In multiple-place remote control the closed circuit switches are connected parallel with each other.

From the motor name-plate data determine

a. Number of poles 4   d. volts 220E
b. Stator field R.P.M. 1800   e. amps. 15
c. VA at full load 5709

PLUGGING CONTROL FOR MACHINE TOOLS, CONVEYORS, CRANES, COLLENDERS, ETC.



Plugging a motor to a dead stop is accomplished by applying reverse power to the stator winding while operating in the normal direction of rotation. If the limit switch is opened by the driven machine, the Plugging relay is energized through contact "C" and the Zero Speed plugging switch which is mounted on the end of the motor shaft. The circuit for relay M_R is closed through contact "F", and connects the motor to the line with two leads reversed. The motor tends to reverse direction of rotation and is brought to a rapid stop. This opens the Zero Speed switch and de-energizes relays "P" and "M_R". Motor operation may be resumed by closing RESET and START switches.

THREE PHASE WINDING DIAGRAMS

Objective

To learn more about three phase winding, variations and changes to be made in current paths, when different instants are chosen.

References

____

____

Average Time Required:

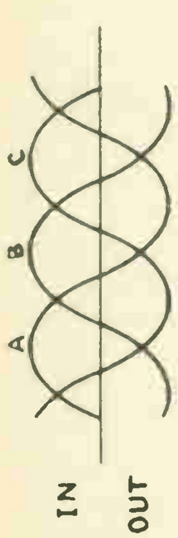
Tools, Materials and Equipment

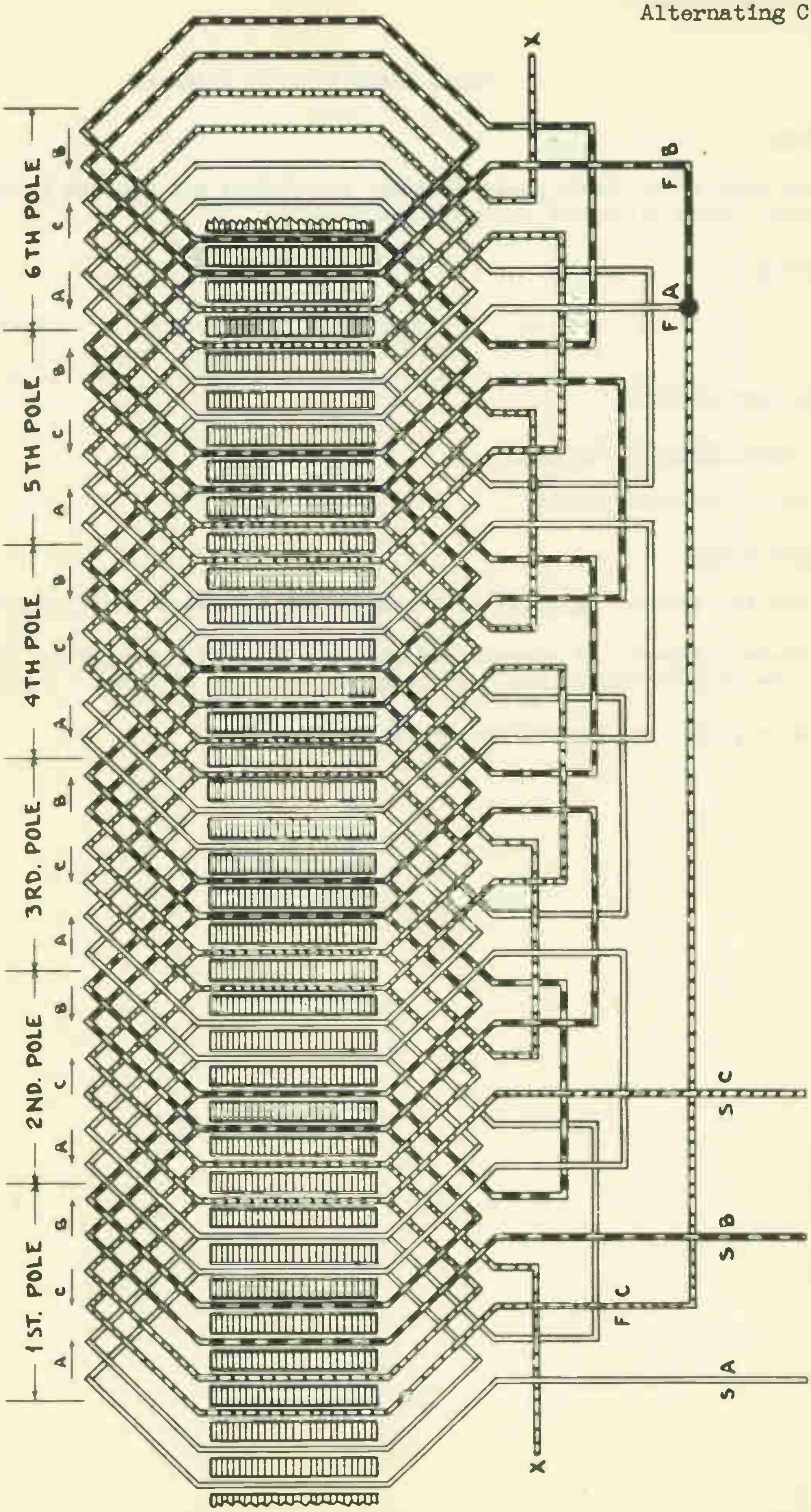
1. Set of colored pencils

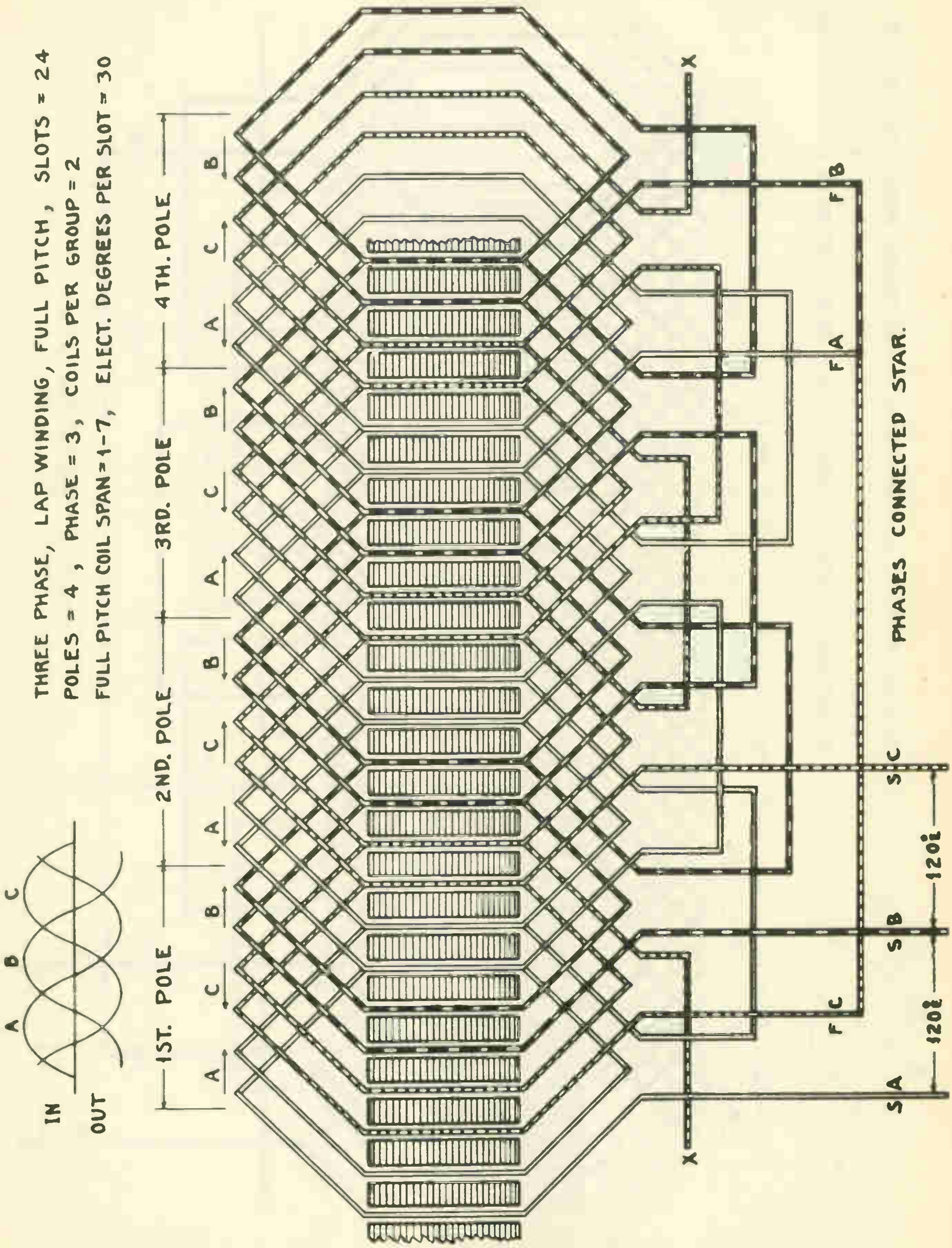
Procedure Steps

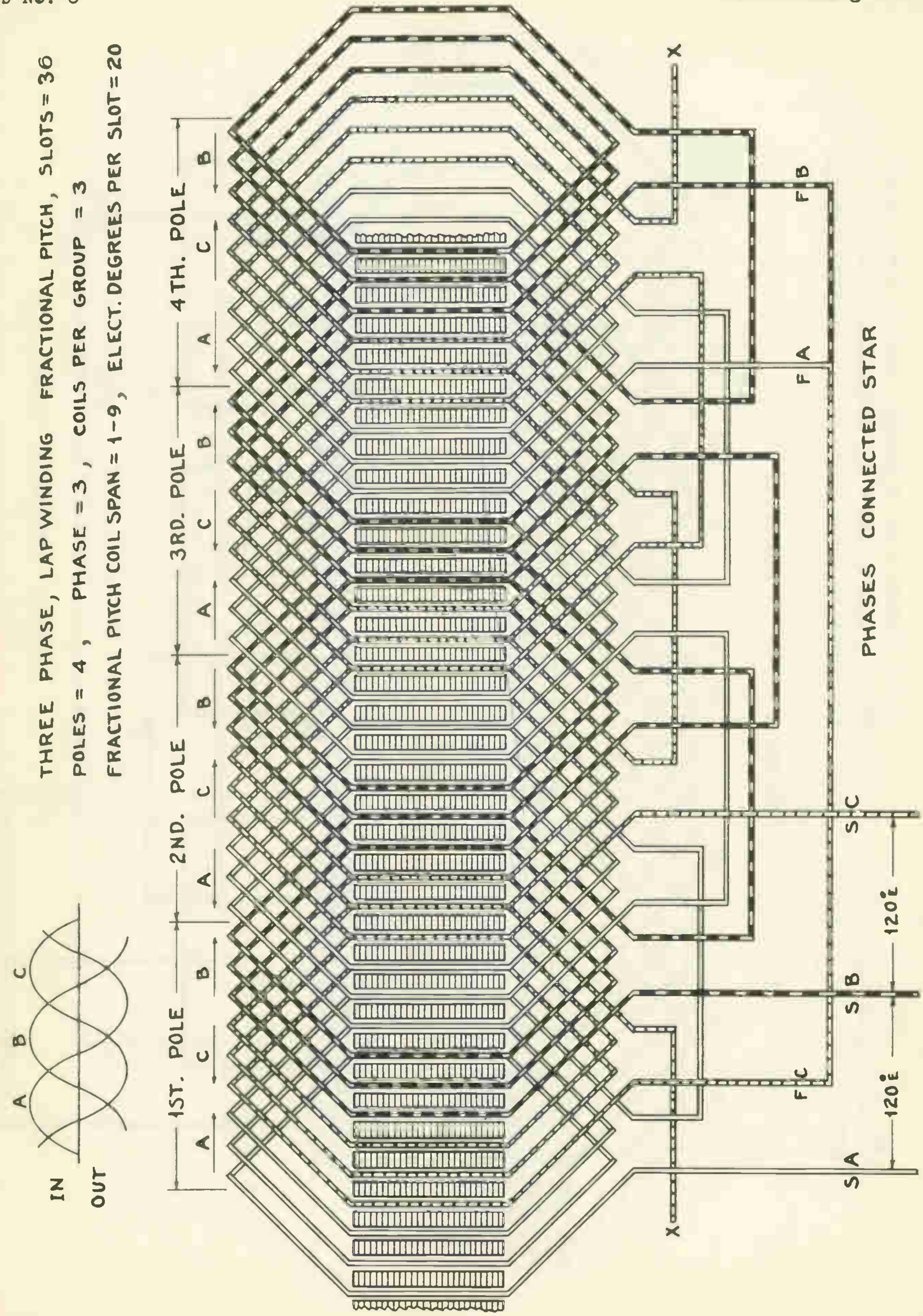
1. Use the instant selected in class period and trace the diagrams indicated.
2. Trace all paths of current and indicate direction of current for each coil side IN EACH SLOT; then, indicate the position of N and S polarities.
3. Have your work checked by the instructor.

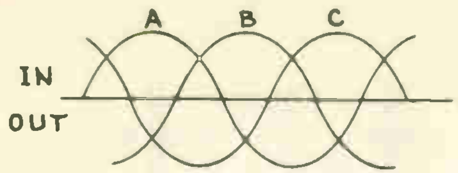
THREE PHASE, LAP WINDING, FULL PITCH, SLOTS = 36
POLES = 6, PHASE = 3, COILS PER GROUP = 2
FULL PITCH COIL SPAN = 1-7, ELECTRICAL DEGREES PER SLOT = 30



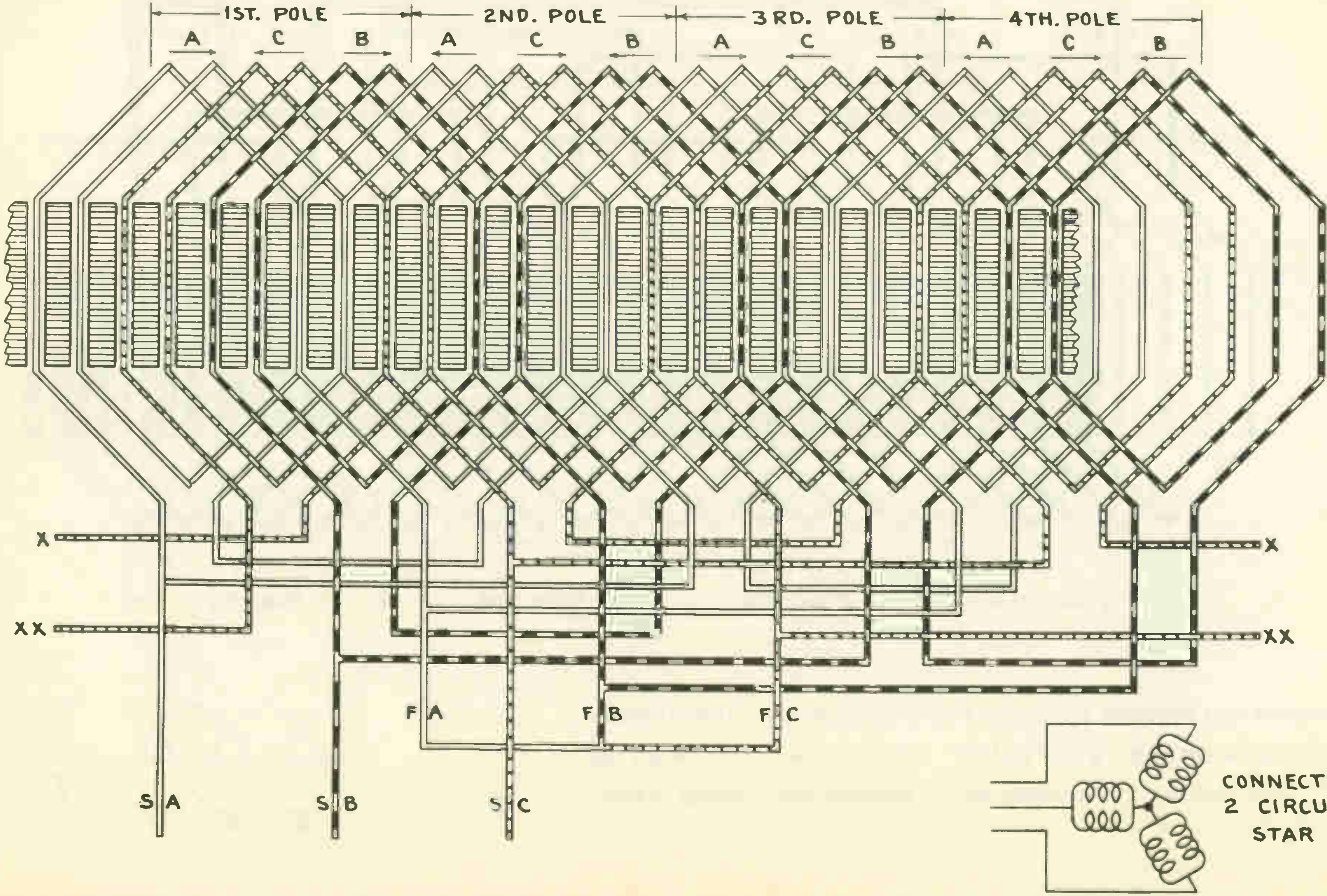



THREE PHASE, LAP WINDING, FULL PITCH, SLOTS = 24
POLES = 4, PHASE = 3, COILS PER GROUP = 2
FULL PITCH COIL SPAN = 1-7, ELECT. DEGREES PER SLOT = 30
IN
OUT
A
B
C
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
A C B A C B A C B A C B
X
X
F B
F A
F C
S C
S B
S A
120°
120°
PHASES CONNECTED STAR.

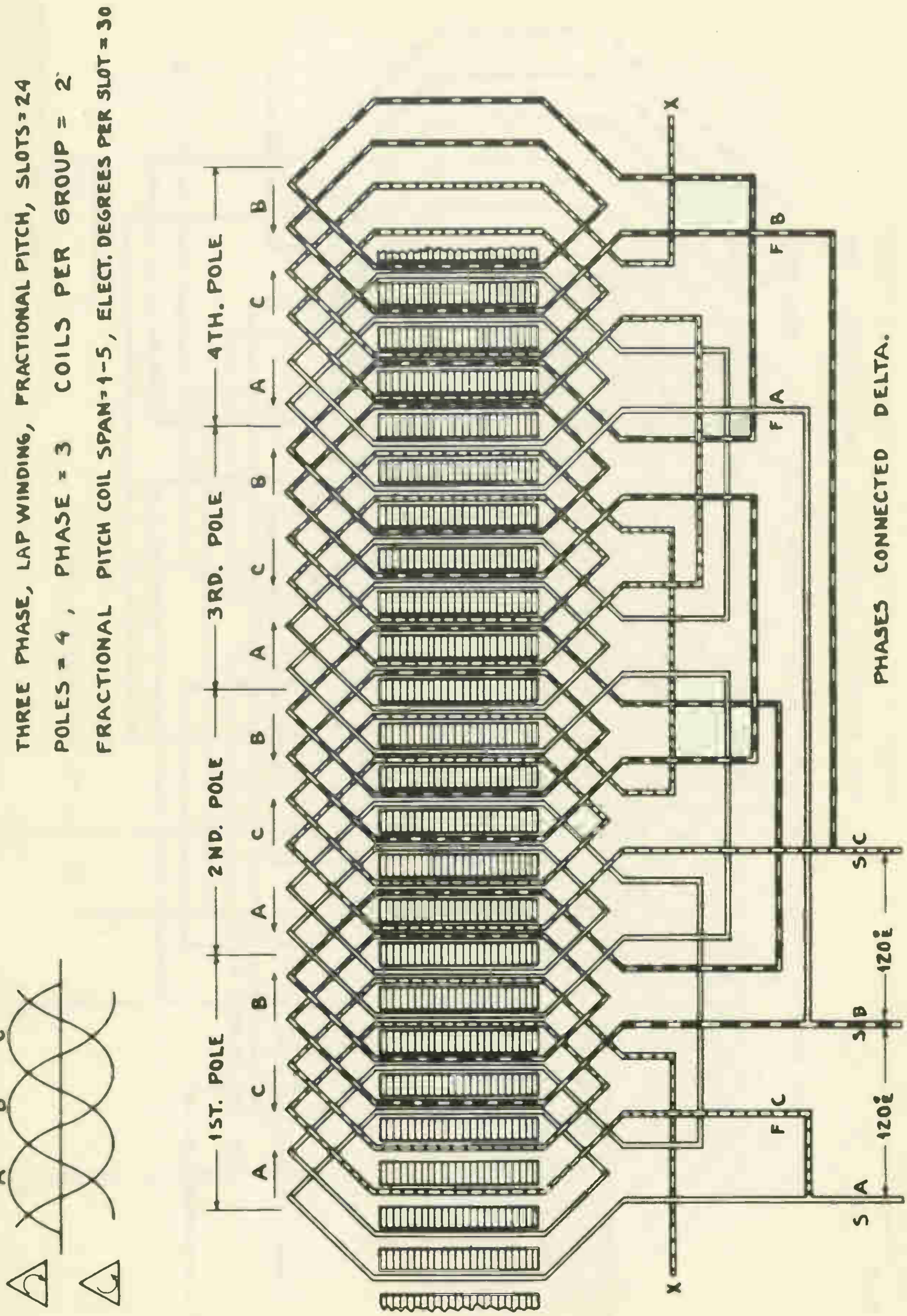

THREE PHASE, LAP WINDING FRACTIONAL PITCH, SLOTS = 36
POLES = 4, PHASE = 3, COILS PER GROUP = 3
FRACTIONAL PITCH COIL SPAN = 1-9, ELECT. DEGREES PER SLOT = 20
IN
OUT
A B C
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
X
X
F B
F A
F C
S C
S B
S A
120°E
120°E
PHASES CONNECTED STAR

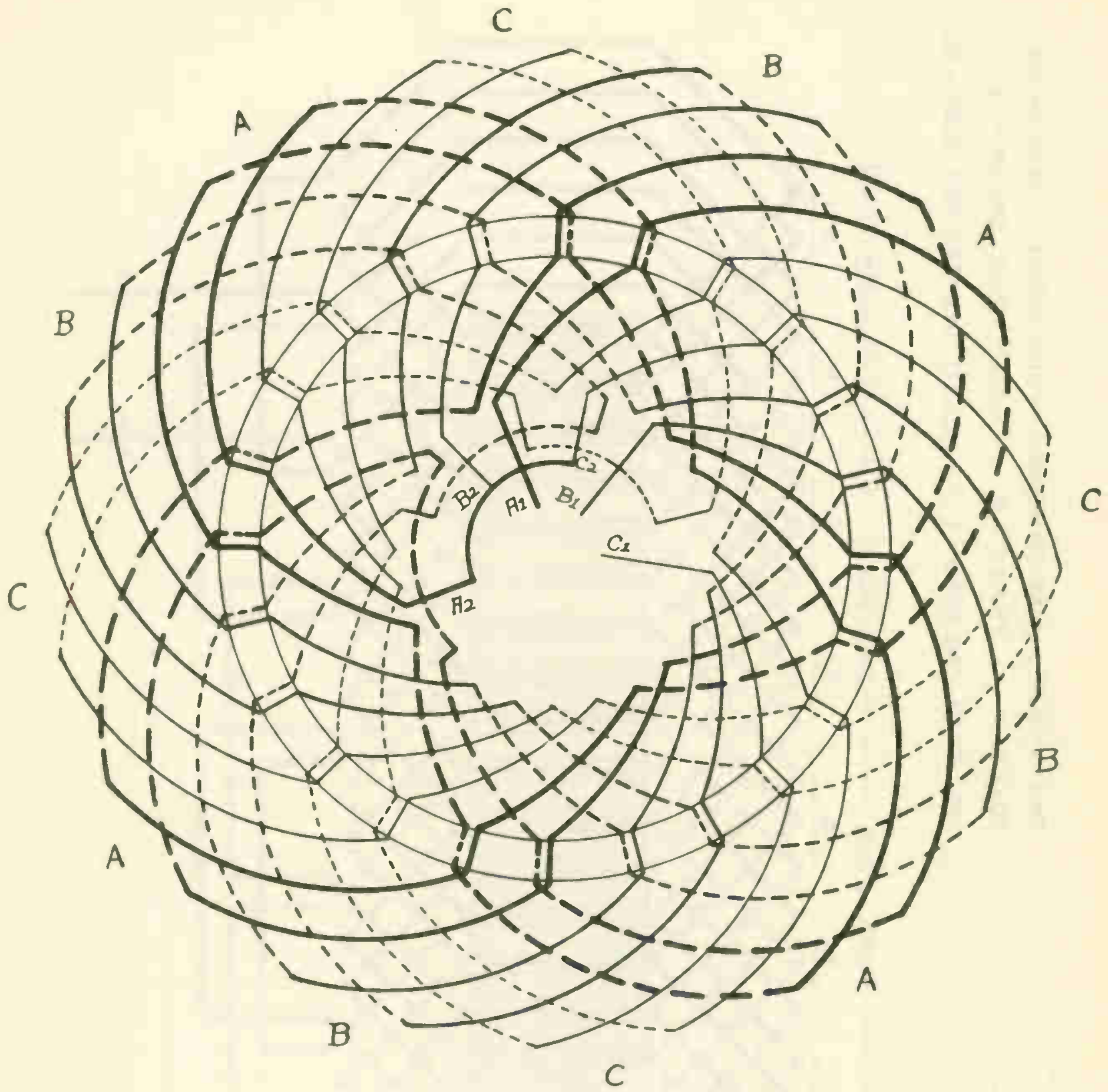


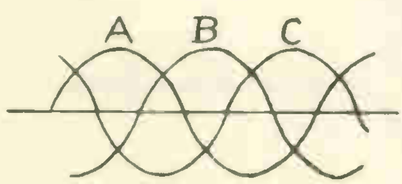
THREE PHASE, LAP WINDING, FULL PITCH, SLOTS = 24
POLES = 4, PHASE = 3, COILS PER GROUP = 2
FULL PITCH COIL SPAN = 1-7, ELECT. DEGREES PER SLOT = 30



CONNECTED 2 CIRCUIT STAR


THREE PHASE, LAP WINDING, FRACTIONAL PITCH, SLOTS = 24
POLES = 4 , PHASE = 3 COILS PER GROUP = 2
FRACTIONAL PITCH COIL SPAN = 1-5 , ELECT. DEGREES PER SLOT = 30
A B C
1ST. POLE
2ND. POLE
3RD. POLE
4TH. POLE
A C B A C B A C B A C B
X
X
S A
S B
S C
F C
F A
F B
120°
120°
PHASES CONNECTED DELTA.





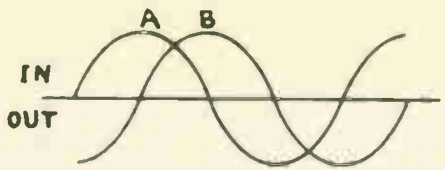
THREE PHASE, WAVE WINDING.

SLOTS = 24, POLES = 4.

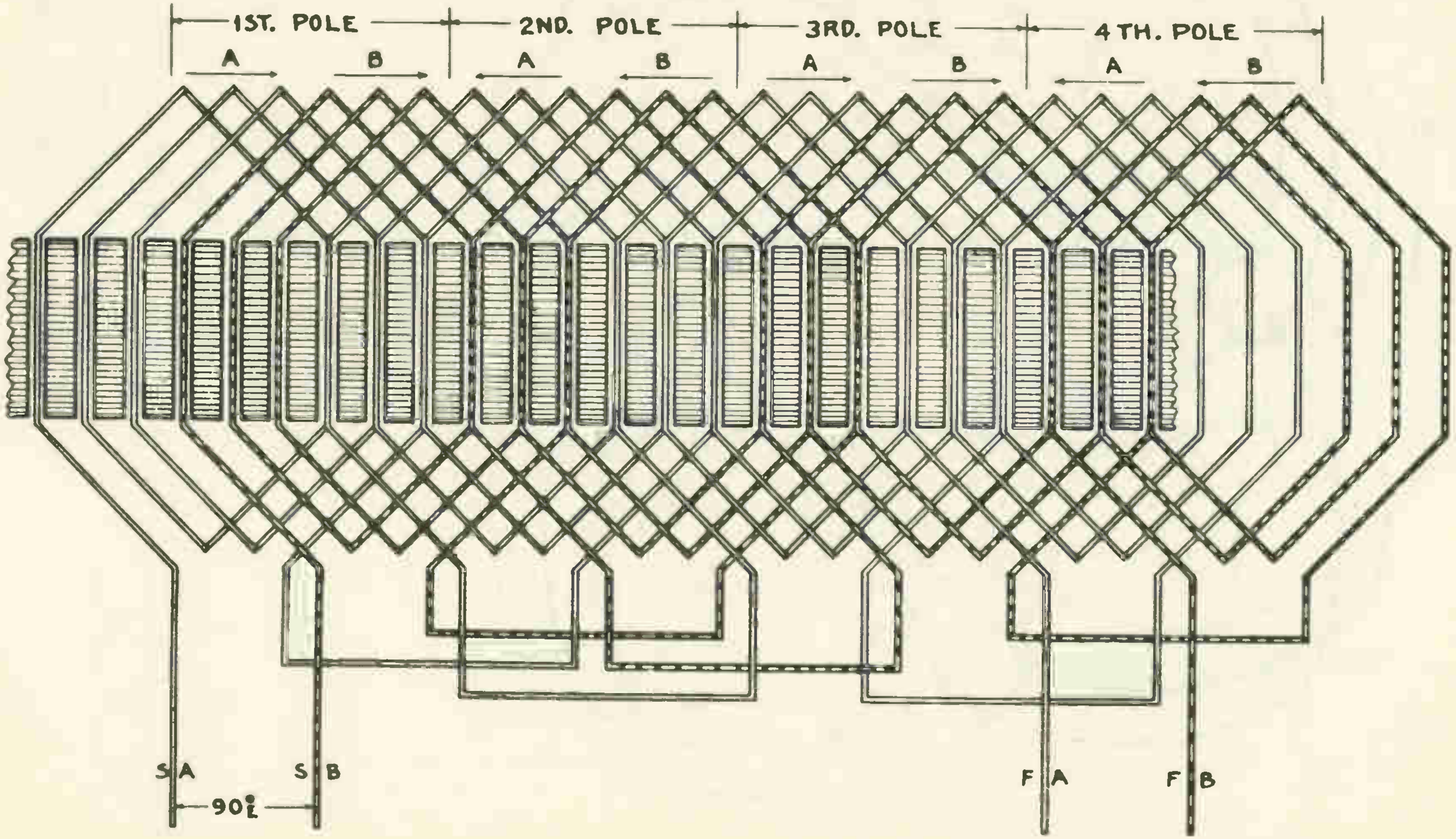
FULL PITCH COIL SPAN = 1:7.

COILS PER POLE PHASE GROUP = 2.

ELECTRICAL DEGREES PER SLOT = 30.



TWO PHASE, LAP WINDING, FULL PITCH, SLOTS = 24
POLES = 4, PHASE = 2, COILS PER GROUP = 3
FULL PITCH COIL SPAN = 1-7, ELECT. DEGREES PER SLOT = 30



CONSEQUENT POLE MOTORS

Objective

To learn more about this special type motor and the methods by which torque or horsepower may be fixed or variable.

References

Average Time Required

Tools, Equipment and Materials

1. Multi-speed motor and control
2. Set of fuses or circuit breaker

Procedure Steps

1. Review chapter on consequent pole windings as that you may refresh your memory on this special type of motor.

2. Trace all circuits on diagrams indicated.

3. Wire diagram selected and be able to explain its operation.

4. Have the instructor check your work.

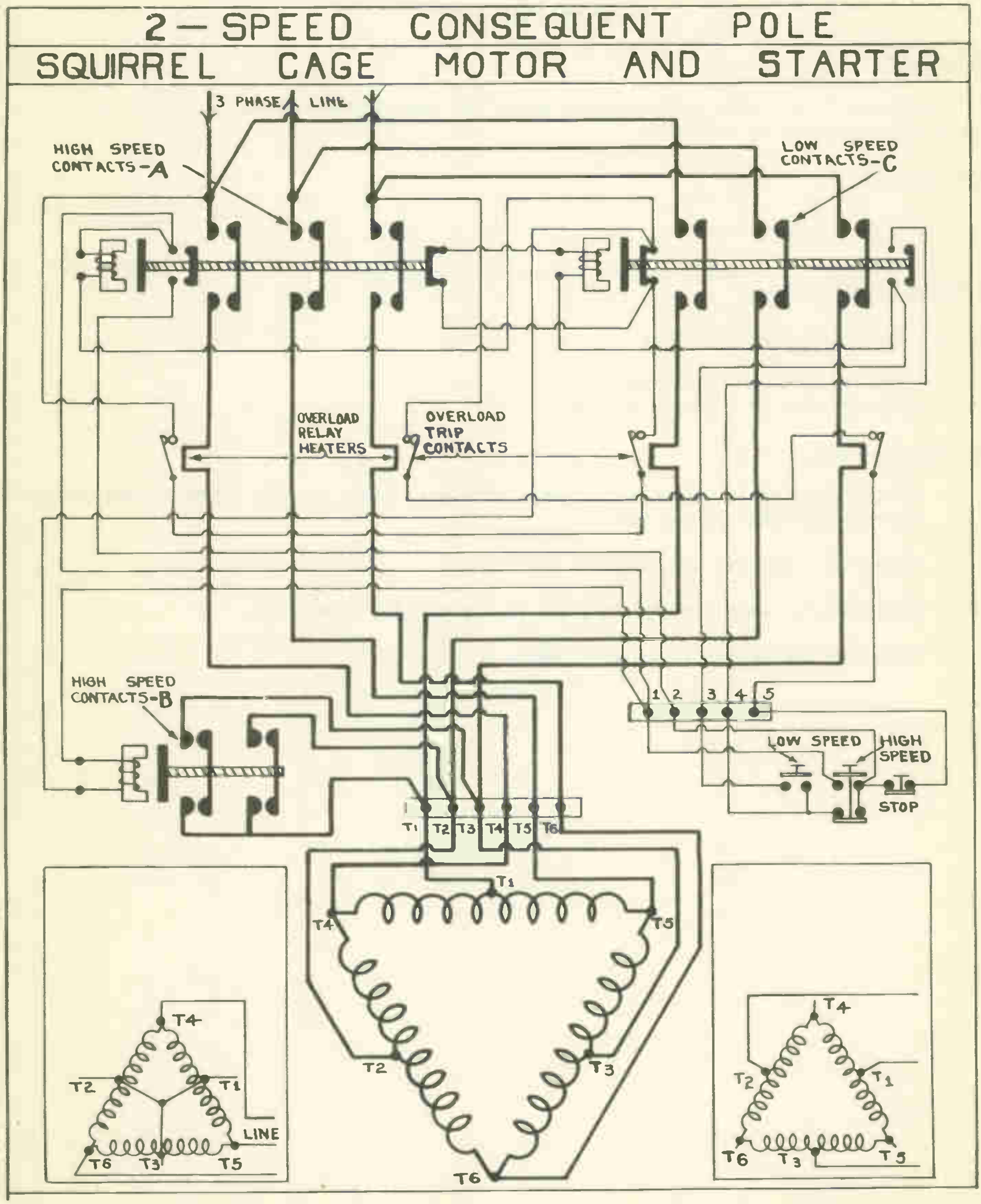

2 — SPEED CONSEQUENT POLE
SQUIRREL CAGE MOTOR AND STARTER
3 PHASE LINE
HIGH SPEED CONTACTS-A
LOW SPEED CONTACTS-C
OVERLOAD RELAY HEATERS
OVERLOAD TRIP CONTACTS
HIGH SPEED CONTACTS-B
1 2 3 4 5
LOW SPEED
HIGH SPEED
STOP
T1 T2 T3 T4 T5 T6
T1
T4
T5
T2
T3
T6
T4
T2
T1
LINE
T6
T3
T5
T4
T2
T1
T6
T3
T5

Fig. 1

CONSTANT TORQUE 4 SPEED - 2 WINDING MOTOR

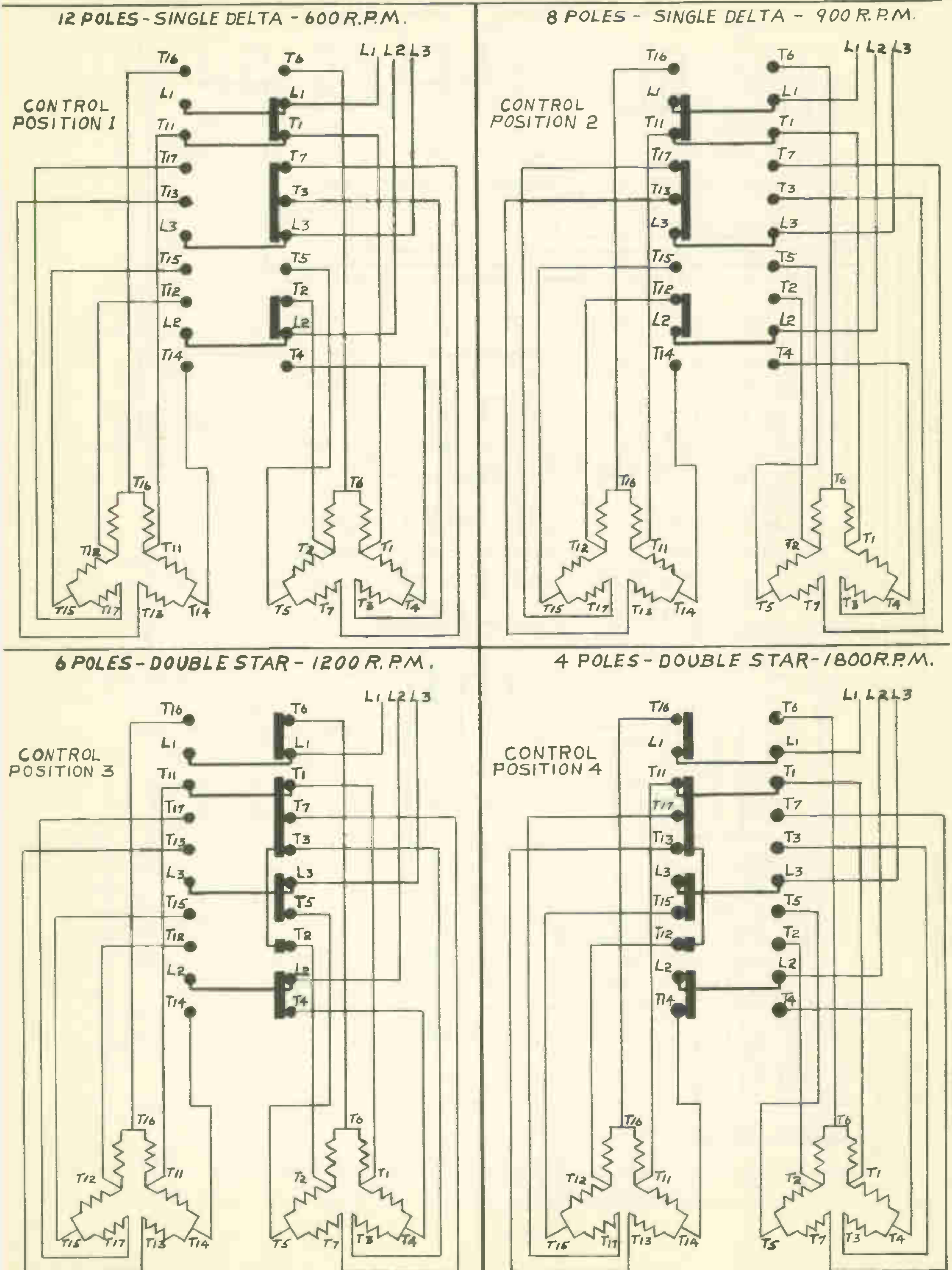


Fig. 2

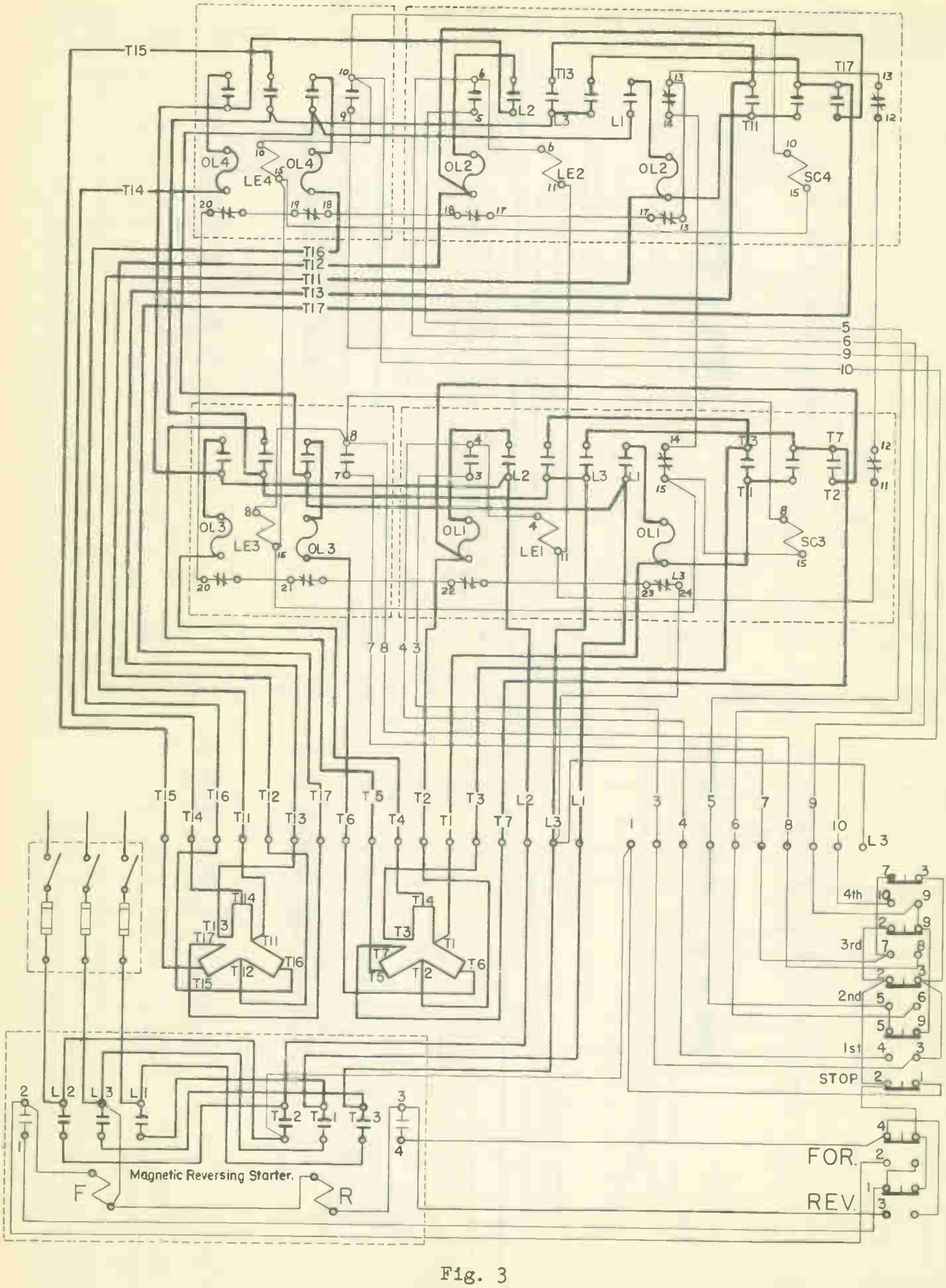
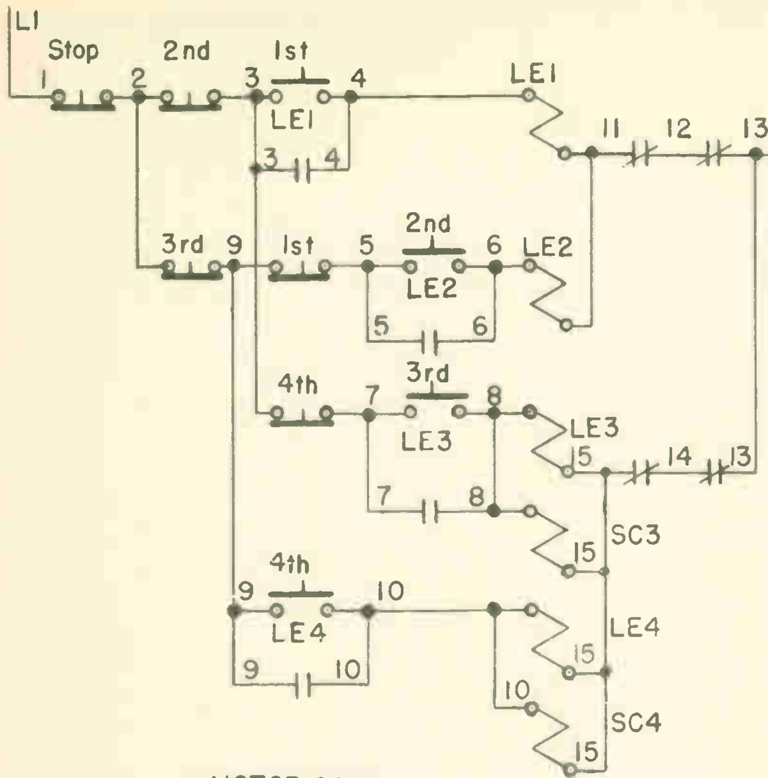


Fig. 3



NOTE-
(1) It is possible to start motor at any speed.
(2) When motor is running on a given speed it is possible to directly select only the next higher or next lower speed.

NOMENCLATURE

LE1, LE2, LE3, LE4 = Speed selector contactors.

SC3, SC4 = Short circuiting contactors.

LE1-SC3
LE2-SC4 Are mechanically interlocked.

CIRCUITS-
LE1- START ——— HOLDING ———
LE2- START ——— HOLDING ———
LE3, SC3- START ——— HOLDING ———
LE4, SC4- START ——— HOLDING ———
MOTOR- 1ST ——— 2ND ———
MOTOR- 3RD ——— 4TH ———
REVERSING STARTER-
FORWARD- START ——— HOLDING ———
REVERSE- START ——— HOLDING ———

MOTOR CONNECTIONS

SPEED	L1	L2	L3	OPEN	TOGETHER
1ST	T1	T2	T3, T7	ALL OTHERS	
2ND	T11	T12	T13, T17	" "	
3RD	T6	T4	T5	" "	T1, T2, T3, T7
4TH	T16	T14	T15	" "	T11, T12, T13, T17

Fig. 4 Elementary control for Fig. 3

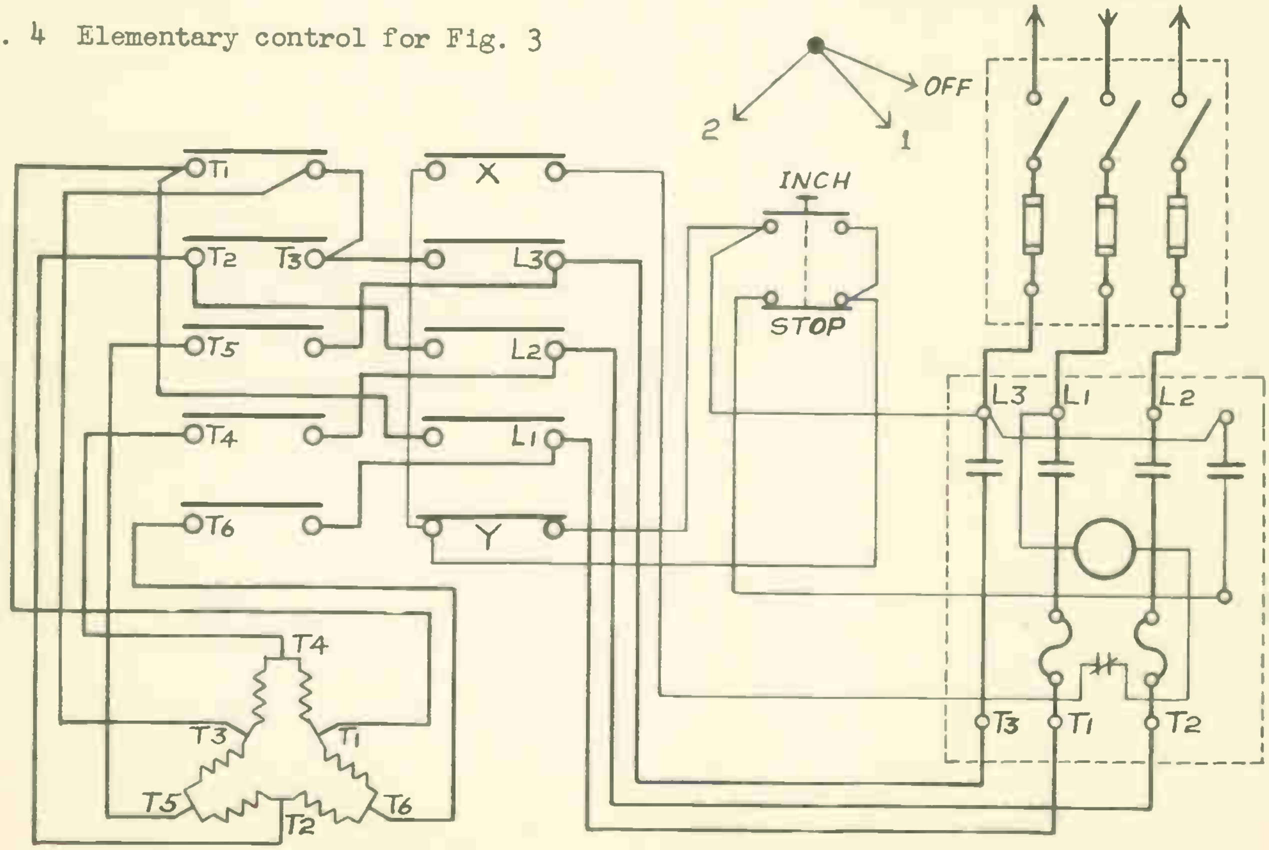


Fig. 5 Two speed motor drum control and inching control

AUTO-TRANSFORMER MOTOR STARTERS (MANUAL TYPE)

Objective

To apply the knowledge gained from across the line starters to a reduced voltage type of a starter of the manually operated style.

References:

____

____

Average Time Required:

Tools, Materials, and Equipment

1. Necessary hookup wire and fuses
2. Mounted motor-starter stand with auto-transformers installed.

Procedure Steps

1. Wire Fig. 1 on its proper stand in the department. Be sure to check and secure the connections as they are completed.

2. Check the overload equipment visually to determine how it operated, whether in the "tripped" position or in the closed position. Perform any necessary maintenance.

3. Check the percentage of tap on the auto transformers used on this job and be able to explain.

4. Trace and label each circuit.

5. When the job is completed test the equipment for proper operation.

6. Repeat steps 1 through 5 for Fig. 2.

7. Answer the questions which pretain to this job AFTER BOTH parts, Fig. 1, and Fig. 2 have been wired and checked.

8. Have an instructor check your answer sheet.

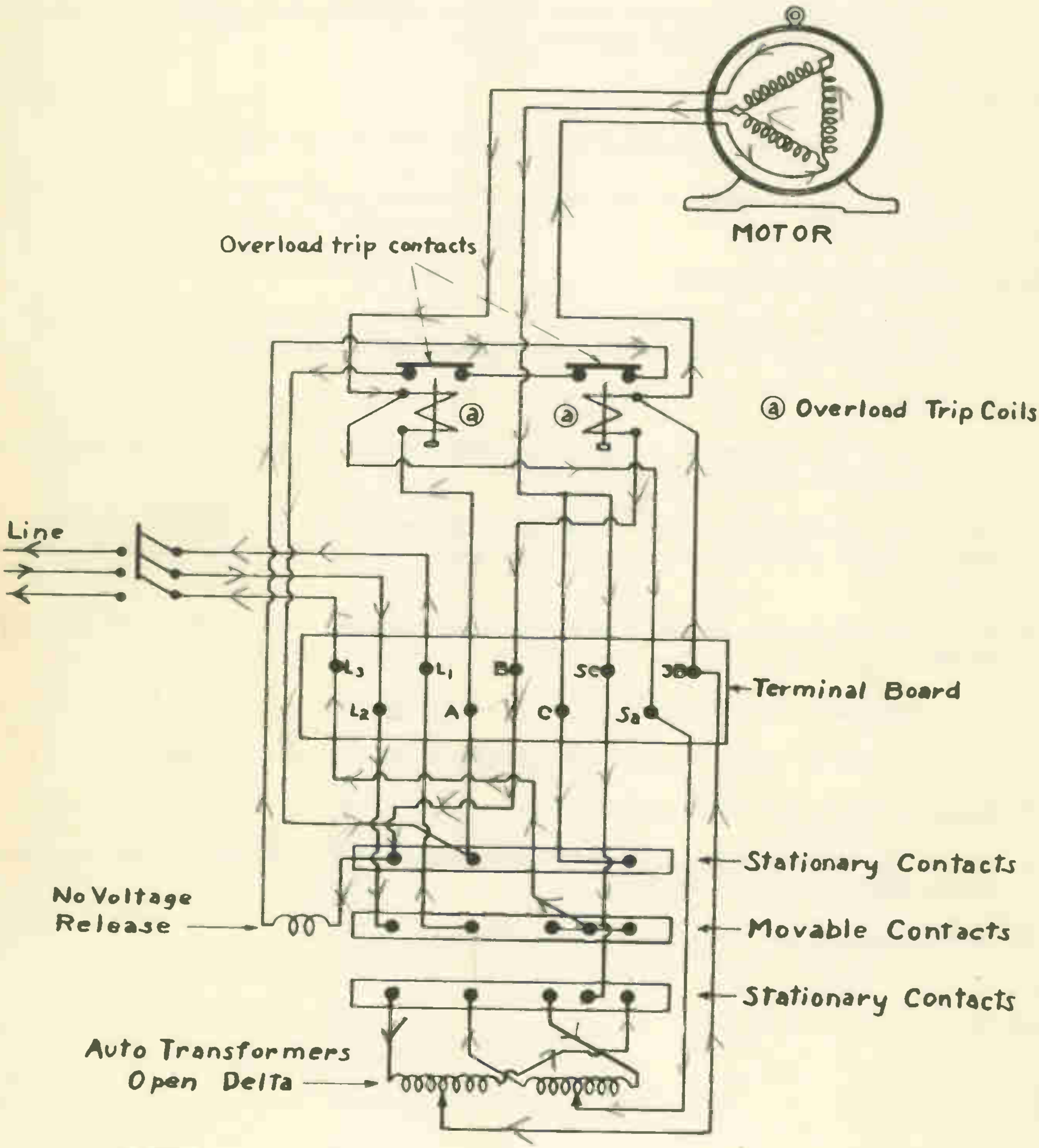


Fig. 1 Reduced voltage manual starter by 3-phase motors, 5-15 HP.
Westinghouse - General Electric - Allis Chalmers

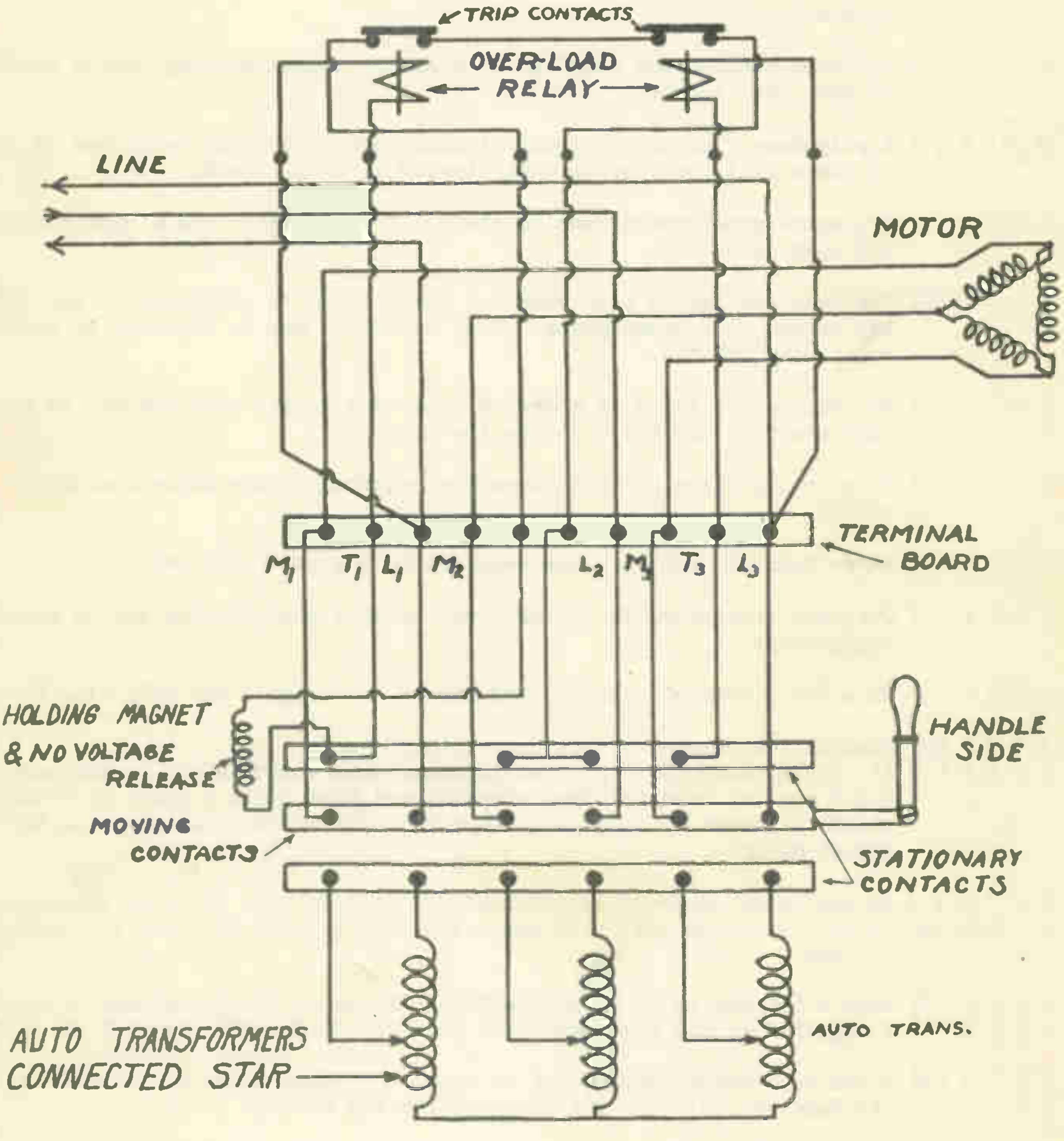


Fig. 2 Reduced voltage manual type starter for 3-phase motor equipment, 5-10 HP. (Western Electric)

QUESTION SHEET

1. T (X) F ( ) This type of starter is commonly used on low torque, polyphase induction motors.

2. T (X) F ( ) The auto-transformer consists of a single tapped winding, which serves as both Pri. and Sec.

3. T (X) F ( ) A polyphase, low torque squirrel cage induction motor developes $1\frac{1}{2}$ to $2\frac{1}{2}$ times full load torque when started at full line E.

4. T (X) F ( ) Two auto-transformers used to start a 3 phase motor are always connected open delta.

5. T ( ) F (X) The acceleration is poor when a 3 phase motor is connected to the 65% tap on the auto-transformer. This condition may be improved by changing to the 50% tap.

6. T (X) F ( ) The mechanical latch is a device used on a manual auto-starter to prevent starting the motor across the line.

7. T (X) F ( ) Five or six pairs of contactors are required in the motor starting switch.

8. T (X) F ( ) Three pairs of contacts are required in the motor run switch.

9. T (X) F ( ) Overload protection is not provided on this type starter during starting periods.

10. T (X) F ( ) On a 220 E starter, the holding magnet is designed for full line E.

11. A ( ) B (X) C ( ) D ( ) What is the purpose of the auto-transformer? (A) To increase the E applied to motor when starting (B) To decrease the E applied to motor when starting and thus limit I drawn by motor. (C) To decrease E, increase I to motor. (D) To increase starting torque of motor.

12. A ( ) B ( ) C ( ) D (X) An induction motor is dstarted at 70% of full line E. What percentage of full E torque will this motor develop? (A) 70% (B) 140% (C) 100% (D) 49%.

13. A ( ) B (X) C ( ) D ( ) When a 65% tap on an auto-transformer is used, the percentage of motor I supplied by the secondary will be: (A) 65% (B) 35% (C) 100% (D) 135%.

14. A ( ) B (X) C ( ) D ( ) Three auto-transformers used to start a 3 phase motor are connected: (A) Parallel (B) Star (C) closed delta (D) series.

15. A ( ) B ( ) C (X) D ( ) The type of overload relay used on this starter is: (A) Thermal with bi-metal diaphram (B) magnetic (C) thermal with bi-metal strip (D) thermal with solder unit.

16. A ( ) B (X) C ( ) D ( ) Oil immersed contactors are frequently used on manual type motor starters to: (A) prevent arcing at contactors (B) quench the arc and thus prevent rapid oxidation of contactors (C) limit current to the motor (D) prevent freezing or sticking of contactors.

REDUCED VOLTAGE STARTERS (AUTOMATIC TYPE)

Objective

To gain knowledge concerning the operation of automatic type auto-transformer motor starters.

References

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Average Time Required:

Tools, Materials, and Equipment

1. Necessary fuses and hookup wire.
2. Mounted automatic motor starter stand.

Procedure Steps

1. Wire Fig. 1 on its respective stand, keeping in mind the following:

   a. Number of wires that would be installed between complete control stations
   b. All connections made by student to be temporary but secure.
   c. How overload protection is afforded and how the various types work.
   d. How rotation may be reversed on the particular controller wired.
   e. Why timers are installed on this type of controller, including the advantages disadvantages, and limitations of each.
   f. Various types of interlocks and why they are used on this controller.

2. Trace and label each circuit in the diagram, Fig. 1.

3. Have your work checked by an instructor.

4. Repeat steps 1, 2, and 3 for the diagrams, in Figures 2,3, and 4.

5. Answer the questions at the end of the job.

6. Have an instructor check your answers to the questions.

   NOTE: Avoid probing, prodding or adjustment of delicate parts of control equipment with screw driver or pencil. Inspect the other types of controls before answering questions concerning timing devices.

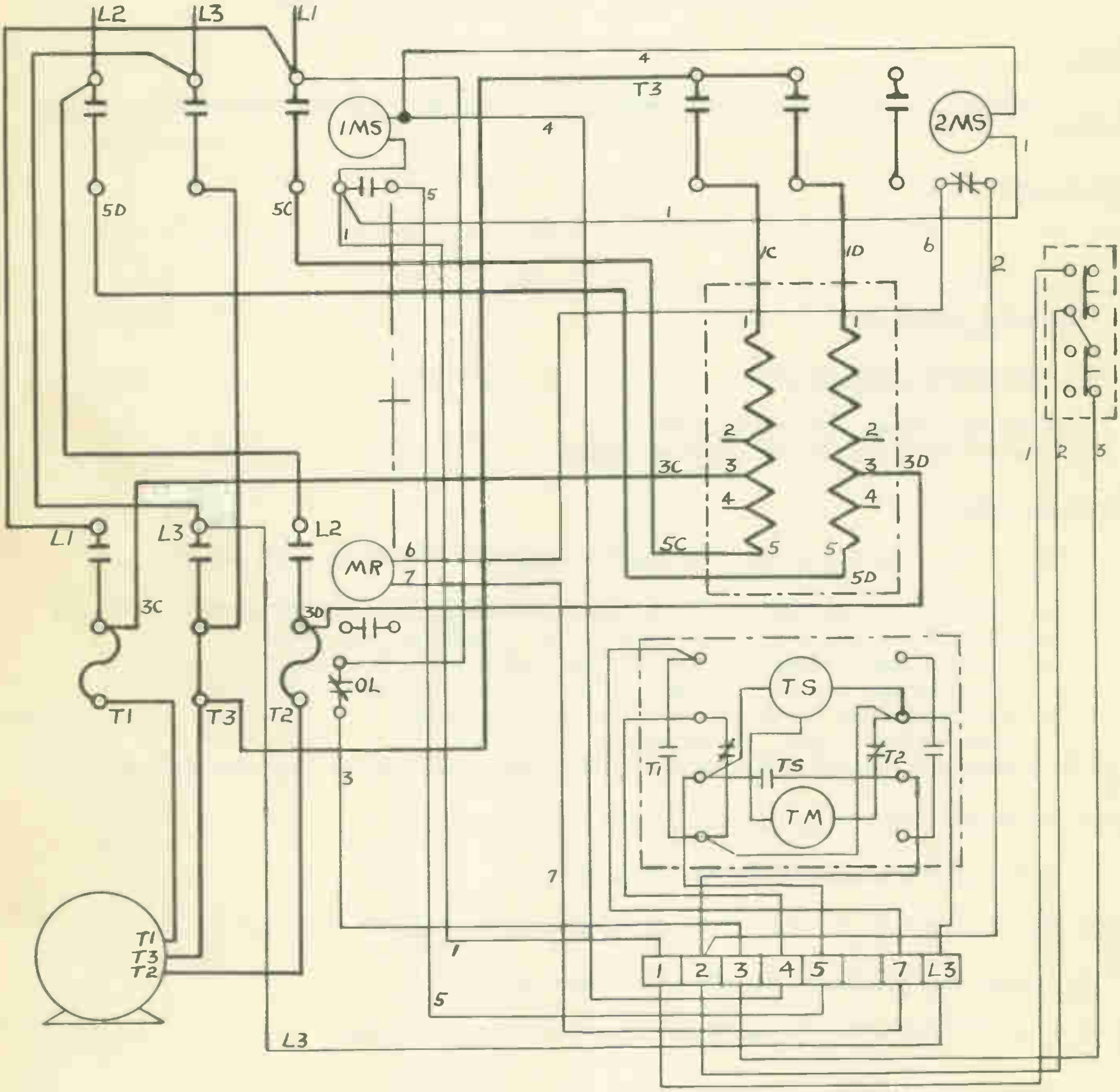

Fig. 1 Reduced voltage squirrel cage induction motor starter
(Westinghouse)

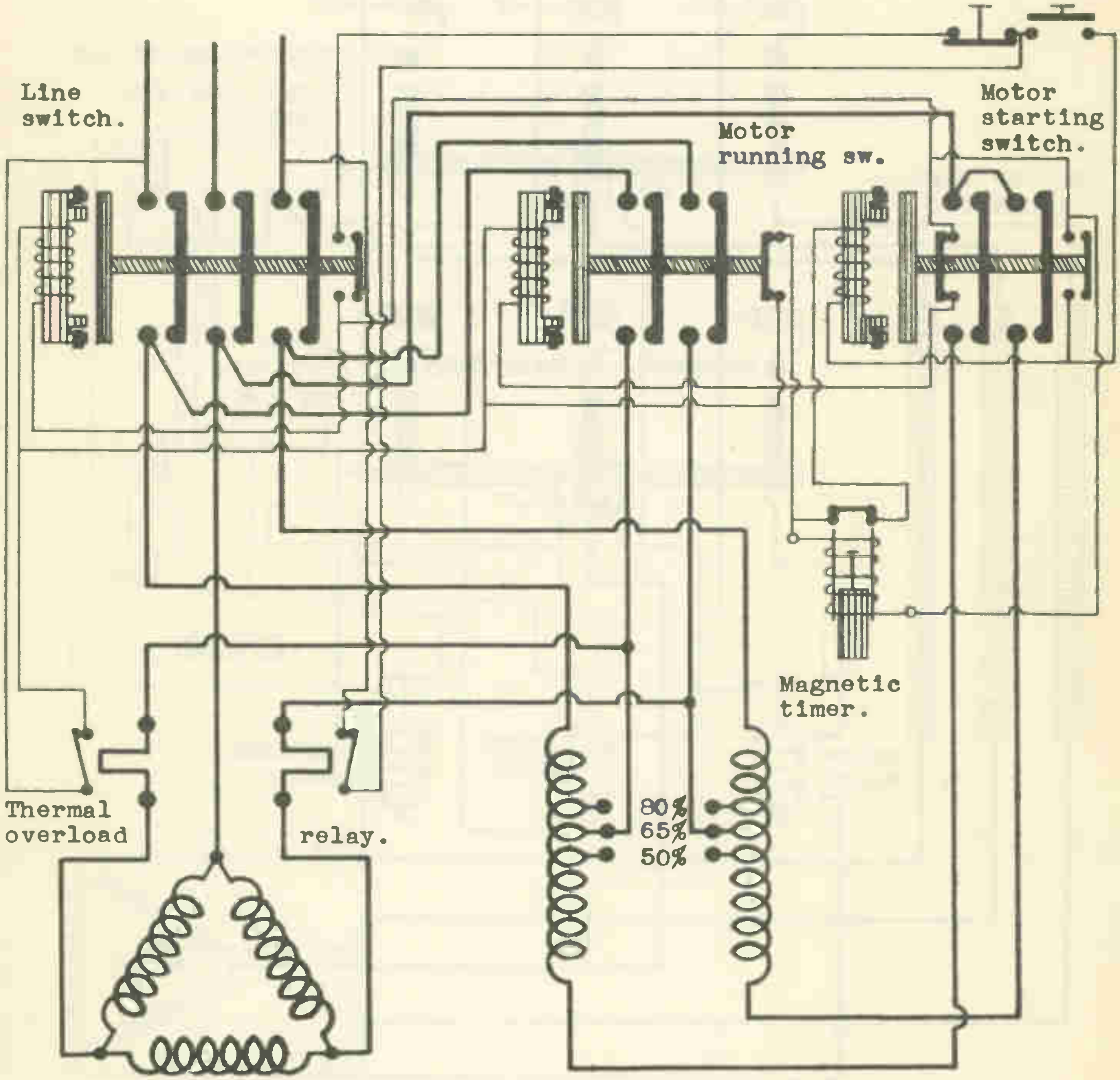

Fig. 2 Auto transformer starter
(Allen Bradley)

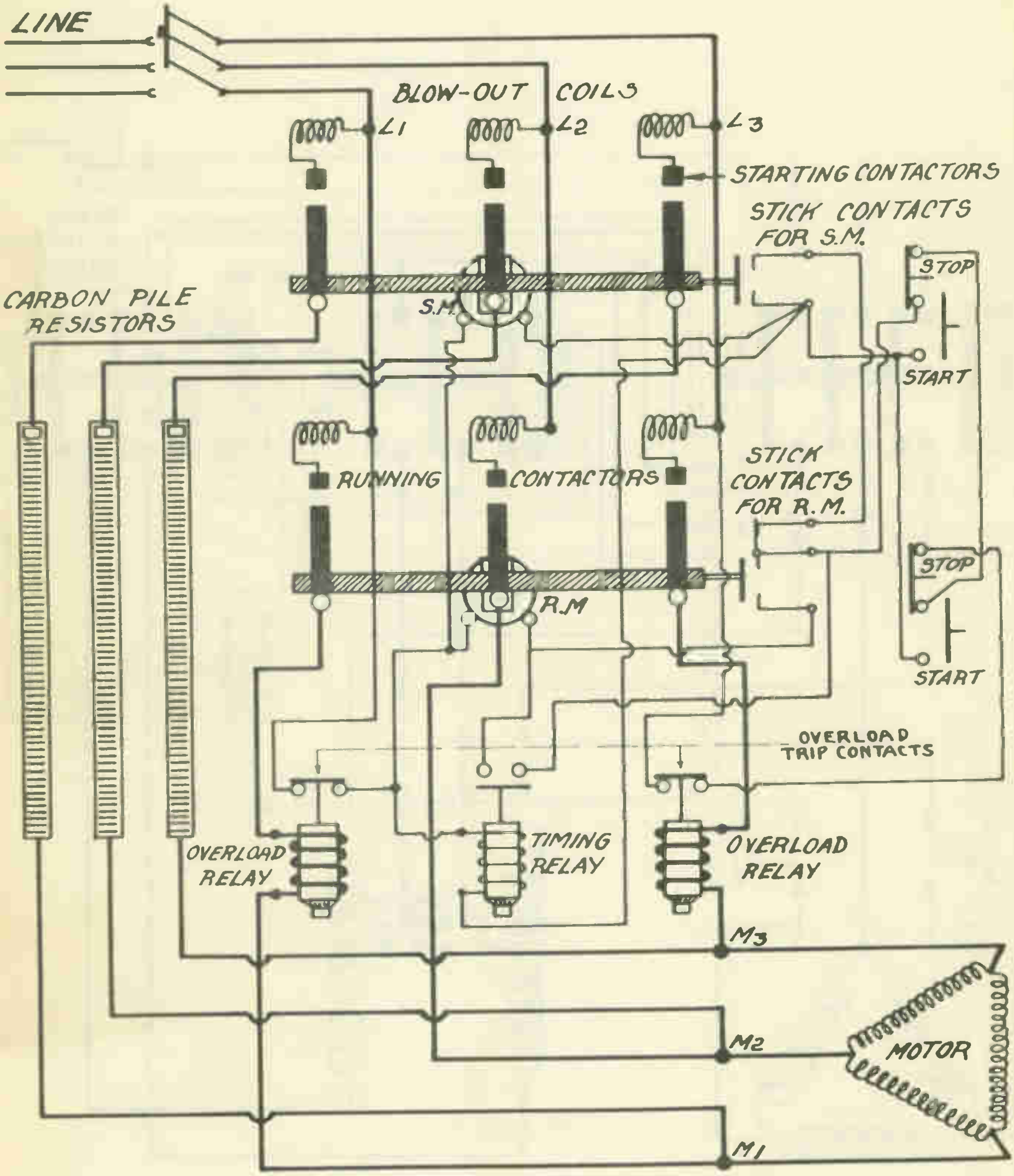

Fig. 3 Automatic resistance 3 phase starter
(Allen Bradley)

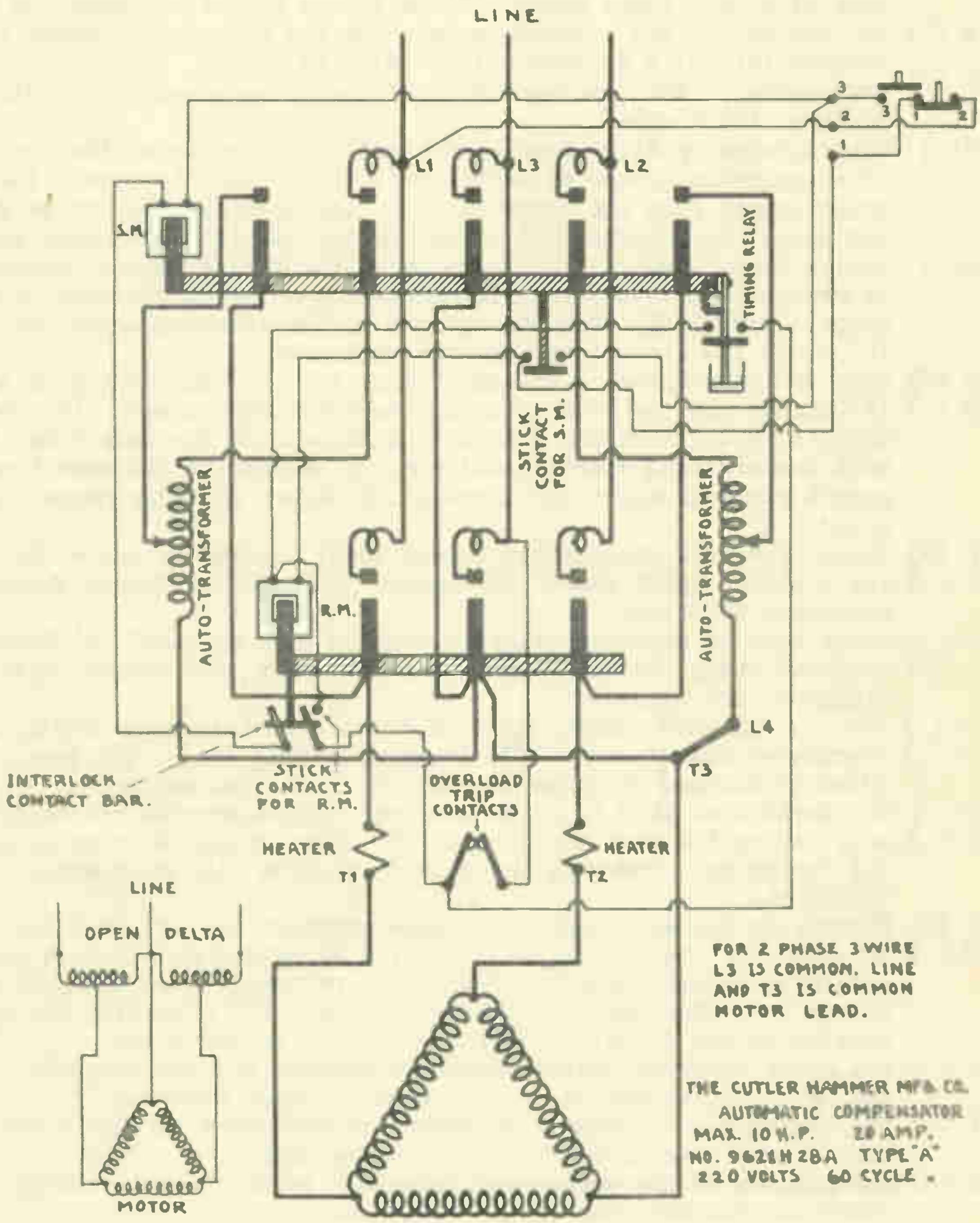
LINE
L1
L3
L2
3
2
1
S.M.
TIMING RELAY
STICK CONTACT FOR S.M.
AUTO-TRANSFORMER
AUTO-TRANSFORMER
R.M.
L4
T3
INTERLOCK CONTACT BAR.
STICK CONTACTS FOR R.M.
OVERLOAD TRIP CONTACTS
HEATER
HEATER
T1
T2
LINE
OPEN DELTA
MOTOR
FOR 2 PHASE 3 WIRE L3 IS COMMON. LINE AND T3 IS COMMON MOTOR LEAD.
THE CUTLER HAMMER MFG. CO.
AUTOMATIC COMPENSATOR
MAX. 10 H.P. 20 AMP.
NO. 9621H28A TYPE "A"
220 VOLTS 60 CYCLE.

Fig. 4

QUESTION SHEET
AUTOMATIC TYPE AUTO TRANSFORMER MOTOR STARTER

1. A (X) B ( ) C ( ) D ( ) This type of starter is commonly used on: (A) Low Torque polyphase induction motors; (B) High torque polyphase induction motors (C) any type of single phase motor (D) polyphase slip ring induction motor.
2. A (X) B ( ) The number of, and connection made for the auto-transformers in this starter is: (A) 2 in open delta (B) 3 in star.
3. A ( ) B (X) C ( ) The remote control system for this starter requires: (A) 2 wires (B) 3 wires (C) 4 wires.
4. A ( ) B(X) C ( ) (Westinghouse or Allen Bradley Control) The purpose of the timing device (magnetic, motor or mechanical) is to: (A) Disconnect the auto-transformers from the motor circuit (B) Open the circuit to the starting magnet or magnets (C) close the circuit to the running magnet.
5. A ( ) B( ) C (X) (Cutler Hammer Control) The purpose of the timing device (magnetic, motor or mechanical) is to: (A) Disconnect the Auto-transformers from the motor circuit (B) Open the circuit to the starting magnet or magnets (C) close the circuit to the running magnet.
6. A ( ) B (X) C ( ) D ( ) What is the purpose of the electrical interlocking switch or switches? (A) change the tap connection on the auto-transformers (B) prevent energizing the starting and running magnets at the same time (C) prevent deenergizing starting and running magnets at the same time (D) permit running magnet to be energized before starting magnet is energized.
7. A ( ) B (X) C ( ) D ( ) Which type of 1-phase motor (where used) is used to drive the timing (A) 1-phase, split phase (B) shaded pole (C) universal series (D) repulsion induction.
8. A ( ) B ( ) C ( ) D (X) Which type of overload relay is used on this starter? (A) Thermal with bi-metal strip (B) Thermal with solder unit (C) Thermal with bi-metal diaphram (D) magnetic.
9. A ( ) B ( ) C (X) D ( ) What is the most common cause of trouble in this type of starter? (A) overheated magnet coils (B) Damaged shading coils (C) burned or oxidized contactors in motor circuit (D) Defective mechanical interlock.
10. A ( ) B ( ) C (X) D ( ) On starters of this type the overload relays provide protection: (A) only during the starting period (B) Only during the running period (D) During both starting and running periods (D) When motor is not in operation.
11. A ( ) B (X) C ( ) D ( ) Thermal or heater elements on these starters are adjusted for the proper value of overload current by: (A) adjusting an oil dash pot (B) selecting heater elements of proper I rating (C)selecting bi-metal strips or solder units of the proper size (D) adjusting the spring tension on the bi-metal strips, or in the solder units.
12. T (X) F ( ) The motor starting switch magnet or magnets are energized by closing the open circuit switch at the remote control station.
13. T (X) F ( ) The timing device (magnet or motor) is energized through a holding contact which is closed by the starting magnet.
14. T (X) F ( ) The purpose of the mechanical interlock is to prevent closing the motor start and run switches at the same time.
15. T (X) F ( ) The overload trip switch on thermal type overload relays must be reset by hand.
16. T ( ) F (X) Multiple place remote control cannot be used on this type starter.
17. T ( ) F (X) The auto-transformer consists of 2 separate windings.

NINE LEAD MOTORS

Objective

References

Average Time Required:

Equipment, Tools, and Materials

1. Coyne Multimeter
2. Tags and leads
3. Nine-lead Motor

Precaution

Make no connections and do not change any connections while the motor is connected to the line. Watch the range setting on the VOM.

Procedure Steps

1. Determine whether the motor is star or delta connected.

2. Test the leads according to the test procedure which is explained in Lesson No. 18.

3. If star, connect the winding in series. (Finish the diagram found in Fig. 1.)

4. Make the voltage checkes as indicated in the chart (Fig. 2.)

5. Have your work checked by an instructor.

6. Connect the winding parallel, and show voltages measured in Chart Fig. 2.

7. Have your work checked by an instructor.

8. Apply the above procedure to another motor. (If delta, show results in Fig. 3 and 4.)

9.

NOTE: Avoid prolonged motor operation as much as possible when motor connections are incomplete.

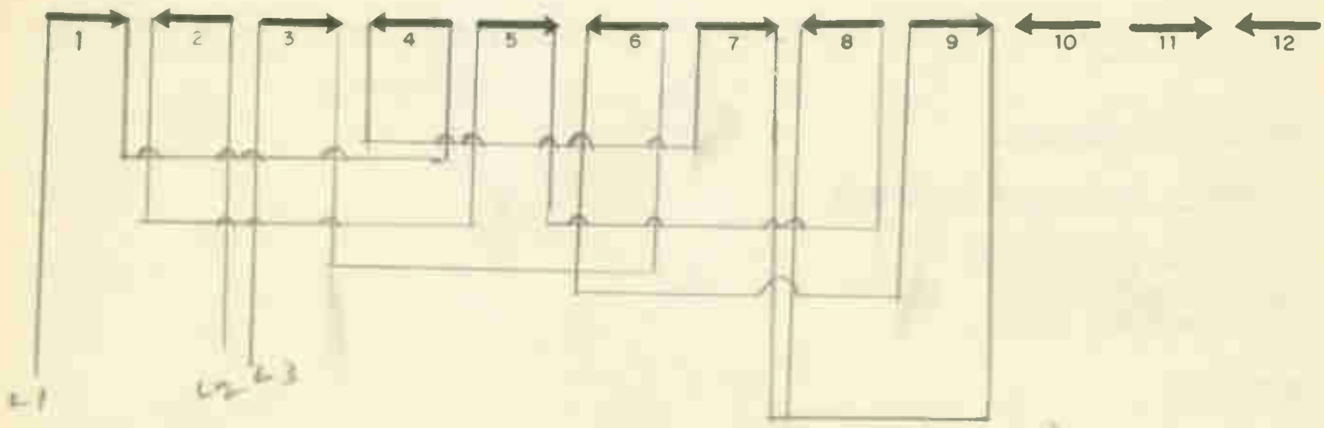

Figure 1 (~~Star~~ Series Connection)

NAMEPLATE	NOMENCLATURE	TERMINAL POINTS	VOLTAGE
Manufacturer	Gen. Elec.	Between T7 & T8	150
Horsepower	1/4	" T1 & T4	80
Phase	3	" T2 & T3	240
Voltage	440	" T9 & T6	0
Current	50-65	" T4-T7 & T3	220
Speed	1725-1425	" T5-T8 & T2	0-80
Frequency	60-50	" T6-T9 & T3	0-80
Poles	4 Poles	" T1 & T7	80
Serial Number	5K43AC465R	" T2 & T6	210

Figure 2 (Voltage Chart for Single Ckt. Y).

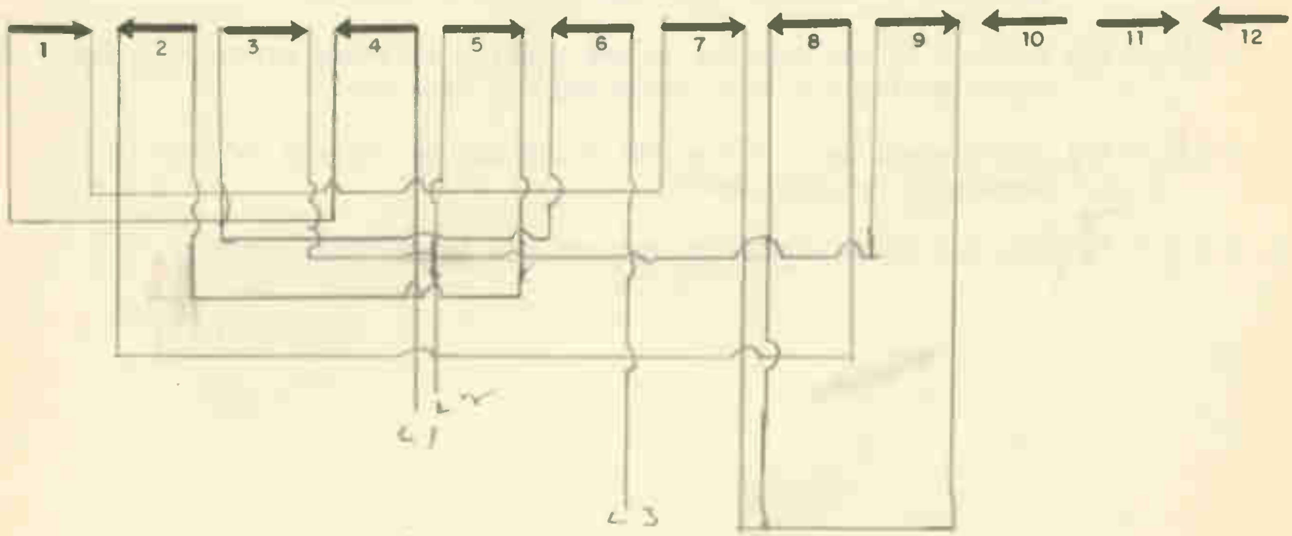

Fig. 3 ([redacted] Connection)

NAMEPLATE - NOMENCLATURE		TERMINAL TEST POINTS	VOLTAGE
Manufacturer	GEN ELEC.	Between T7 & T8	240
Horsepower	1/4	" T1 & T4	120
Phase	3	" T2 & T3	240
Voltage	440	" T9 & T6	130
Current	50-65	" T4-T7 & T3	70
Speed	1725-1425	" T5-T8 & T2	70
Frequency	60-50	" T6-T9 & T3	70
Poles	✓	" T1 & T7	0
Serial Number	5K43AO465R	" T2 & T6	70

Fig. 4 Voltage Chart for single circuit Delta

Questions

1. T ( ) F (X) Which leads should be changed to reverse rotation of a nine-lead motor? Any two leads.

2. T (X) F ( ) When properly connected, the horsepower output of the motor is unaffected if changed from one voltage to another.

3. T ( ) F (X) An open in one section of the winding will not affect operation of the motor noticeably when connected for two-circuit.

4. T ( ) F (X) A nine-lead delta connected motor may be changed to star by rearranging external leads.

5. T (X) F ( ) Phasing tests should be made at the low voltage rating.

STAR-DELTA STARTERS

Objective

To learn the methods of testing leads or ends of phases on a three phase winding. To put into practice an emergency starting and operating hookup when reduced voltage equipment is not available.

References

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Tools, Equipment, and Materials

1. Obtain a test lamp and voltmeter at the a-c desk.
2. Necessary conductors or hookup wire and fuses.
3. A 3P DT Knife switch.
4. A three phase motor with six exposed leads.

NOTE: Proper connection of the windings on any 3 phase motor, generator, or transformer must be preceeded by identification for the phase ends as starts and finishes. The simplest method of finding the starts and finishes of the phases in a three phase motor is given by the following procedure steps. Follow each step carefully. With the windings connected star, a test will show unequal voltage per phase with an incorrect connection. The incorrectly connected phase will show the highest voltage reading. The currents drawn will be unbalanced and magnetic noises will be increased.

Procedure Steps

1. Using the test lamp, find the ends of the phases by using the method illustrated in Fig. 1.

2. After determining which terminals are matched for phases, assume three ends to be finished and connect them together as shown in Fig. 2. Connect the three remaining leads which are assumed to be starts to the line.

3. Close the line switch momentarily, to determine if the motor is noisy. If the motor is noisy, reverse leads connected to phase "A". See Fig. 3.

4. If no improvement is made, replace "A" leads and reverse "B" phase, as shown in Fig. 4. Close the line switch and observe operation.

5. If still no improvement, replace "B" phase leads and reverse leads to Phase "C", as shown in Fig. 5. The motor should now operate normally.

6. When this normal operation takes place, mark the phases as shown in Fig. 6.

7. Trace all circuits on the wiring diagram Fig. 7 for both star and delta, being able to explain each.

8. Using the voltmeter make all voltage tests required, and fill in readings on the following page.

9. Answer all questions on this job and have your work checked by your instructor.

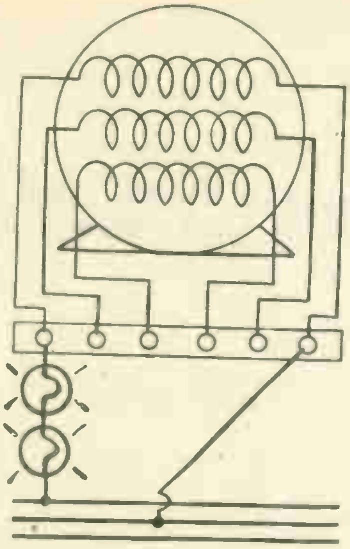


Fig. 1

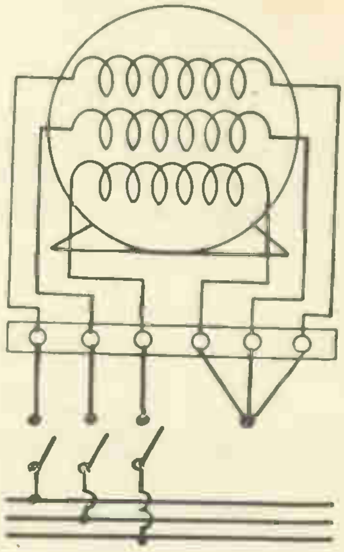


Fig. 2

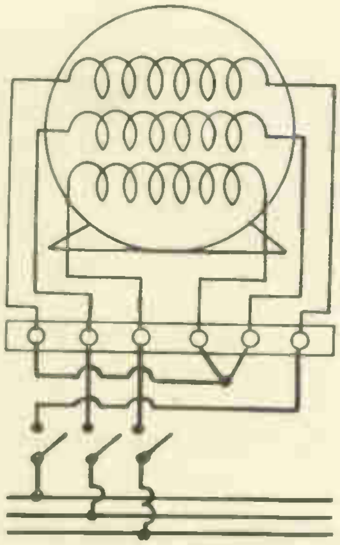


Fig. 3

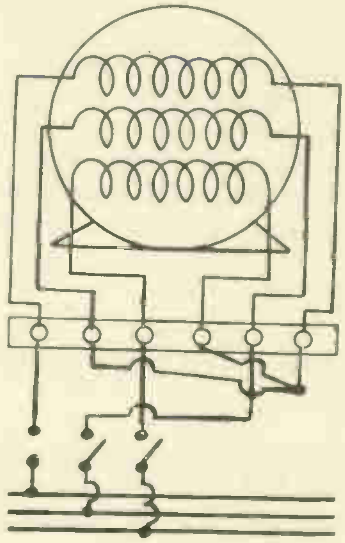


Fig. 4

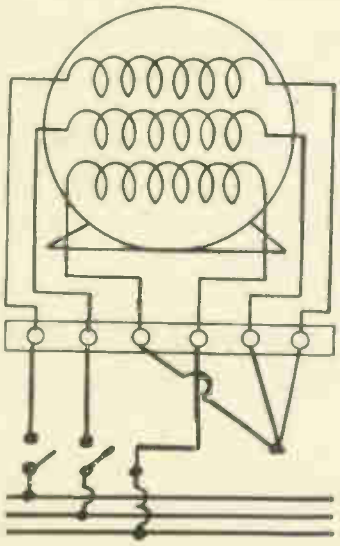


Fig. 5

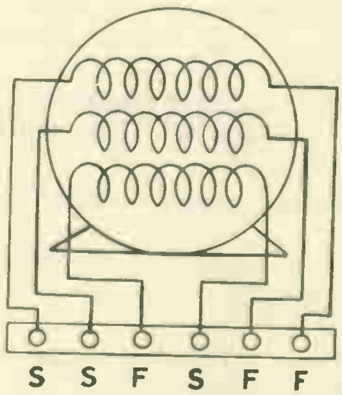
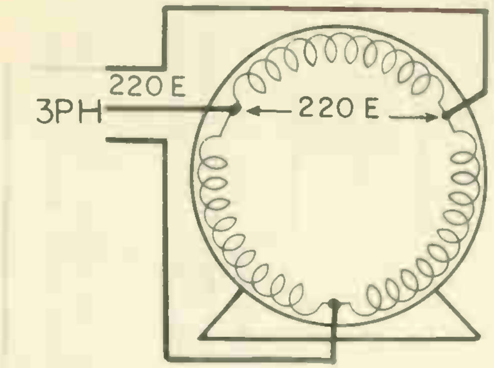
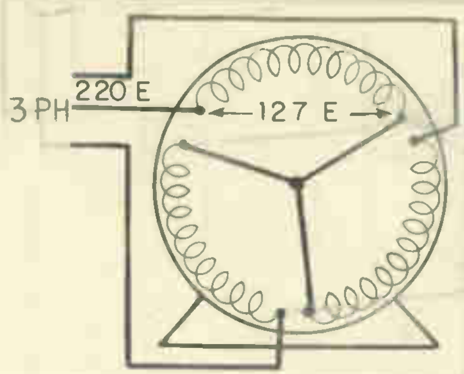


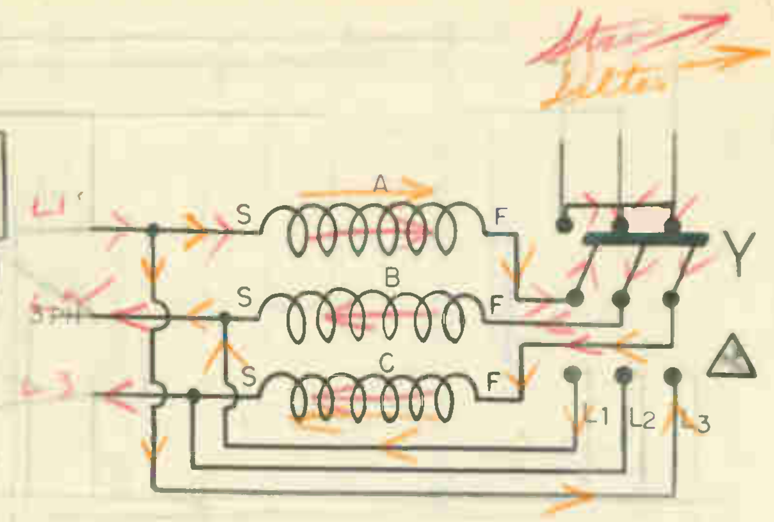
Fig. 6



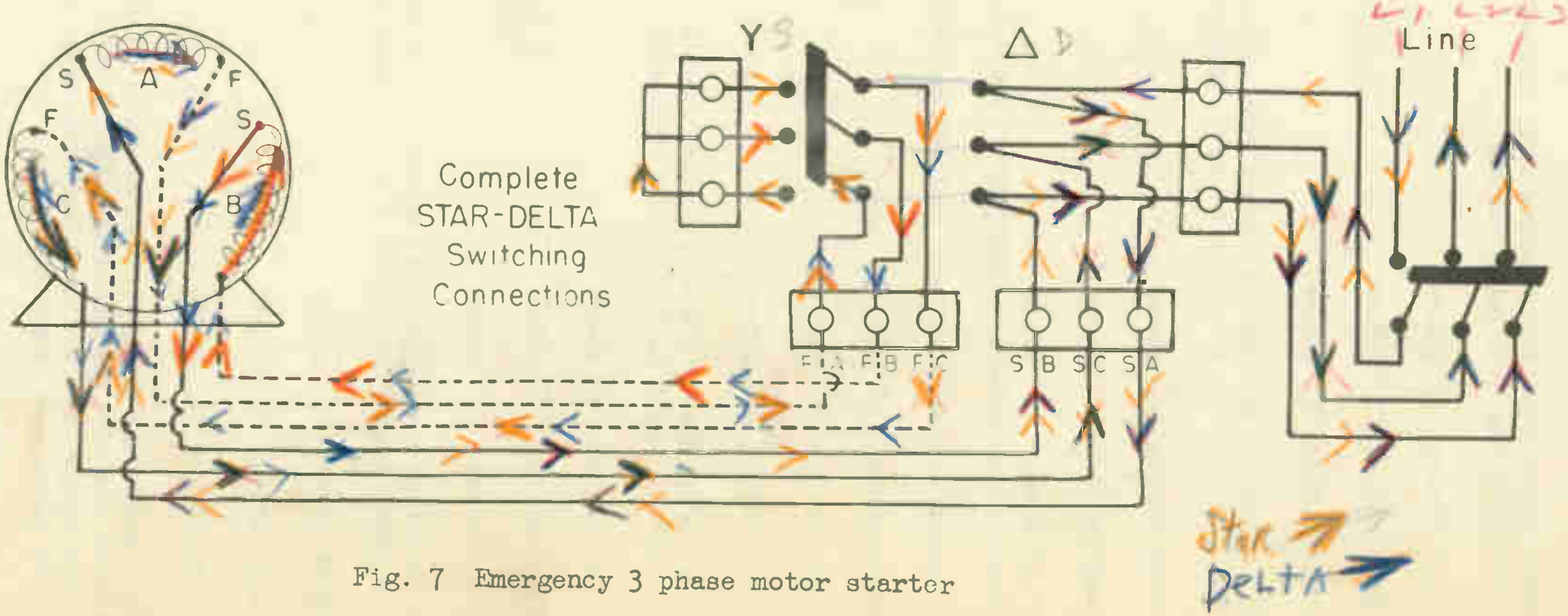
Delta Connection
Symbol = Δ
PH. E = Line E



Star Connection. Symbol = Y
Phase **E** = .58 x Line **E**
Line **E** = 173 x Phase **E**



Simple Diagram of a
STAR - DELTA Starter



Complete
STAR-DELTA
Switching
Connections

Fig. 7 Emergency 3 phase motor starter

Line voltage . . . . 250 volts

Connect motor star for phasing out, assuming starts and finishes. If motor is properly phased, make the following tests:

Voltage across "A" phase . . . . 148 volts

Voltage across "B" phase . . . . 148 volts

Voltage across "C" phase . . . . 128 volts

With the motor improperly phased and connected star, make the following tests: (NOTE: do not connect the motor delta with improper phasing.)

Voltage across "A" phase . . . . 165 volts

Voltage across "B" phase . . . . 125 volts

Voltage across "C" phase . . . . 125 volts

Indicate which phase is **improperly** connected.

With motor properly phased, and connected delta, make the following test:

Voltage across "A" phase . . . . 250 volts

Voltage across "B" phase . . . . 250 volts

Voltage across "C" phase . . . . 250 volts

With motor properly phased, connect delta and bring up to full speed. Open 1 line from the 3 phase supply and make the following tests:

Voltage across "A" phase . . . . 250 volts

Voltage across "B" phase . . . . 225 volts

Voltage across "C" phase . . . . 320 volts

With motor properly phased, connect star and bring up to full speed. Open 1 line from the 3 phase supply and make the following tests:

Voltage across "A" phase . . . . 85 volts

Voltage across "B" phase . . . . 100 volts

Voltage across "C" phase . . . . 100 volts

An a-c voltmeter may be obtained from an instructor at the desk upon deposit of your job card. Handle the meter carefully while make tests. Be careful to select proper voltage range before attempting any test. Please return the meter to the desk promptly when tests are completed.

NOTE: All phases will give a voltage reading even though the motor is incorrectly phased or 1 line wire is disconnected. Zero readings will result from incorrect connections for the voltmeter.

1. Draw schematic diagrams on the following page, for both star and delta connections. Identify: a. phase winding b. start and finish leads of each phase c. line wires.

2. A ( ) B (X) The 3-phase motor selected for this method of starting should have an original connection of: (A) star (B) delta.

3. A (X) B ( ) C ( ) Phasing out of motor (identification of start and finish leads) should be accomplished by connecting the motor: (A) star (B) delta (C) open delta.

4. A (X) B ( ) Line wire connections for Star-Delta Starter should be made at: (A) The open side of switch along with Star leads: (B) the blades of 3-pole switch along with finish leads.

5. A ( ) B (X) A Delta connection may be formed at the switch by connecting: (A) start and finish leads of the same phase to correspondingly located points on the 3-pole switch (B) start and finish leads of the same phase to staggered points on the 3-pole switch.

6. A ( ) B (X) C ( ) D ( ) The incorrectly connected phase winding of a 3-phase motor will give a voltage reading which is: (A) normal (B) zero (C) above normal (D) below normal.

7. A ( ) B (X) C ( ) D ( ) When starting a star connected motor, phase voltage will be: (A) equal to line E (B) 58% of line E (C) line E multiplied by 1.732 (D) 33.6% of line E.

8. A ( ) B ( ) C (X) D ( ) Phase current of a Delta connection will be: (A) equal to line I (B) one half of line I (C) 58% of line I (D) line I multiplied by 1.732.

9. A ( ) B (X) C ( ) D ( ) When operating on single phase energy, a 3-phase motor will carry without excessive overheating: (A) 100% full load (B) 33.6% full load (C) 58% full load (C) 66.6% full load.

10. A ( ) B ( ) C (X) D ( ) A 3-phase motor connected to a star-delta starter will operate normally in a reverse direction by: (A) changing leads of 1-phase (B) changing leads of 2 phases (C) changing any 2 line leads (D) changing all 3 line leads.

11. A ( ) B (X) C ( ) D ( ) Phase voltage for a Delta connected motor will be: (A) 58% of line E (B) equal to line E (C) line E multiplied by 1.732 (D) 33.3% of line E.

12. T (X) F ( ) A continuity test to locate ends of phase windings may be made with either a test-lamp or voltmeter.

13. T (X) F ( ) When passing out a motor by the trial and error method, it is necessary to replace leads of phases before changing the next pair.

14. T (X) F ( ) The Starting torque developed by a motor connected Star will be 33.6% of the torque developed by the motor connected Delta. (Assuming same line E used on both connections).

15. T (X) F ( ) A 3-phase, Delta connected motor will start with an open in one phase winding.

SLIP RING INDUCTION MOTOR

Objective

To learn about connections, applications, and necessary conditions of this variable speed motor, which may be applied to conveyers, punch presses, elevators, printing presses or any job which requires variable speed with only AC available for power.

References

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Average Time Required

Tools, Equipment, and Materials

1. Slip ring motor
2. Necessary control for the motor
3. Fuses and necessary conductor hookup wire.

Procedure Steps

1. Choose one job from Figures 1 to 3.
2. Select the motor stand that matches the diagram. Trace the circuits on the digram and locate parts on actual unit.
3. When working with the six position drum control, Fig. 2, be sure to fill in the contactor sequence chart at the base of this page.
4. Wire each step of the digram you have chosen, and check the completed step before proceeding.
5. Complete the wiring and check the overload equipment.
6. Put in the fuses and close the line switch.
7. Operate the control to discover if variable speed can be noticed. Explain why the speed varies or does not vary as the case may be.
8. Answer the questions pertaining to this job.
9. Have your job checked before removing the wiring.

CONTACTOR SEQUENCE.

CONTACTS.	FORWARD.						OFF.	REVERSE.					
	6	5	4	3	2	1		1	2	3	4	5	6
R22													
R12													
R2													
R3													
R13													
R23													
L1													
T1													
T2													
L2													
ST													

Connector sequence chart for Fig. 2

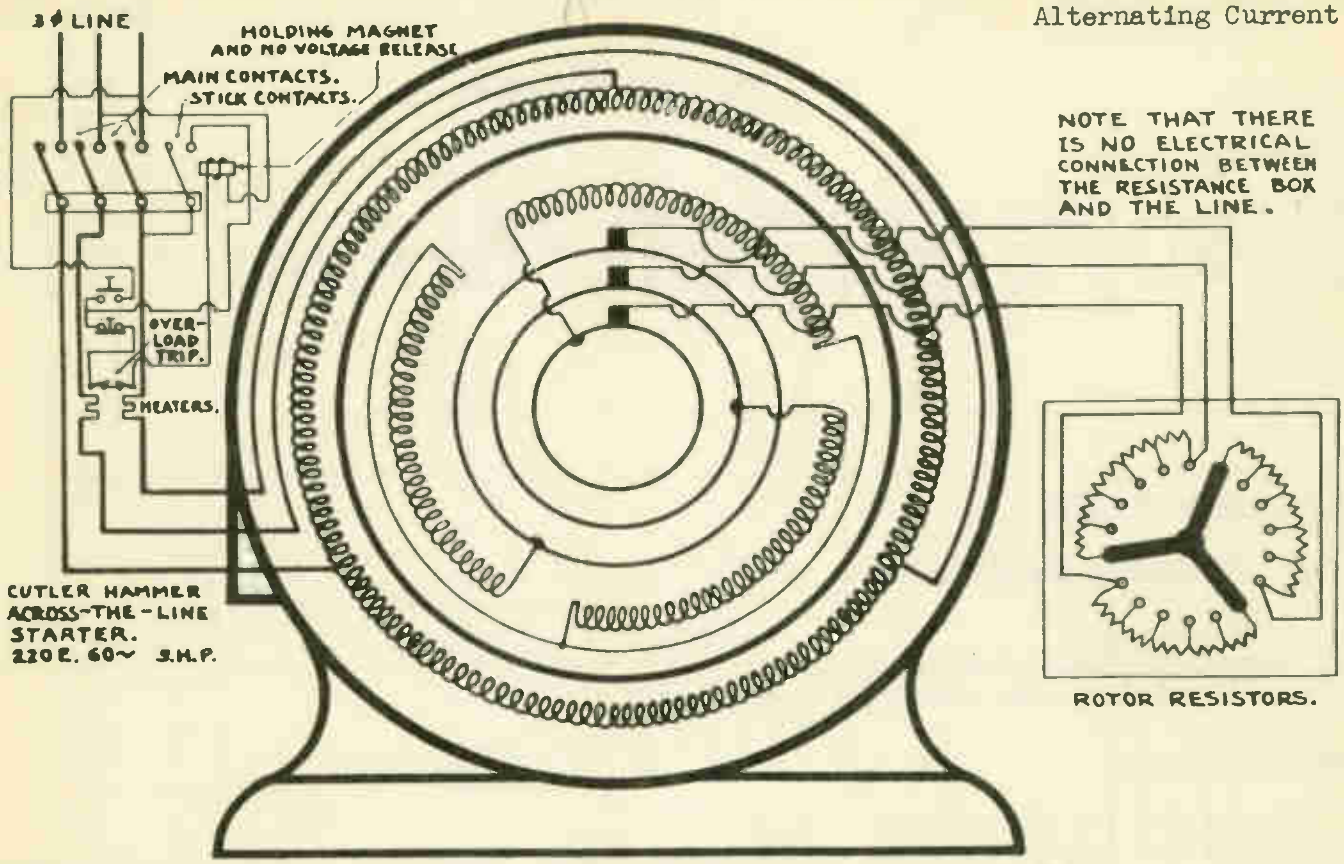


Fig. 1 Slip ring induction motor with Y-box

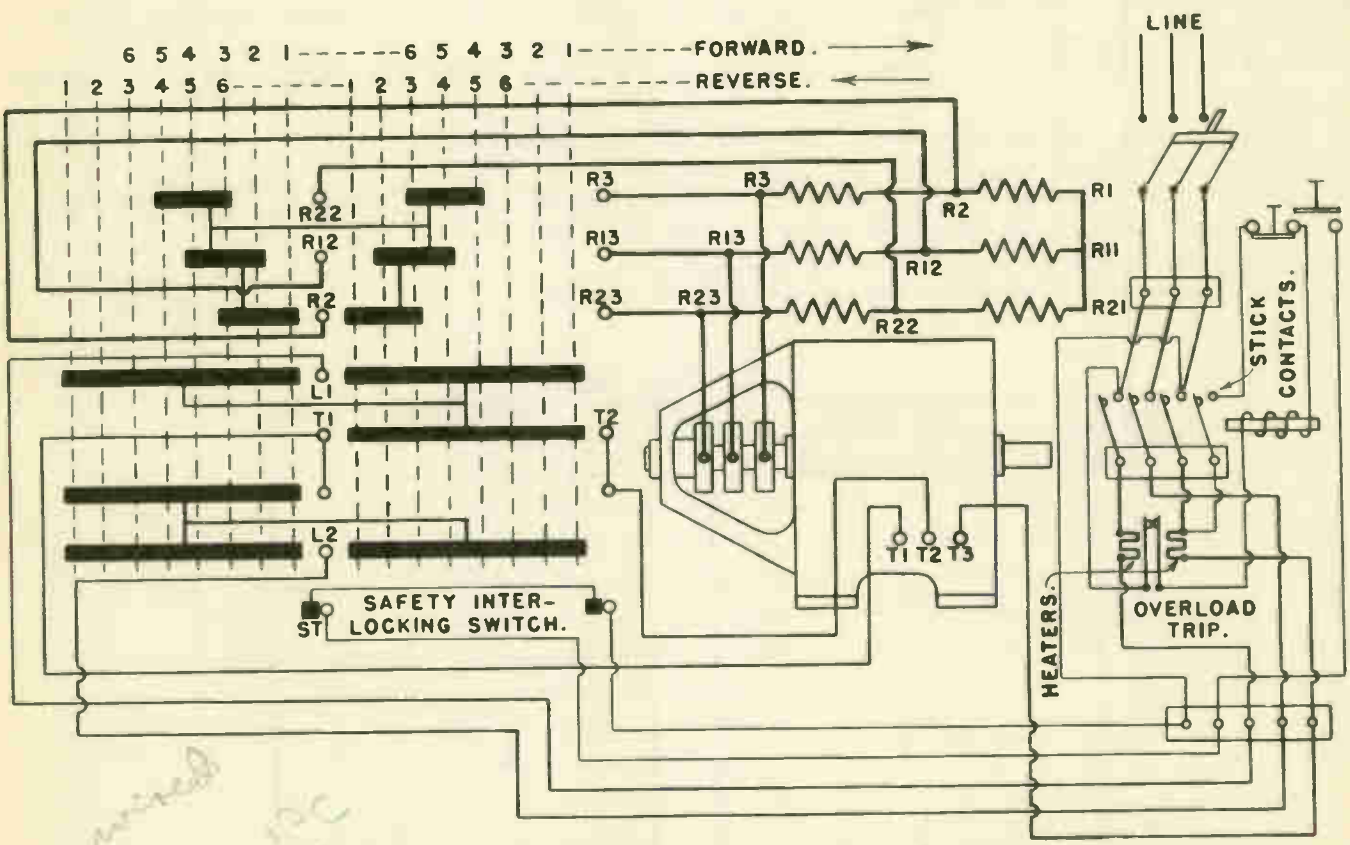


Fig. 2 Six position forward-reverse drum control for slip ring motors.

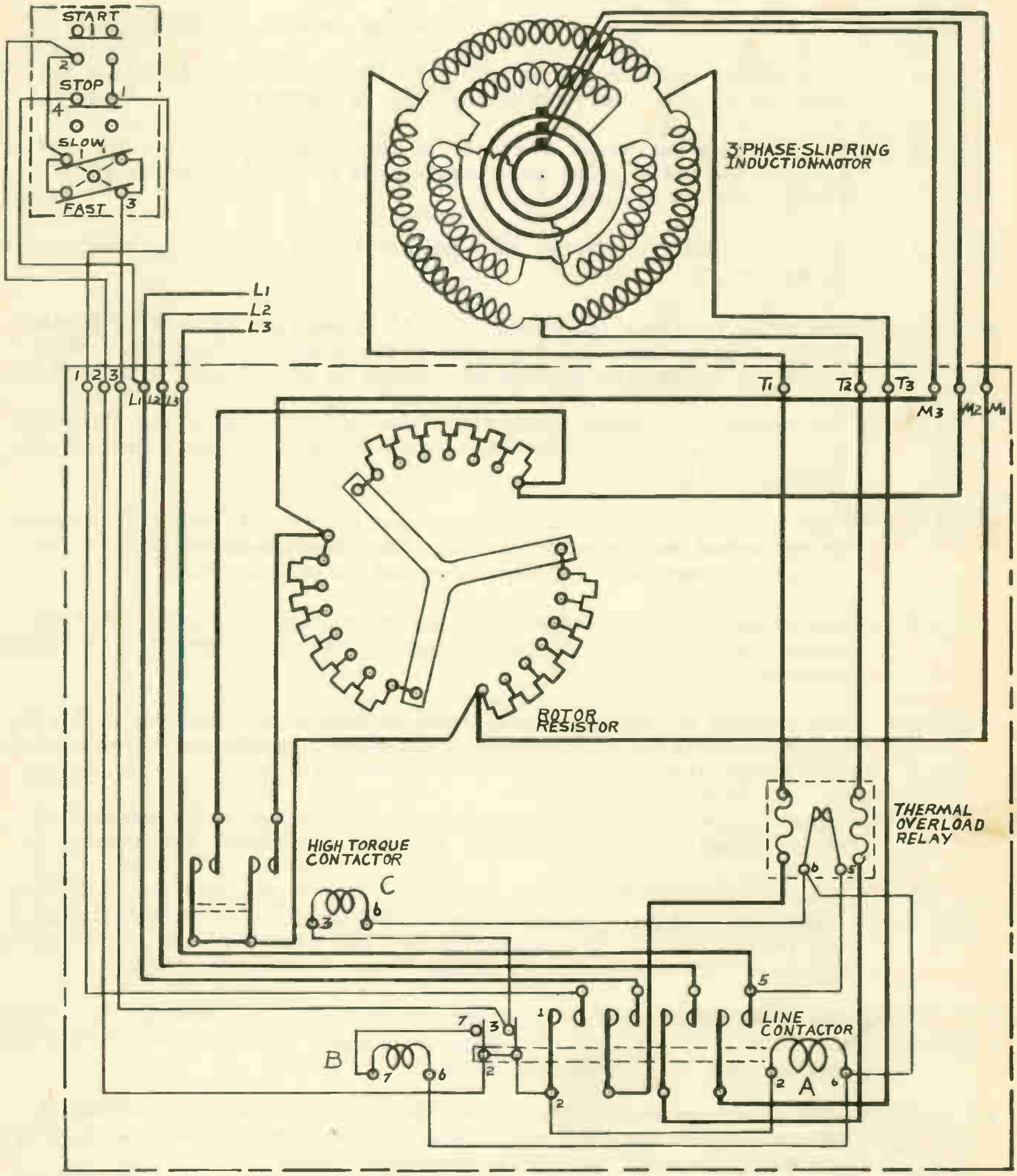


Fig. 3 Hosiery machine controller for 3-phase slip ring induction motor.

1. T (X) F ( ) The stator winding is phase wound and may be connected either Star or Delta.

2. T (X) F ( ) The rotor winding is phase wound and is usually connected Star.

3. T (X) F ( ) If external resistor is connected in the rotor circuit during the starting period, starting torque will be improve.

4. T (X) F ( ) The starting torque is increased by resistance in the rotor circuit because the rotor poles move into a more favorable postion with respect to the stator poles.

5. T ( ) F (X) It is possible to reverse rotation of the motor by interchanging the rotor leads?

6. A ( ) B (X) The rotor receives its energy by: (A) Connection through slip rings to the 3-phase line (B) Electromagnetic induction from the stator field (C) connection through slip rings to an external source of DC.

7. A ( ) B (X) C ( ) The external resistor usually consists of: (A) 3 sections connected Star (B) 3 sections connected closed Delta (C) 2 sections connected open Delta.

8. A (X) B ( ) C ( ) When motor is started the external resistor should be: (A) inserted or connected in the rotor circuit (B) inserted in the stator circuit; (C) connected in both stator and rotor circuit.

9. A ( ) B (X) The presence of the resistor in the rotor circuit during starting period results in the motor drawing: (A) minimum current (B) maximum current.

10. A (X) B ( ) The purpose of the electrical interlocking switch used on slip ring motor controls is to: (A) insure presence of resistor in rotor circuit; (B) insure absence of resistor in rotor circuit.

11. A ( ) B (X) C ( ) Inserting resistance in the rotor circuit controls the speed: (A) above normal (B) below normal (C) does not affect the speed.

12. A ( ) B ( ) C (X) Measure external voltage of rotor at slip rings under the following conditions and post values in left hand margin: (A) Motor running all resistance in (B) motor running, all resistance out (C) insulate 2 sets of brushes from slip rings, connect stator to line.

13. A ( ) B ( ) C (X) D ( ) The most common trouble encountered in this type motor is: (A) damaged resistor unit (B) Worn bearings (C) worn, dirty or burned slip rings and brushes (D) Damaged windings.

14. A ( ) B ( ) C (X) Will this type motor start under the following faulty conditions? (A) One leg of resistor unit open. (B) Two legs of resistor unit open. (C) One phase open in a Delta connected stator.

15. A ( ) B ( ) C (X) How many lines (3-phase circuit) must be carried through the contractors of a reversible drum control? (A) 1 (B) 2 (C) 3.

16. __10%__ How much torque is developed, and how much current is drawn by this motor with respect to full load values when motor is started? Express answers in percentage and post in left hand margin.

POWER IN THREE PHASE AND POWER FACTOR

Objective

To learn more about the measurement of power in 3 phase, how to calculate the circuits power factor, how to correct the power factor if it needs correction, and to learn how to compare as well as compute volt-amperes and watts.

References

____

____

Average Time Required

Tools, Equipment, and Materials

1. Hookup wire and fuses
2. Necessary wattmeters
3. Voltmeter with a range of at least 250 volts.
4. Ammeter with a range of at least 10 amperes.
5. Mounted motor-generator units, etc.

NOTE: Even though you may not be required to do both of the power factor jobs, it is recommended that you be thoroughly familiar with the methods used in testing terminals, etc.

Procedure Steps

1. Test to ascertain, if necessary, which terminals are voltage coil terminals, current coil terminals, etc. Mark same on the next page.

2. Arrange meters as shown in sketch "A" with the individual current coils in series in the same lines.

3. Now check the meters and see if they both read alike; if they do not, one or both meters are inaccurate, since they are both measuring the same load. If one meter reads backwards, reverse that meter's voltage coil leads.

4. Disconnect wattmeter W2 at x - x and, without disturbing the voltage coil connections and insert the current coil in line 3, taking care not to change the position of the terminal "S" and "L" with respect to the circuit. See part B.

5. When a polyphase meter is used follow the circuit wiring diagram shown in "E" for three wire, three phase and diagram "F" for 4 wire three phase.

6. Check meter for forward reading, if reading seems to be low, reverse one of the voltage coils. This should correct the faulty reading.

7. Make all readings and tests on part A and B in the chart on the following page.

8. Answer all questions and have your work checked.

In this test a D-C generator is used to impose full-load on the motor. The output of motor in watts is determined by measuring the output of a D-C generator and add-in to this the I^2R losses of the generator and also its friction and windage losses. The resistance of the different circuits must be known. These values are given on the job. In the following outline, the armature resistance will be designated as R_1; the shunt field resistance R_2; and the series field resistance as R_3.

PART A -- Take meter readings and mark in proper places.

DIRECT CURRENT

E = ______
I = ______
W = E X I ________ = ________ Watts

ALTERNATING CURRENT

E = ______
I = ______
W = $W_1 \pm W_2$ = ______ + ______ = ______ Watts

LOSSES

Watts lost in shunt field I^2R_2 = ________ = ________ Watts
Watts lost in armature I^2R_1 = ________ = ________ Watts
Watts lost in series field I^2R_3 = ________ = ________ Watts
Watts lost in friction & windage = ________ = ________ Watts
Total Watts lost = ________

Total Watts output of motor = Watts output of generator + Generator losses
= ______ + ______ = ________ Watts

Eff. of motor = $\frac{\text{W Output}}{\text{W Input}} = \frac{\text{Output}}{W_1 + W_2}$ = ________ = ______ %

Power Factor of 3 ph. motor = $\frac{\text{True W. Input}}{\text{App. W. Input}} = \frac{W_1 \pm W_2}{E \times I \times 1.73}$ = $\frac{\_\_\_\_ W_1}{E \times}$ + $\frac{\_\_\_\_ W_2}{I \times 1.73}$

= $\frac{\text{Total W}}{\text{Total V.A.}}$ = ________ = ________ %

PART B -Connect ______ K.V.A condenser to motor: Take meter readings and mark as above.

DIRECT CURRENT

E = ______
I = ______
W = E X I ________ = ________ Watts

ALTERNATING CURRENT

E = ______
I = ______
W = $W_1 \pm W_2$ = ______ + ______ = ______ Watts

LOSSES

Watts lost in shunt field I^2R_2 = ________ = ________ Watts
Watts lost in armature I^2R_1 = ________ = ________ Watts
Watts lost in series field I^2R_3 = ________ = ________ Watts
Watts lost in friction & windage = ________ = ________ Watts
Total Watts lost = ________

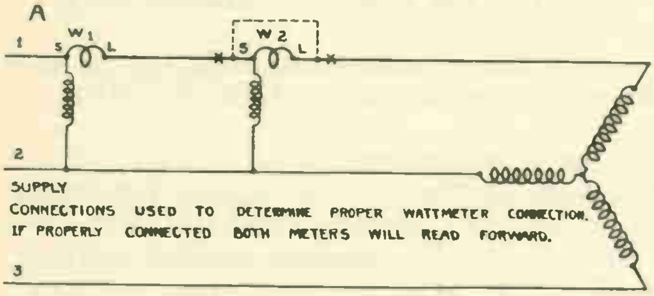
Total Watts output of motor = Watts output of generator + Generator losses
= ______ + ______ = ________ Watts

Eff. of motor = $\frac{\text{W Output}}{\text{W Input}} = \frac{\text{Output}}{W_1 + W_2}$ = ________ = ________ %

Power Factor of 3 ph. motor = $\frac{\text{True W. Input}}{\text{App. W. Input}} = \frac{W_1 \pm W_2}{E \times I \times 1.73}$ = $\frac{\_\_\_\_ W_1}{E \times}$ + $\frac{\_\_\_\_ W_2}{I \times 1.73}$

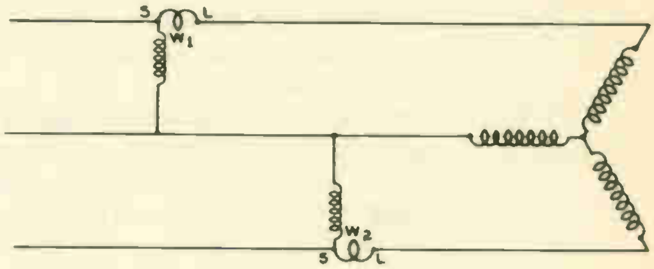
= $\frac{\text{Total W}}{\text{Total V.A.}}$ = ________ = ________ %

A

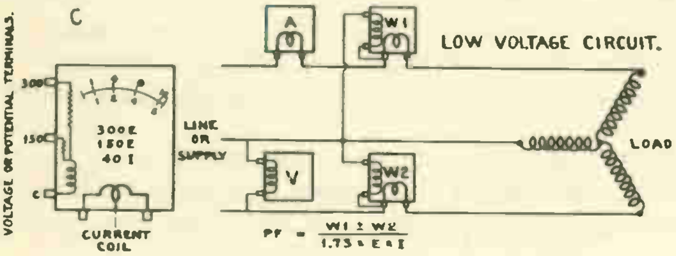


B

CORRECT CONNECTION FOR MEASURING 3 PHASE POWER

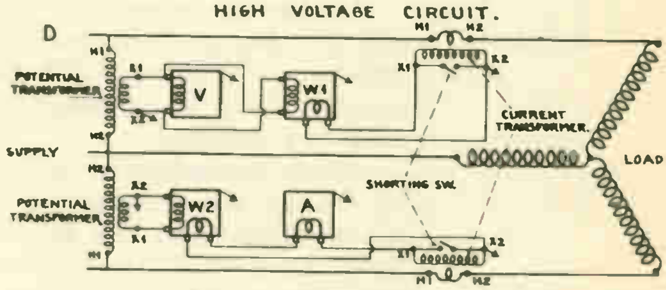


C



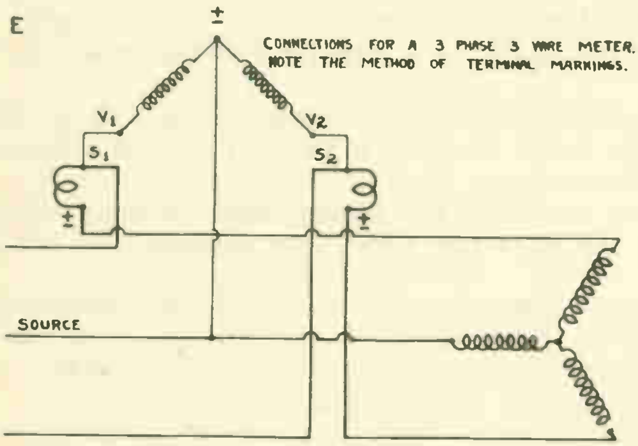
D

HIGH VOLTAGE CIRCUIT.



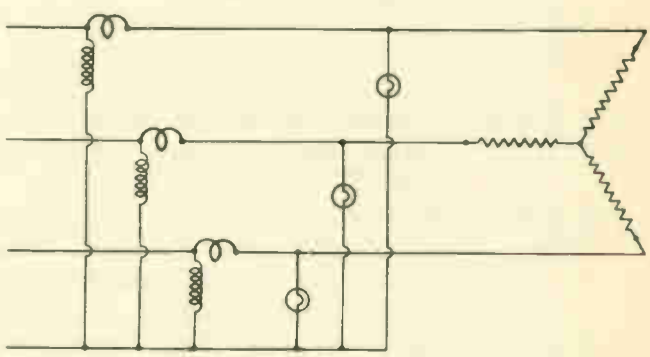
E

CONNECTIONS FOR A 3 PHASE 3 WIRE METER.
NOTE THE METHOD OF TERMINAL MARKINGS.



F

CONNECTIONS FOR A 3 PHASE 4 WIRE SYSTEM



1. A ( ) B ( ) With respect to the line, what is the connection (Series or parallel) made for: (A) the current element (B) the potential element of a wattmeter.
2. A ( ) B ( ) C ( ) D ( ) What is the minimum number of single phase wattmeters required to measure the total power of a 3-phase, 3-wire AC circuit? (A) 1 (B) 2 (C) 3 (D) 4.
3. A ( ) B ( ) C ( ) Procedure for polarizing or phasing 2 wattmeters is as follows: (A) connect current coils series with different line wires, potential coils parallel with any pair of lines (B) connect potential and current coils series with line 1 and line 2 (C) connect current coil of W1 series with line 1, that of W2 series with the same line, connect potential coils between line 1 and line 2.
4. A ( ) B ( ) C ( ) D ( ) If W1 reads 8000 W, W2 reads zero, the circuit power factor will be: (A) 100% (B) 80% (C) 50% (D) 40%.
5. A ( ) B ( ) C ( ) D ( ) An ammeter is generally connected in series with the wattmeter current coil to: (A) prevent overloading current coil (B) indicate wattless component of current (C) indicate total current carried by current coil and thus avoid overloading the element (D) indicate <u>in</u> phase component of current.
6. A ( ) B ( ) C ( ) A current transformer is used to: (A) Step up the current of the line (B) reduce the current to current elements of meters and relays, also isolate them from the high voltage, high power line (C) step the voltage up to a very high value.
7. A ( ) B ( ) C ( ) D ( ) Capacitors used to correct power factor of motor circuits are rated in: (A) MF (B) kw (C) KVA (D) ohms.
8. A ( ) B ( ) C ( ) D ( ) Capacitors used to correct power factor should be connected: (A) Series with line and load (B) parallel with line and load and located close to load center (C) Parallel with line and load and located at the source of power.
9. A ( ) B ( ) C ( ) If the load carried by an induction motor is increased from 75% to 100% how is the power factor of this motor circuit affected? (A) No effect (B) P.F. decreases (C) P.F. increases.
10. A ( ) B ( ) C ( ) D ( ) Current elements of wattmeters, ammeters and relays used in conjunction with current transformers are designed for a maximum current of: (A) 2I (B) 5I (C) 10I (D) 15I.
11. A ( ) B ( ) C ( ) Ammeter shunts are not used on a-c ammeters because: (A) they overheat in AC circuits (B) they cannot be constructed to carry very heavy currents (C) the effective resistance of the shunt varies due to skin effect resulting in inaccurate current indications.
12. T ( ) F ( ) The wattmeter registers the true power in watts because it responds only to that component of current which is in phase with the voltage applied.
13. T ( ) F ( ) Correct interpretation of readings on 2 single phase wattmeters is always possible without making a polarity or phasing test in 3 phase.
14. T ( ) F ( ) In a 3-phase, 4-wire circuit containing 3 single phase wattmeters, total W equals W1-plus W2 plus W3.
15. T ( ) F ( ) The secondary of an energized current transformer may be opened without damage to the unit or without endangering personnel.
16. T ( ) F ( ) A Potential transformer is a low capacity unit used to reduce voltage to meters and relays.
17. T ( ) F ( ) A 3-phase, 3-wire wattmeter will read forward regardless of circuit power factor because positive W always exceeds negative W.
18. ____________ A 3-phase, 3-wire circuit contains 3 wattmeters, an ammeter and a voltmeter. Write the formula for P.F. in such a manner as to indicate the presence of these meters in the circuit.

TRANSFORMER CONNECTIONS

Objective

To learn how to connect single phase transformers into three phase banks of transformers, which are used in distribution work, and to learn about single and three phase energies.

References

____

____

Average Time Required:

Tools, Equipment and Materials

1. 3 single phase distribution type transformers (on the job).
2. Test meters including a voltmeter (0-300) and ammeter (0-10-20) (on the job).
3. Necessary fuses and hookup wire
4. An ammeter plug type fuse.

Related Information

By way of review, the necessary voltage and current formulae are shown below:

STAR OR WYE	DELTA OR MESH	OPEN DELTA OR V
Line I equals Phase I	Line E equals Phase E	Line E equals Phase E
Line E equals Phase E x 1.73	Line I equals Phase I x 1.73	Line I equals Phase I
Phase E equals Line E x 0.58	Phase I equals Line I x 0.58	

NOTE: These formulae may be used to check meter reading accuracy.

Procedure Steps

1. Conduct "polarity test" as illustrated in the lesson. Identify starts and finishes of each phase. Indicate polarity as additive or subtractive.

   NOTE: You should be able to parallel two adjacent banks consisting of three single phase transformers or two three phase banks.

2. Study over part one (Fig. 1) on the next page to determine the necessary wiring and how it is to be done for a single phase transformer. Finish the wiring diagram.

3. Wire this part and double check each connection as it is put in place.

   NOTE: Start with the primary and when completed, wire the secondary. Ground connections when used, should be added last.

4. Before applying power to the circuit, have an instructor check your wiring.

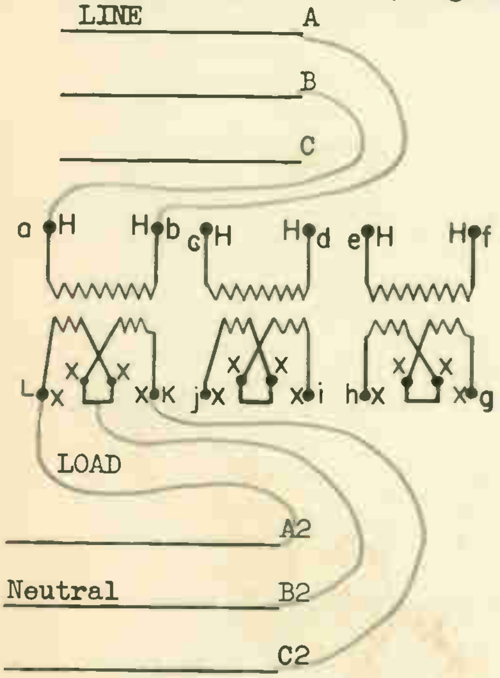
5. After your work is certified as correct, close line switch and record in the chart, the current and voltage values for phase and line. Have readings checked.

6. Proceed in the same manner with all of the remaining charts and parts according to required specifications.

7. Answer the summary questions at the end of the job.

8. Have the instructor check your completed job.

CONNECT
Pri. - Single Phase
Sec. - Single Phase (CT grounded)



PRI. LINE E	240
SEC. LINE E	120
E RATIO	2 to 1
PRI. LINE I	5A
SEC. LINE I	9A
I RATIO	2 to 1
A2 - B2 (E)	60
A2 - C2 (E)	120
C2 - B2 (E)	60

CONNECT
Pri. - Delta (Δ)
Sec. - Delta (Δ)

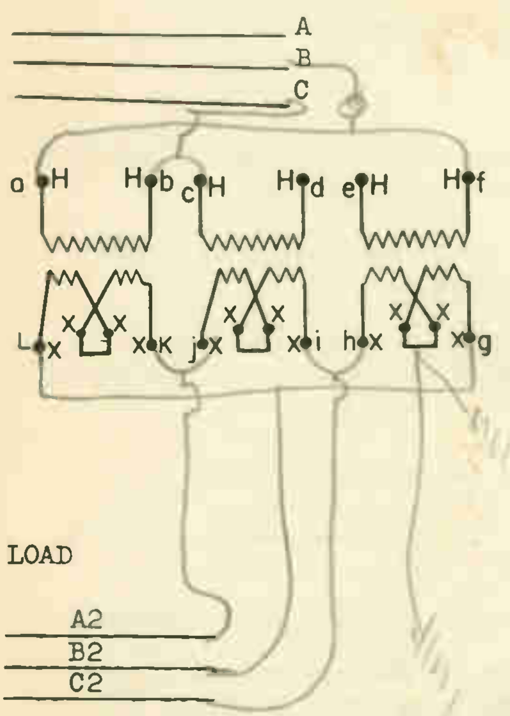


Fig. 2

VOLTAGE	VALUE
A - B	120
B - C	120
C - A	240
a - b	120
b - c	0
c - d	240
A2 - B2	60
B2 - C2	60
C2 - A2	120
l - k	60
j - i	120
h - g	60
A2 - gnd	0
B2 - gnd	0
C2 - gnd	90

CURRENT	VALUE
I_A	6
I_a	6
I_c	6
I_{A2}	11
I_l	6
I_j	6
E Ratio	2 to 1
I Ratio	1 to 2

NOTE: When voltages for primary and secondary have been recorded, connect to a secondary center tap and record voltages in the provided spaces.

CONNECT
Pri. - △
Sec. - Y

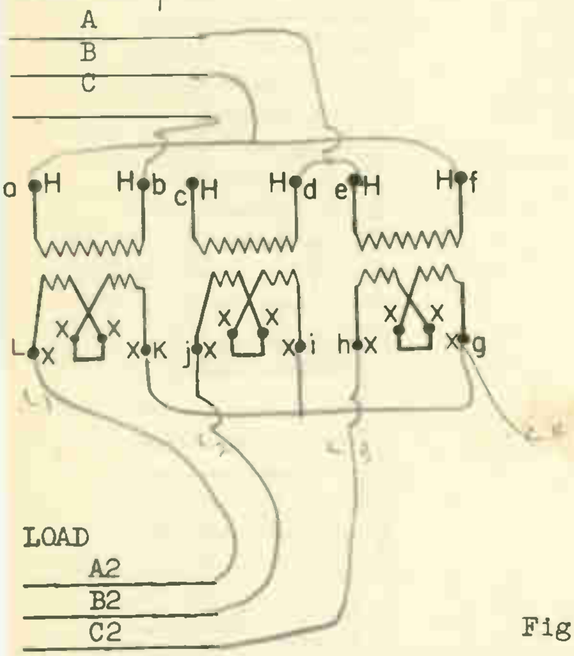
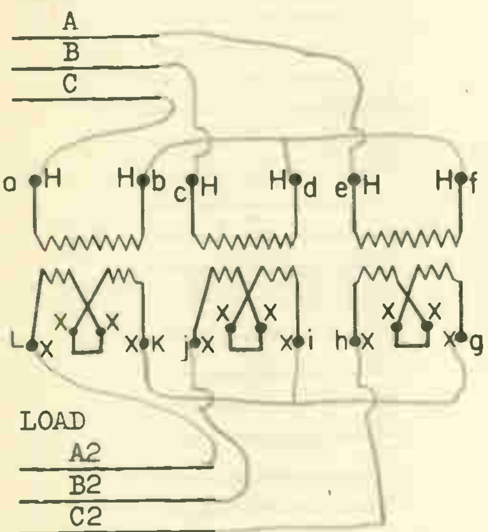


Fig. 3

VOLTAGE	VALUE
A - B	240
B - C	240
C - A	240
a - b	240
b - c	0
c - d	240
A2 - B2	208
B2 - C2	208
C2 - A2	208
l - k	120
j - i	120
h - g	120
A2 - Gnd	120
B2 - Gnd	120
C2 - Gnd	120
CURRENT	**VALUE**
I_A	17 A
I_a	17 A
I_c	17
I_{A2}	17
I_l	17
I_j	17
E Ratio	2:1
I Ratio	1:1

NOTE: Ground star point and record voltages obtained from ground to A2, B2, and C2.

CONNECT
Pri. - Y
Sec. - Y

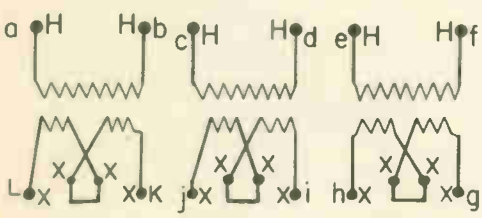


VOLTAGE	VALUE
A - B	240
B - C	240
C - A	240
a - b	140
b - c	140
c - d	140
A2 - B2	120
B2 - C2	120
C2 - A2	120
l - k	70
j - i	70
h - g	70
A2 - gnd	70
B2 - gnd	70
C2 - gnd	70
CURRENT	**VALUE**
IA	5
I_a	5
I_c	5
I_{A2}	10
I l	10
I j	10
E Ratio	2:1
I Ratio	2:1

NOTE: When voltages for Primary and Secondary lines and phases have been taken, connect a ground to the secondary star point and measure voltages from ground to A2, B2, and C2.

CONNECT
Pri. - Y
Sec. - Δ

LINE
A
B
C



LOAD
A2
B2
C2

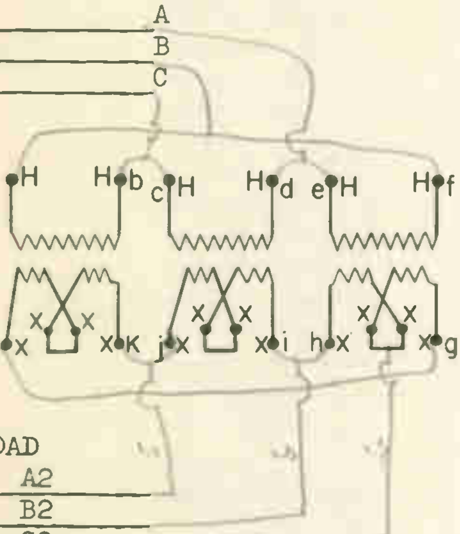
VOLTAGE	VALUE
A - B	240
B - C	240
C - A	240
a - b	146
b - c	146
c - d	146
A2 - B2	20
B2 - C2	20
C2 - A2	20
l - k	20
j - i	20
h - g	20

CURRENT	VALUE
I_A	1
I_a	1
I_c	1
I_{A2}	6
I_l	6
I_j	6

E Ratio [illegible]
I Ratio [illegible]

Fig. 5

CONNECT
Pri. - V
Sec. - V
LINE
A
B
C



LOAD
A2
B2
C2

VOLTAGE	VALUE
A-B	240
BcG	240
C-A	240
a-b	240
b-c	0
c-d	0
A2-B2	120
B2-C2	120
C2-A2	120
l-k	120
j-i	0
h-g	120

CURRENT	VALUE
I_A	5
I_a	5
I_c	0
I_{A2}	10
I_l	10
I_j	0

E Ratio [illegible]
I Ratio [illegible]

Fig. 6

1. A ( ) B ( ) C (X) The primary winding is identified as: (A) High voltage winding (B) low voltage winding (C) winding which is connected to the supply lines.

2. A ( ) B (X) The number of magnetic circuits in a shell type core is: (A) 1 (B) 2.

3. A ( ) B (X) C ( ) D ( ) Transformer oil in good condition should withstand: (A) 10,000 E (B) 22,000 E (C) 30,000 E (D) 50,000 E, on flash test with test electrodes separated one-tenth inch.

4. A ( ) B ( ) C (X) D ( ) Polarity of a transformer indicates: -- (A) Voltage ratio (B) If connection is Star or Delta (C) Relationship between correspondingly located terminals of Primary and Secondary at any instant (D) Polarity of Primary and Sec. windings.

5. A ( ) B (X) C ( ) D ( ) A polarity test may be made with: -- (A) A megger (B) A voltmeter (C) An ohmmeter (D) An ammeter.

6. A ( ) B (X) Secondary voltages to ground are as follows: Line 1 to ground--1150; line 2 to ground--1150; line 3 to ground--1992. Line E equals 2300. This transformer is connected: (A) Star (B) Delta.

7. A ( ) B ( ) ΔY ΔY Which 3 phase transformer connection gives?-- (A) Least line to line voltage <u>step down</u> ratio (B) Greatest line to line voltage <u>step up</u> ratio.

8. A ( ) B ( ) Y 4415 The voltage between secondary lines 1, 2, 3, and ground is 255. (A) what is connection made for secondary? (B) what is the line voltage?

9. A ( ) B (X) C ( ) D (X) What is the proper location of the high tension fuses used to protect the transformer? (A) Series with Sec. line (B) Series with Pri. Lines on high E side (C) Series with ground lead (D) Series with each phase on high E side.

10. Yes (X) No ( ) Is it possible to parallel two transformers, one of which is connected Delta-Delta, the other Star-Star?

11. A ( ) B ( ) 208 41.6 Three 5 KVA, 240/120E transformers are connected Delta-Delta. (A) What is the current rating of each unit on the high E side? (B) What is the current of each line on the high E side?

12. T ( ) F (X) Transformer cores are laminated to increase magnetic coupling between primary and secondary winding.

13. T (X) F ( ) Transformer oil serves as a cooling medium as well as insulation.

14. 51.9A If phase current of a Delta connected transformer is 30 I, what is the value of line I?

15. T (X) F ( ) Secondary V.A. is approximately equal to Primary V.A. because I ratio is inverse to E Ratio.

16. 20-1-20 If Np/Ns equals 20/1, what is the voltage ratio? What is the I ratio?

17. 51.29 3 Transformers of equal rating in closed Delta have a total capacity of 90 K.V.A. What is the capacity of 2 connected in open Delta.

18. 86.6 Two transformers of 50 KVA each are connected open Delta. What is the maximum load in KVA that may be carried without overloading these units?

SYNCHRONOUS MOTORS

Objective

To learn the principles of operation and the effects of using a power factor correction revolving capacitor called a synchronous motor.

References

____

____

Average Time Required

Tools, Equipment and Materials

1. Synchronous motor
2. Control panel with a three phase dry-disc rectifier

Procedure Steps

1. Study the diagrams carefully. If any part is not clear, refer to lesson 23 on synchronous motors and their controls.

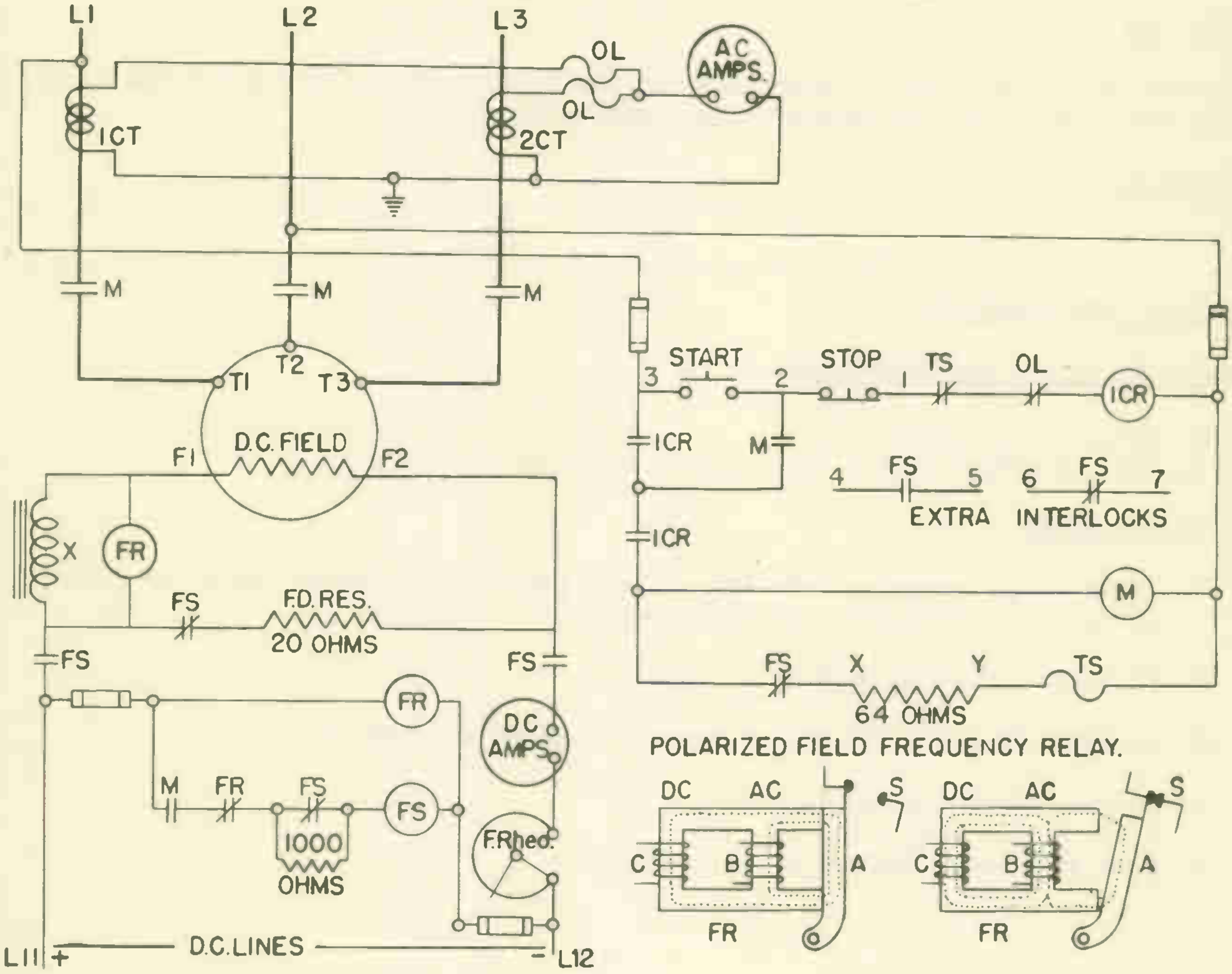
2. Trace all circuits and name them.

3. Operate the unit and adjust power factor to desired value.

4. Answer the review questions.

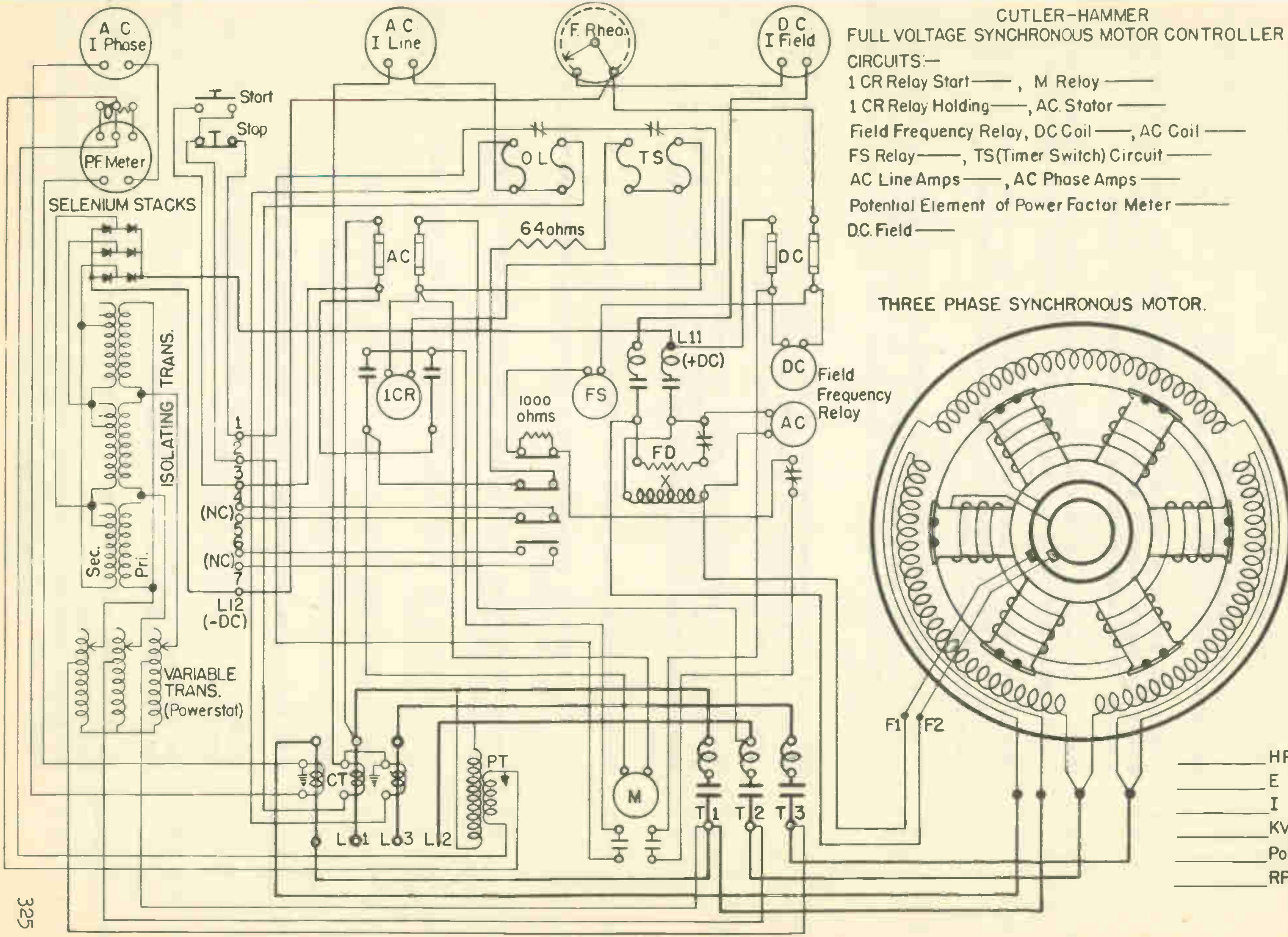
5. Have your work checked by an instructor

ELEMENTARY DIAGRAM, SYNCHRONOUS MOTOR CONTROLLER



CUTLER-HAMMER
FULL VOLTAGE SYNCHRONOUS MOTOR CONTROLLER

CIRCUITS:—
1 CR Relay Start ——, M Relay ——
1 CR Relay Holding ——, AC Stator ——
Field Frequency Relay, DC Coil ——, AC Coil ——
FS Relay ——, TS (Timer Switch) Circuit ——
AC Line Amps ——, AC Phase Amps ——
Potential Element of Power Factor Meter ——
D.C. Field ——



HP ______
E ______
I ______
KVA ______
Poles ______
RPM ______

Job No. 16

1. A ( ) B ( ) C ( ) D ( ) This motor is started as:-- (A) A split phase motor (B) a repulsion induction motor (C) A synchronous motor (D) An induction motor.

2. A ( ) B ( ) C ( ) DC field excitation should be applied when motor speed is:-- (A) Near synchronism (B) 50% of synchronous speed (C) at synchronism.

3. A ( ) B ( ) C ( ) D ( ) With field discharge switch in discharge position, the discharge resistor completes a circuit on:-- (A) Source of excitation (B) DC field winding (C) AC stator winding (D) the damper winding.

4. A ( ) B ( ) C ( ) D( ) What is the source of DC field excitation on this job? (A) Batteries (B) DC generator (C) Selenium rectifier (D) Tungar bulb rectifier.

5. A ( ) B ( ) C ( ) The power factor of the motor may be varied by: -- (A) Changing AC voltage applied to stator (B) Varying DC field excitation (C) Varying current of damper winding.

6. A ( ) B ( ) C ( ) D ( ) A synchronous motor operating in parallel with a group of induction motors corrects the power factors of the circuit up to 100%. At what P.F. is the synchronous motor operating? (A) 100% (B) Zero (C) lagging (D) leading.

7. A ( ) B ( ) C ( ) How would you reverse rotation of this type motor? (A) Reverse leads of DC field (B) Reverse 2 leads of AC supply lines (C) Remove stator core and turn it through 180 degrees then replace it.

8. A ( ) B ()) C ( ) D ( ) When operating normally the speed of the motor may be controlled by:-- (A) Varying the Ac voltage (B) Varying the DC field excitation (C) Varying the frequency of the AC applied (D) changing the number of poles.

9. T ( ) F ( ) The synchronous motor develops high starting torque.

10. T ( ) F ( ) Hunting action is impossible in a synchronous motor operating with normal field excitation.

11. T ( ) F ( ) Over-excitation of field causes the motor to draw a lagging current from the supply lines.

12. Yes ( ) No ( ) Is it possible to carry both a mechanical and a P.F. load on this moto at the same time?

13. A ( ) B ( ) The stator of this motor is connected: -- (A) Star (B) Delta.

14. __________ What is the value of phase current at full load?

15. __________ From motor name-plate data determines KVA rating of motor.

16. __________ If this motor carries a ______ KW mechanical load, how much RKVA can carry for power factor correction?

17. T ( ) F ( ) The position of the field discharge switch is not important during the starting period for a synchronous motor.

18. __________ At what speed will this motor operate if the frequency is reduced from 60 to 50 cycles?

19. T ( ) F ( ) The damper winding is entirely inactive during normal synchronous operation.

PARALLELING THREE PHASE GENERATORS

Objective

To learn, by practical experience, how to operate a generator and parallel another to the first to increase the total generator output capacity.

References

____

____

Average Time Required

Tools, Materials and Equipment

1. Six small cartridge fuses
2. Three large cartridge fuses
3. Necessary hookup wire
4. Two generators
5. Phasing equipment such as motors, lamps, etc.

Procedure Steps

1. Study diagram carefully and review chapter 25.

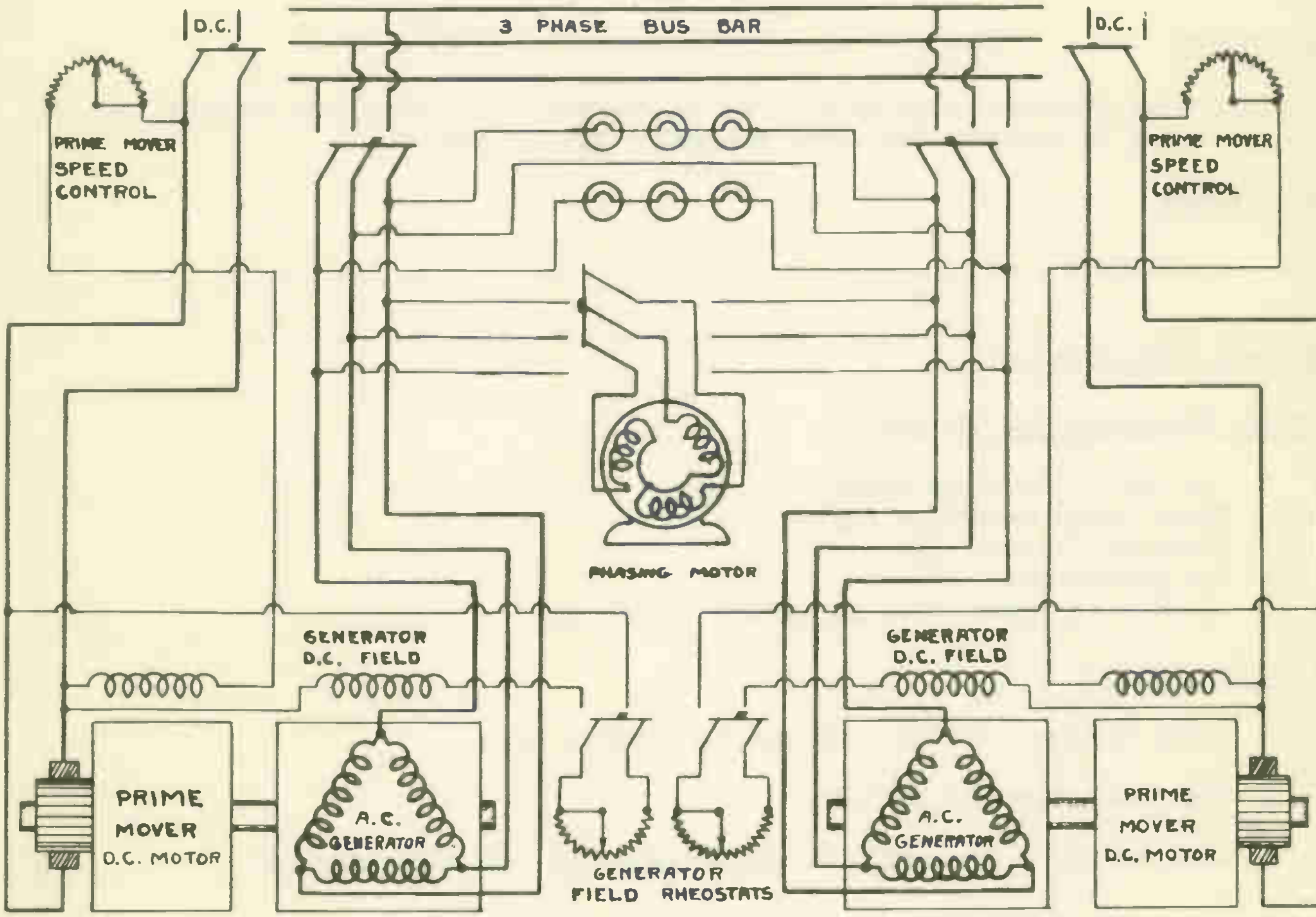
2. Trace and name all circuits

3. Wire the units according to the diagram and test each machine.

4. Phase out generators

5. Parallel units

6. Have the instructor check your work and questions.


D.C.
3 PHASE BUS BAR
D.C.
PRIME MOVER SPEED CONTROL
PRIME MOVER SPEED CONTROL
PHASING MOTOR
GENERATOR D.C. FIELD
GENERATOR D.C. FIELD
PRIME MOVER D.C. MOTOR
A.C. GENERATOR
GENERATOR FIELD RHEOSTATS
A.C. GENERATOR
PRIME MOVER D.C. MOTOR

1. A ( ) B ( ) C ( ) Alternators with capacities above 50 KVA commonly have: (A) revolving d-c fields and stationary armatures (B) stationary d-c fields and revolving armatures (C) both field and armature windings on the stator.

2. A ( ) B ( ) C ( ) Rotors with non salient poles are used on: (A) induction type alternators (B) large high-speed alternator (C) large low-speed alternators.

3. A ( ) B ( ) C ( ) D ( ) Induction type alternators are employed where: (A) high frequency is desired (B) large amounts of power are required (C) unusually low frequencies are desired (D) high current at low voltage is required.

4. A ( ) B ( ) C ( ) D ( ) The most common source of d-c field excitation for alternators is: (A) Batteries (B) A separate motor-generator set (C) a d-c generator mounted on the shaft of the alternator (D) self excitation.

5. A ( ) B ( ) C ( ) The procedure of correctly connecting 2 or more alternators to the common bus bar is known as: (A) Phasing out (B) Synchronizing (C) Paralleling.

6. A ( ) B ( ) C ( ) When the instantaneous value of voltage of 2 alternators is exactly equal and at exactly the same point in the cycle, the generators are said to be: (A) Phased out (B) in synchronism (C) Paralleled.

7. A ( ) B ( ) C ( ) Varying the d-c field excitation of an alternator which is operating independently of others will: (A) vary the frequency (B) vary the terminal voltage (C) vary the speed of the prime mover.

8. A ( ) B ( ) C ( ) A synchronscope is an instrument used to indicate (A) proper phasing (B) synchronism (C) frequency.

9. A ( ) B ( ) C ( ) An alternator operating in parallel with others may be caused to take up a power load by: (A) increasing d-c field excitation (B) increasing power input to the prime mover (C) Decreasing power input to the prime mover.

0. A ( ) B ( ) C ( ) From generator name plate data determine: (A) Number of poles ______ (B) Frequency ____________ (C) Va at full load ____________

1. T ( ) F ( ) Alternators used in hydro-electric plants are usually of the vertical shaft type.

2 T ( ) F ( ) A field discharge switch is used to connect a resistor across the DC field of the alternator to protect the field from high self induced voltages at the instant excitation is discontinued.

3. T ( ) F ( ) The paralleling switch should be closed at the instant when the synchronizing lamps are dark.

4. T ( ) F ( ) If field excitation is reduced below normal on an alternator operating in parallel with others, it will draw a leading current.

5. T ( ) F ( ) The frequency of a-c generator varies directly as the number of poles and directly as the speed at which it operates.

6. T ( ) F ( ) The amount of energy required for field excitation rarely exceeds 5% of the amount of energy carried by the stator winding of an alternator.

SWITCHBOARD OPERATION

Objective

To learn how to parallel generators on an operating line. To learn to "load" generators and basic switchboard procedure.

References

Average Time Required:

Tools, Equipment, and Materials

1. Power distributions switchboard
2. Two motor-generator sets

Procedure Steps

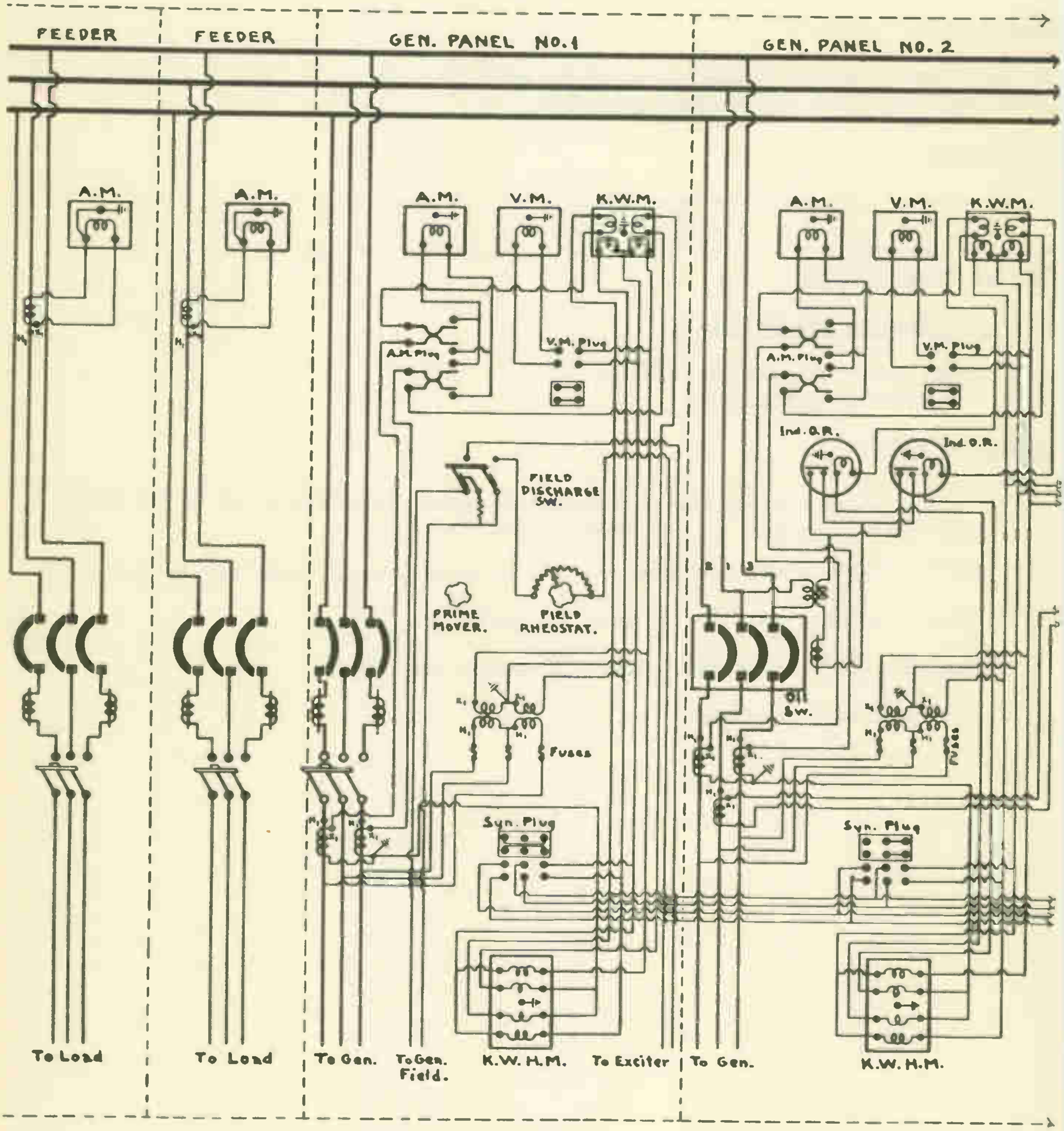
1. Listen carefully, to the instructor who gives the explanation of all parts and their purposes, on the power switchboard.

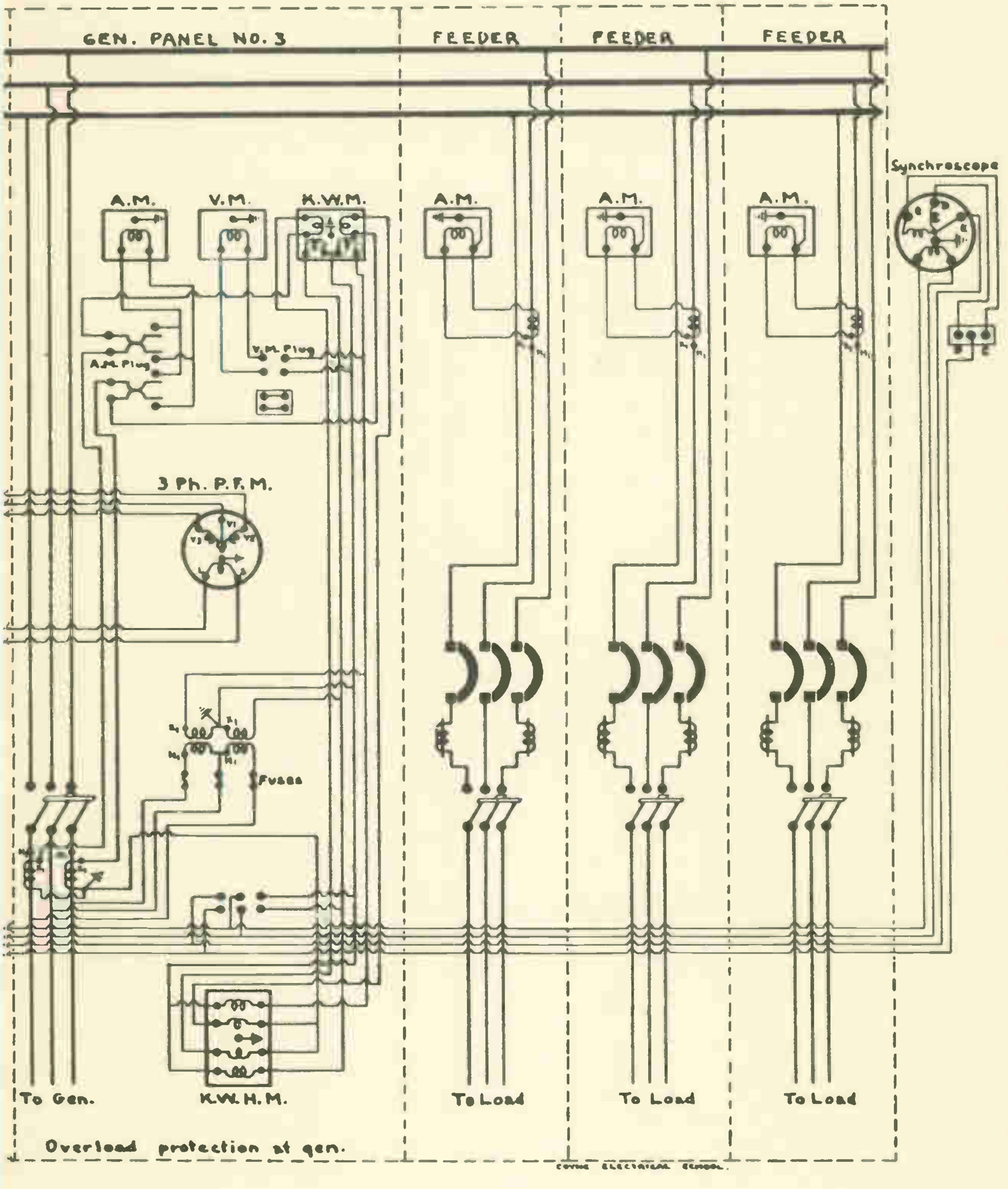
2. Review chapters on "transmission of electrical energy" and "generators".

3. Trace circuits indicated by your instructor.

4. Parallel switchboard generators with public service.

5. Have your work checked.


FEEDER
FEEDER
GEN. PANEL NO. 1
GEN. PANEL NO. 2
A.M.
A.M.
A.M.
V.M.
K.W.M.
A.M.
V.M.
K.W.M.
A.M. Plug
V.M. Plug
A.M. Plug
V.M. Plug
Ind. O.R.
Ind. O.R.
FIELD DISCHARGE SW.
PRIME MOVER.
FIELD RHEOSTAT.
Oil Sw.
Fuses
Fuses
Syn. Plug
Syn. Plug
To Load
To Load
To Gen.
To Gen. Field.
K.W.H.M.
To Exciter
To Gen.
K.W.H.M.


GEN. PANEL NO. 3
FEEDER
FEEDER
FEEDER
Synchroscope
A.M.
V.M.
K.W.M.
A.M.
A.M.
A.M.
A.M. Plug
V.M. Plug
3 Ph. P.F.M.
Fuses
To Gen.
K.W.H.M.
To Load
To Load
To Load
Overload protection at gen.

FREQUENCY CONVERTER

Objective

'o learn about frequency changers and the uses where this machine may be used to advantage.

References

Average Time Required

Tools, Equipment and Materials

Related Information

High speed tools such as drills, polishers, routers, and shapers are sometimes driven by three phase induction motors operating at high frequencies obtained from a frequency changer set. Figure 1 shows the schematic diagram of the necessary equipment. The frequency changer consists of a slip ring or wound rotor machine, which has its stator excited from the 60 cycle supply line. If the rotor is driven in a direction opposite to that it would normally rotate with closed rotor circuit, higher frequency is induced in the rotor winding and is available at the slip rings for application to load apparatus. When the rotor is driven at normal speed against the revolving field of the stator, rotor frequency will be doubled or 120 cycles. A 2 pole motor supplied with this frequency will operate at a speed of 7200 RPM (stator field). If the rotor is driven at 2 times normal speed, rotor frequency will be tripled or 180 cycles per second. The motor speed then becomes 10,800 RPM (stator field).

A constant torque, 2 speed consequent pole motor is used as a prime mover, to drive the frequency converter. It is designed to operate as a 2 pole (salient) motor at 3600 RPM with T4 T5 T6 connected to the supply, T1 T2 T3 shorted together to form a parallel star connection.

Procedure Steps

1. Complete these connections by jumper on the drum switch shown in the figure.

   NOTE: The slow speed connection is completed at the drum with T1 T2 T3 connected to the supply lines, and T4 T5 T6 are left open to form a series delta for 4 poles consequent (1800 RPM - Stator field).

2. Complete these connections on the drum switch also.

3. Trace the circuits and name them.

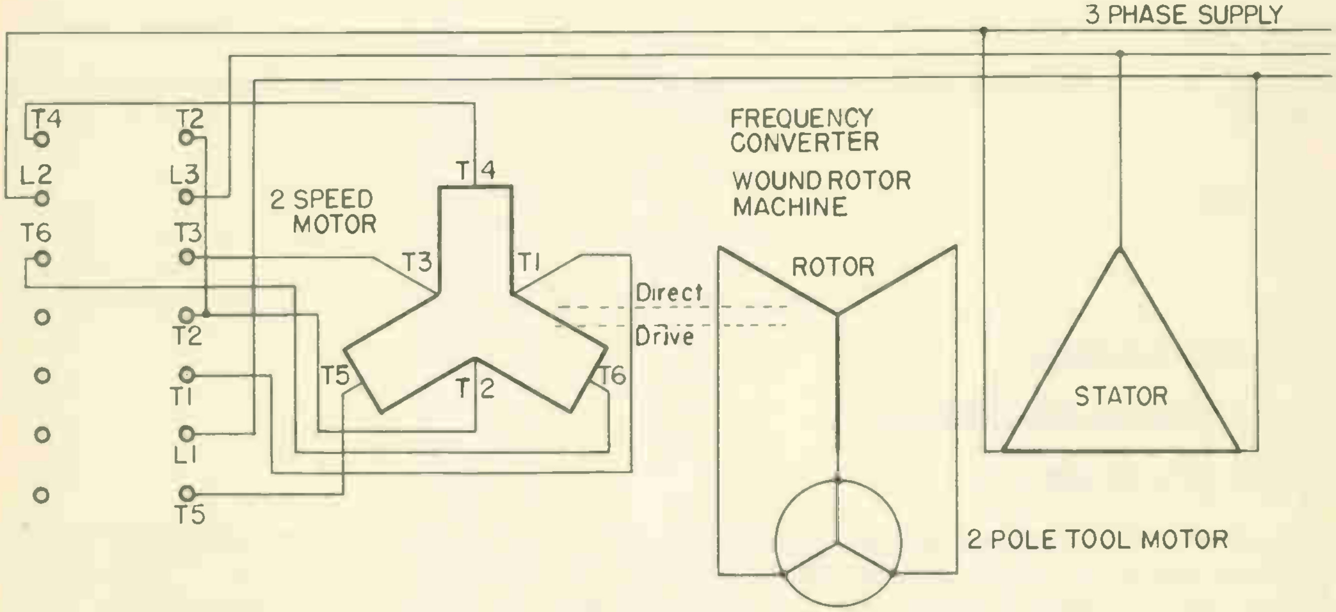

3 PHASE SUPPLY
T4
L2
T6
T2
L3
T3
T2
T1
L1
T5
2 SPEED MOTOR
T4
T3
T1
T5
T2
T6
Direct
Drive
FREQUENCY CONVERTER
WOUND ROTOR MACHINE
ROTOR
STATOR
2 POLE TOOL MOTOR

Fig. 1