A STUDY OF RE-CONNECTING
INDUCTION MOTORS

A Thesis Submitted to

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By

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Bibliography

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PREFACE

The advance of electricity in the commercial field in replacing steam, water, or gas accentuated prime movers has been extremely rapid in the past half century. It was soon found that alternating current was the most feasible form of power transmission so that apparatus was designed to use this.

In trying to reproduce the good characteristics of the direct current machines, the induction motor was the first to be developed and up to the present time it has not been surpassed although it is by no means perfect. The large installations and then the necessity of a change meant that the machines must be changed to meet these new conditions or else they must be scrapped and new machines purchased. The reasons for these changes are:

(a) Moving the site of the factory.

(b) Changing over to central station service.

(c) Raising of the line voltage because of over-loaded system.

If the industry was to prosper some remedy for this frequent necessity of scrapping machines must be found. Investigation and research discovered as one means of solution the possibilities of re-connecting the motors to meet the new conditions.

This phase of the several solutions has been chosen as the field of our investigation as applied to the machine in the department which is a rebuilt 220 volt, 4 ampere, 2 phase, 4 pole, 60 cycle, 2 horsepower, series connected induction motor manufactured by the General Electric Company, Inc.

We wish to express our thanks to the department for the assistance which they gave us in the preparation of this thesis.

PART I

In all problems involving a change in motors there are at least two fundamental conceptions that must be understood. The first is that

$$\text{Horse-power} = \frac{\text{Torque} \times \text{Speed}}{5252}$$

and conversely,

$$\text{Torque} = \frac{\text{Horse-power} \times 5252}{\text{Speed}}$$

Torque is the rotative effort produced by current flowing in conductors in the presence of a magnetic field. It is proportional then, to the current in the conductors and the flux in the iron. In changing a motor the amperes per square inch in the copper and the flux density per square inch in the iron should be kept constant or as near the value which the designer intended for the machine as is possible. This would always be true were it not for the fact that with these quantities constant the motor would run hotter at slow speeds due to the reduction of cooling air which the machine circulates through itself by centrifugal action. For this reason the capacity of a motor may increase in proportion with the speed when increasing the speed above normal but when decreasing the speed below normal there is a more rapid decrease in the capacity of the motor than the proportional speed decrease would lead one to assume. So returning to our equation, keeping the densities constant means that our torque remains constant and so the horse-power will vary with the speed.

It is essential then that we do not confuse the terms horse-power and torque. It is the function of a motor to produce torque but it is not till this torque is allowed to cause rotation that we have horse-power produced. In other words although a motor may be drawing a current equal to that which it draws at full load yet our horse-power is zero until the motor begins to rotate.

The second conception is that all motors act as generators in addition to the motor action. If we, for the moment, forget the torque action of a conductor carrying current in a magnetic field and think of that conductor as passing through a magnetic field thus cutting lines of force, this produces an electro-motive force which is called counter electro-motive force. This counter electro-motive force is nearly equal to the impressed electro-motive force or the line voltage so that the design of a motor is really the design of a generator for the line voltage. This gives us fundamental equations to work from in the changing of any of our factors.

The capacity of our machine will depend upon the capacity of the copper for carrying the current and the capacity of the iron for carrying the flux. The heating of the machine will depend upon the amount of current flowing in the conductors and the hysteresis loss in the iron. But if we change the voltage, frequency, or phase of the supply we must still keep these densities the same unless we also change the speed of the motor. The result is that the capacity of the machine must remain constant and we therefore, sacrifice the possible horse-power obtainable in altering our machine in any way unless we divert from our rule for constant densities.

To better illustrate this point the following are given as an example: If a motor was originally connected in series for 440 volts and we changed the connections to parallel star the voltage should be cut in half and the latter connection draws twice as much current as the original machine. If we change from series star to series delta the new voltage should be 0.5775 of the original or the reciprocal of 1.73 giving us the new voltage as 254 volts.

In changing from the star to the delta connection we now only have 75% of the original torque. The characteristics of our machine, however, are not changed appreciably in changing from a series to a parallel connection. Another change which is by no means common or suggested as good practice is changing from three phase to two phase or vice versa. The resulting performance with regard to heating, efficiency, power factor, and insulation is the same as if the machine was operated on three phase at 125% normal voltage. That is, the heating or rise in temperature is greater and the power factor is reduced. Also when such changes are made the position of the phase coils must be changed in order to bring them at the point of maximum difference of potential which is between phases.

The more common practice in re-connecting motors of three phase work is to make them two speed machines. In such a connection the distribution factor is only 86.6% as good on the low speed as it is on the high because the coils for one pole of the former are spread over an equal part of the periphery as for the machine with the lesser number of poles. The operation on such a connection is only possible by the production of consequent poles in that all the coils of any one phase are so connected as to give the same polarity. It being impossible to establish a field with only one kind of pole we have produced immediately an equal number of consequent poles of the opposite polarity. Another point to consider in the two speed consequent pole connections is the resultant torque and horse-power of the motor. To change from a parallel star to a series star on such a connection and applying the proper voltage for such a connection the result is to leave the torque constant and there is twice the horse-power on the series connection. To change from a parallel star to a series delta with the corresponding voltage change the horse-power remains constant but the torque is cut in half for the series connection.

The things which are possible of change to the supply of any motor are voltage, phase, and frequency. That which may be changed on the motor itself is the number of poles and consequently the speed of the machine. The two factors which determine the possibility of re-connecting, by their effect on the operating characteristics are:

(a) The throw of the coils.

(b) The phase insulation, it's location and number. The span of the coils should be the quotient of the periphery divided by the number of poles. It is a mechanical possibility to spring form wound coils one or two slots if necessary to do so. Such a motor with symmetrically placed phase windings gives full pitch and is the ideal motor. The flux density, primary current, and secondary current in such a motor are sinusoidal. But there are times when attempting to obtain the proper number of effective turns, or desiring to use form wound coils in a motor of small bore and few poles, or in the desire to reduce the space required for end connections, or wishing to secure better ventilation of the motor, or desiring to save in the amount of copper and insulation that we cannot use full pitch. We can then resort to what is known as fractional pitch or the space covered by the coil is not equal to the quotient of the periphery divided by the number of poles. The effect of using this fractional pitch is the same as would be produced on full pitch when the number of conductors are reduced with the added reduction of course in the end-wise length of the coils. In an induction motor of the low-resistance squirrel cage style supplied with a simple harmonic electro-motive force the gap flux is approximately sinusoidally peripherically distributed. But to use the fractional pitch means a change in the chord factor which causes a loss in the effectiveness of the electro-motive force generated because different conductors of the same phase are under the influence of electro-motive forces of opposite sign at the same instant.

So, in considering the various forms of useful re-connection a factor must be taken into consideration which has a great deal to do with the operating characteristics due to this differental effect of the motor after the change is made. This factor is the throw of the individual coils or the number of slots spanned by the two sides of a coil.

Theoretically, the span of the coil must equal the quotient of the periphery divided by the number of poles or the number of slots in the periphery divided by the number of poles. It is, however, not generally understood that increasing or decreasing the span of the coil has an effect similar to increasing or decreasing the effective number of turns of wire in a coil. The coil produces it's maximum effect upon the magnetizing field when it is exactly from the center of one pole to the center of the next. The coil is then said to span 180 degrees electrically. It is sometimes necessary and appropiate to make the span of the coil less than or greater than full pitch to obtain the desired number of effective turns. This is known as fractional pitch or chord winding.

To illustrate this, let us take our machine of thirty-six slots and wind it for four poles. The coils will be in full pitch if wound with a span of 36/4 or 9 slots. This means that one side of the coil would lie in slot number one and the other side of the coil would lie in slot number ten thus giving us a span or throw of nine. This coil would span 180 electrical degrees. The sine of one-half of 180 degrees or 90 degrees is 1. Therefore, the turns in this coil would have a maximum effect in producing the magnetic field. Suppose that the coils are left in their slots with a span

of one to ten but that the coils are re-connected for a six pole machine. Full pitch on the six pole machine would mean a span of one to seven or a throw of 6. Therefore, we are using 150% pitch on the six pole connection. And 180/6 equals 30, therefore, each represents 30 electrical degrees. Also 30 x 9 equals 270 degrees which represents the actual span of the coil in degrees by using a throw of nine instead of six. The sine of one-half of 270 degrees or 135 degrees equals 0.707 which means that when connected for six pole the coils have an effect of only 0.707 as against 1.0 when connected for four pole. The expression "sine of one-half the angle" spanned by the coil is called chord factor and must always be considered when re-connecting motors. In changing from four pole to six pole in the above example the chord factor changes from 1.0 to 0.707 and the new line voltage should be 1/0.707 of the old, neglecting the effect of other changes. If the motor had a normal voltage of 220 on four poles the new voltage on six poles should be 220/0.707 or approximately 310 volts. If it was still operated at 220 volts it would be thought of as operating at about 29% under voltage. This of course is beyond the limitations of good operating characteristics.

A clearer conception may be obtained by comparing the windings of an actual machine with those of an ideal motor. The theoretically ideal motor would have a large number of equal, symmetrical, simple harmonic electro-motive forces. In this case the gap flux would be distributed sinusoidally around the gap periphery at any instant and these distributions would revolve smoothly around the periphery at synchronous speed.

In the actual machine the number of phases is small however and there must therefore be several adjacent conductors carrying current of the same phase at any one instant thus forming what might be called a "belt of conductors" in which the current increases and decreases as a unit. On either side of this belt would be another belt the current in which differs from that of the first by 60 degrees for three phase and 90 degrees for two phase. Thus it is seen that the current varies from point to point around the periphery by steps rather than gradually as in an ideal motor.

If now these coils are wound less than full pitch it can readily be seen that the current in the two coils of different phase but in the same slot will over-lap and decrease the effectiveness of this magnetizing flux. Also different conductors of the same phase belt will at certain periods have induced in them electro-motive forces of opposite sign. This cutting of the flux by conductors of the same phase belt may be termed differential action and the factor by which the total electromotive force must be multiplied in order to obtain the actual resulting electro-motive force is termed the differential factor. Thus the differential factor though used in a different sense than chord factor has an effect similar to that of chord factor. The two terms frequently used indiscriminately inasmuch as the one cannot be changed without changing the other by a proportionate amount.

In all induction motors we have reactance caused by slot leakage, tooth-tip leakage, coil end leakage, and reactance component of the exciting current. The effect of fractional pitch on these factors is to reduce the leakage reactance components, the over-all length of the motor, to make it more convenient for winding and a saving of space, and to decrease the reactance component of the exciting current.

The voltage supplied to the machine may be changed from the normal about 10% either way without changing the end connection or effecting the performance characteristics to any great extent. Changes above normal which are greater than this should not be attempted because of the possibility of insulation break-down in addition to the effect on the performance curves. Manufacturer's have two classes of insulation, the first of which is good for voltage up to 500 and the other being good for 2500 volts. The former is used, of course, on most of the machines because voltages as supplied to the building do not exceed 500 volts as a rule. As far as insulation properties are concerned a decrease in voltage from normal would not be objectionable but when this decrease is greater than 10% the characteristics are changed to a great disadvantage. More specifically stating the effects of voltage change, we have the following changes in performance characteristics for 10% decrease from normal:

(a) Decrease the magnetic density because there is less exciting current at the lower voltage.

(b) Increase the leakage current.

(c) The starting torque remains the same but the pull-out torque is less.

(d) There is an increase in the percent of slip.

(e) The friction and windage remain the same because there is no change in the speed of the machine.

(f) In decreasing the magnetic density we decrease the iron losses in the laminations of the machine.

(g) The power factor is slightly better.

(h) The primary and the secondary losses are slightly increased.

(i) The apparent efficiency of the machine remains the same due to the change in the various losses but the actual efficiency is somewhat lower.

To consider the other change which is operating at over voltage our performance characteristics are changed as follows:

(a) The magnetizing current is increased thus raising our magnetic density and making our iron losses greater.

(b) The speed remaining constant the friction and windage are not changed.

(c) The primary and secondary copper losses are less thus decreasing the leakage current. Thus as an aggregate the losses are smaller and our efficiency is slightly increased.

(d) An increase in our magnetizing current causes greater flux and therefore the torque is increased in proportion.

(e) Our power factor is lowered and our slip is decreased.

(f) The apparent efficiency of the machine remains the same and there is an increase in the temperature rise due to magnetic density being raised.

The characteristic changes as outlined for both 10% under and over-voltage are present at fractional loads as well as at full load. As a result of these points we might say that any change greater than 10% from normal would give a wide variation from the performance at rated voltage and is therefore prohibitive.

Refering again to change in the number of poles it might be said that a change of two poles either way is permissible but not recommended. And if it is done without changing the span of the coils then the chord factor must be determined to be positive that it is not too low or too high. At the same time the impressed voltage should be altered in proportion with the change in chord factor or else it should be clearly understood that the motor is operating above or below normal voltage. This gives rise to a change in our performance curves and since the usual change is greater than 10% then the operation is only fair. The exception to this when changing the number of poles is when the number is doubled or consequent poles are used.

Phase changes have been mentioned before so here we will only sum up a few points which refer to this change when not in conjuction with other changes. The most usual change is re-connecting the motor from two phase to three phase or vice versa. Theoretically for the same line voltage there should be 25% more current in the two phase motor than in the three phase. To have the same current density on the three phase machine as there is on the two phase the horse-power should be cut 12% from that of the two phase. But on the whole it is bad practice to change the phase of the machine not only for the reason of changing the performance curves but also the fact that the phase coils must be changed which means that all the coils must be taken out of the slots and then put back in again in order to properly locate the phase coils. This is a mechanical job that requires skill and inherently causes many shorts due to damaging the insulation when taking out and replacing the coils.

We now come to the discussion of a change which though rare is not nevertheless without the scope of possibility and which when it is encountered touches upon several points all of which must be carefully considered in making the desired re-connection. If no alterations were made on the machine then a change in frequency would be accompanied by a change in speed of the motor. The first and most important question then is "Will the mechanical design stand the new speed?" If so then the load must be adapted to this new spedd by some means such as a change in the ratio of the pulleys if it is a belt drive. If not possible to make the load operate under the new conditions then the motor should be changed to a new load where it will meet the requirements of the drive under it's new performance characteristics. If the frequency of the supply is to be changed and it is desired to keep the speed of the motor the same then the number of poles in the machine must be changed in the same ratio as the frequency was changed. Also to keep the same density in the motor the voltage should be varied in the same proportion as the frequency. In changing the number of poles in the motor to keep the same speed we encounter the difficulties of taking care of the changes in the magnetic circuit. Because we must remember that the total magnetic flux is divided into as many equal parts as there afe poles. And the iron below the teeth has to carry this flux for each circuit. The greater the number of poles which we have the less amount of flux there will be for the iron below the teeth to carry and consequently the cross-sectional area may be reduced. We can thus see that it is an easy matter to raise the frequency because therew ould be less material required and consequently a motor has a surplus of iron for the magnetic circuits. This readily explains the reason that the rotor diameter is different in machines of the same horse-power and speed operated on different frequencies when the outside size of the motor is the same for both conditions. And, too, we must remember that the rotor short circuiting rings have their current paths divided in propörtions to the number of poles, the total rotor current being constant. This would require rings in motors for low frequencies.

The question now arises what effect will the change of frequency have upon performance characteristics? To lower the frequency we have the following changes:

(a) The iron loss is higher due to the greater density of the iron.

(b) The friction and windage are less due to a decrease in speed.

(c) The copper losses remain constant.

(d) Magnetization current is increased because working higher on the B-H.

(e) The power factor is decreased.

(f) The slip is the same.

(g) The torque is greater because of increase in magnetic density.

(h) The resulting efficiency is the same.

As a total result we have the same efficiency, a lower power factor, reduced speed, and an increased torque.

On increasing the frequency the changes are almost diametrically opposite to the preceeding discussion. To enumerate them they are as follows:

(a) Better power factor.

(b) Decreased torque due to decrease in magnetic density.

(c) Friction and windage increased.

(d) Iron losses are lower.

(e) Copper losses remain the same.

(f) Decrease in magnetizing current.

(g) Higher leakage factor.

(h) The slip is the same.

(i) Efficiency not changed.

As a general rule then we may say that a change in frequency should be accompanied by a corresponding change in voltage to correct the changes in performance curves.

In grouping the slots to determine the number per phase per hole it is not always necessary that the total number of slots shall equal the product of the phase and the number of poles. In other words the grouping need not be equal and those groups which have a different number of coils in the group from the required number can be placed symmetrically around the machine and the total effect will not distort the performance characteristics. Mr. E. M. Tingley has an article in the Electrical Review, January 1915, on this problem which he calls the Least Common Multiple method of winding induction motors of odd number slots.

As a general conclusion to our discussion on possibilities of re-connection we may say that those changes which give satisfactory performance are:

(a) Voltage changes.

(b) Pole changes which are limited by the mechanical form of the coils.

(c) Frequency changes either alone or in combination with voltage or phase, but at the expense of a change in the speed of the motor. Also in such changes the fact must be always in mind that the peripheral speed of the rotor should never be over

7000 feet per minute without checking the mechanical design for the strains produced.

In determining the effect of changes either phase, poles, or frequency it is best to handle the change by reducing them to an equivalent voltage change and then determine the factors for good performance.

PART II

EXPERIMENTAL DATA

In order to perform the experiment of re-connecting the machine for the various two and three phase connections and to determine the relationship of voltage exsisting with these various connections it was necessary to remove the form wound coils which were originally in the machine. These coils consisted of nineteen turns of wire per coil. In their place were inserted six number fourteen rubber covered wires in each slot thus making three turns per coil. The ends of each wire were brought to a separate terminal on the board which was fastened at each end of the motor and were arranged in symmetrical, radial rows on the circumference of six equally spaced circles. The back coil and connections were then permanently made with a throw of one to ten. This is full pitch for the machine as originally wound.

No connections or tests were run which necessitated the changing of the pitch or the removal of the coils from their slots if form wound coils were used or which could not be run if form wound coils were used in place of the single conductors. Number fourteen wire was also used for all coil ends and coil group connections. In all the tests however it was impossible to take any brake tests and make comparisons because of the absence of a pulley to fit the rotor shaft. Therefore all tests and data collected are under no-load conditions.

Connection	Voltage required	Voltage applied	Current amps.	R. P. M. Gen.	R. P. M. Motor	Slip %
Two phase series four pole	52	52	13	1800	1785	0.835
Two phase two parallel four pole	26	50	58	1800	1730	3.88
Two phase three " four pole	17	30	82	1800	1770	1.61
Three phase series star four pole	65	58	21	1775	1761	0.62
Three phase series delta four pole	38	47	33	1775	1756	1.07
Three phase parallel star four pole	33	36	40	1820	1789	1.7
Three phase parallel delta four pole	19	21	47	1805	1785	1.11
Three phase series star eight pole (consequent)	65	87	46	1750	800	10
Three phase series star six pole	91	86	34	1760	1175	
Three phase series delta six pole	53	48	66	1790	1190	
Three phase parallel star six pole	46	35	65	1770	1192	
Three phase parallel delta six pole	27	(Current too large to run test)				
Three phase series delta twelve pole (consequent)	53	50	88	1790	590	1.18
Three phase series star twelve pole (consequent)	91	85	36	1790	593	0.59

The winding diagram shown in this thesis were all employed on the machine tested and are typical of those in general use by all motor manufacturers. They are by no means complete in the sense of covering all possible combinations of phase and poles but they serve to illustrate the points brought out in this thesis and are sufficiently general also to cover all points which may arise in connection with similar diagrams for other number of poles and phases.

Fig. 7 represents a combined conventional and schematic method of representing a three phase four pole winding connected in series star. Since there are three times four or twelve polar groups and thirty-six coils there are three coils connected in series to form what is called a polar phase group. It should be borne in mind that there are not actually twelve magnetic poles in a machine for the reason that three consecutive polar phase groups unite to form one magnetic pole by virtue of the phase difference of the currents in the three phases. Considered magnetically there are two north and two south poles formed by the winding at any instant and these poles are equally spaced around the air gap just as in the case with four mechanically projecting pole pieces excited by four coils carrying direct current. Something of this conception is gained if one imagines the armature of a direct current generator held stationary and the field poles rotated around it. At any given instant the magnetic field can be conceived to be the same as the field which is formed by the winding as shown by Fig. 7 where each polar phase group is numbered 1, 2, 3, etc., and is shown by short arcs on all of the diagrams. The arrows are shown simply to indicate a method of checking up to insure the proper phase relations. There is considerable danger with a three phase connection of getting a 60 degree relation between the phases instead of 120 degrees or as it might be expressed on the diagram there is danger that the wrong end of the B phase for example may be connected to the star point. As a check against this when the diagram is completed the current is assumed as going in at all three leads toward the Y point. Arrows are put on each pole phase group as shown and when all three phases are traced through the winding is correct if the arrows on consecutive groups run alternately clockwise and counter clockwise. It may be argued that this is an artificial assumption and that at no instant is the current flowing towards the star in all three phases. It may also be argued that in a correct winding if the current be assumed as flowing towards the star in two phases and always away from the star in the third the arrows will fall in successive flights of three in the same direction and then three in the reverse direction. These statements are true but a little experimenting will show that an incorrectly connected or 60 degree winding can in this way be shown to give successive flights of three arrows and still be wrong. There is but one exception to the correctness of the check as shown in Fig. 7 and succeeding figures where the current as flowing towards the star in all three phases and the arrows alternate in direction. This exception to the rule is the case where the winding forms consequent poles or pases through all the phase pole groups in a north direction instead of alternately north and south as in Figures 3, 11, 17, and 18.

The schematic diagram placed inside of the winding diagrams tells at a glance what the winding diagrams represents without the necessity of tracing it out. The shcematic diagram may be said to be the engineer's conception of the connection while the winding diagram proper may be called the winder's conception of the motor. Each, however, serves it's purpose as either one of the two may be more easily grasped by a given individual.

Very little more need be said of these diagrams as they are self-explanatory. However, a little obstruction may be met with in the beginner's mind when winding the machine for two phase four pole connection. Two times four equals eight polar groups and the machine has thiryt-six slots. If four coils are put in series in each polar group it will mean the use of only thirty-two slots. And if five coils are placed in series it will necessitate forty slots. The winding diagrams do not show how to over-come this difficulty. Thirty-six coils may be used thus making use of the thirty-six slots by placing four and five coils in series alternately in each polar phase group of each phase.

This distributes the unequal windings symmetrically around the periphery of the machine and gives perfectly balanced voltages in each phase. This is one of the vernier or Less Common Multiple methods of connection as refered to before.

In analyzing the experimental data for a comparison of the voltages required on the machine and those applied on the various connections as indicated it is seen that nearly all of the voltages applied are within the 10% limit of good operating conditions with the exception of the two phase parallel connections. Here it seems that it required twice the necessary voltage to start the motor. After the machine is in running condition, however, it was possible to cut this applied voltage in half and still have the motor operate under normal conditions. The voltage required for the six pole connections were corrected from the required four pole voltage for chord factor.

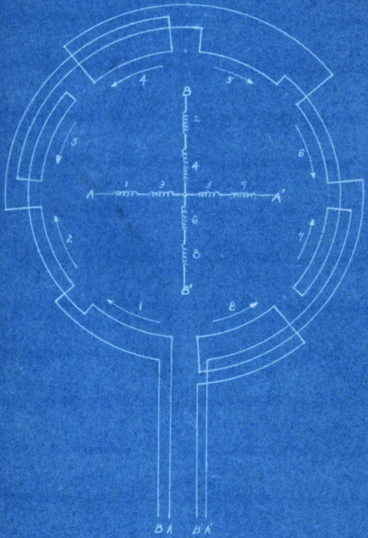
The motor was also connected for eight poles but no data was obtained as it was impossible to make the motor come up to required speed due to great decrease in effective magnetizing flux caused by the large chord factor.

In conclusion it may be stated that any induction motor may be connected for two different pole connections and not more than two excluding the consequent pole connection which is rarely used and then usually on special motors wound for multi-speeds.

Note: In reference to Fig. 3 the eight pole connection is as follows: The ends y and y' are connected to-gether putting half of the coils in one phase in series with half of the coils in the other phase.

Use A_1 — B_1 and A_2 — B_2 for leads and leave a_1 — a_2 and b1 — b2 open.

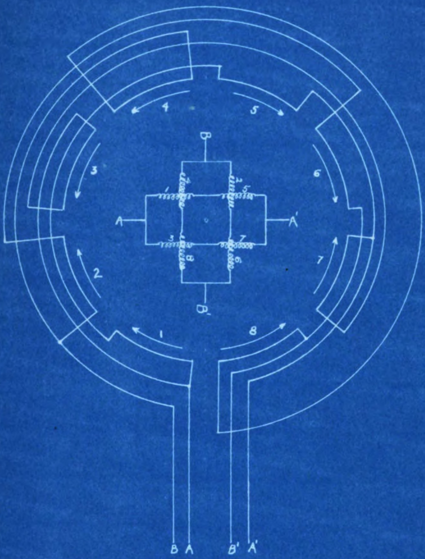
FIG. 1.



TWO PHASE FOUR POLE

series

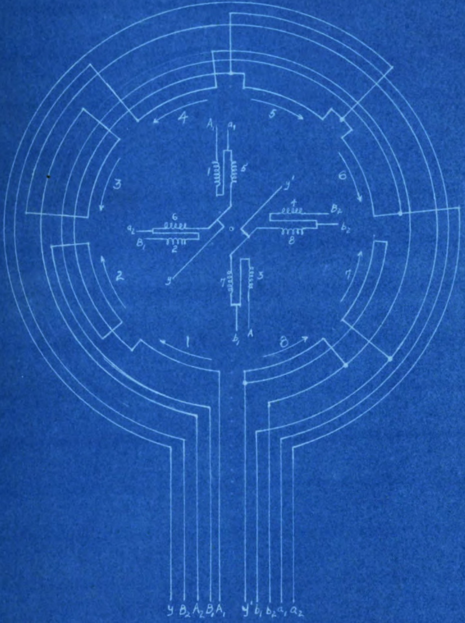
FIG. 2.



TWO PHASE FOUR POLE

PARALLEL

FIG. 3.



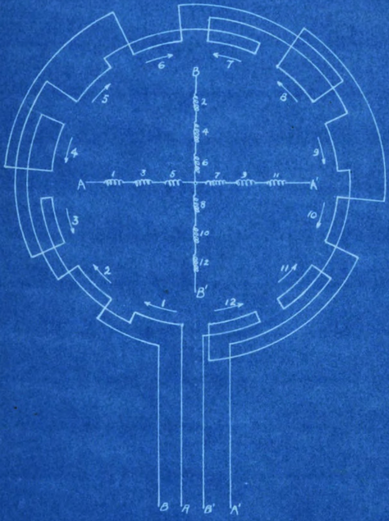
TWO PHASE FOUR-EIGHT POLE

Four pole connection the coils are in parallel.

Eight pole connection the coils are in series.

Four pole: Connect A_1 -- B_1 together and A_2 -- B_2 Leave y and y' open and use a_1 -- a_2 and b_1 -- b_2 for leads.

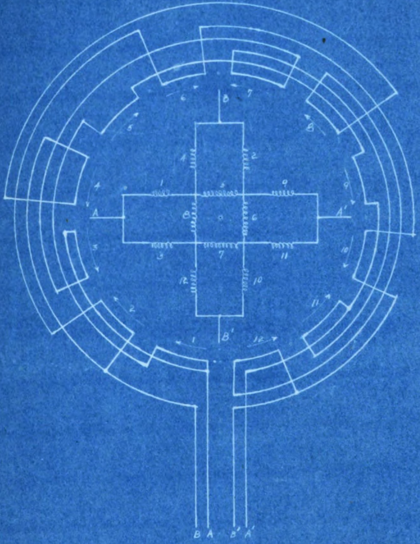
FIG. 4.



SIX POLE TWO PHASE

SERIES

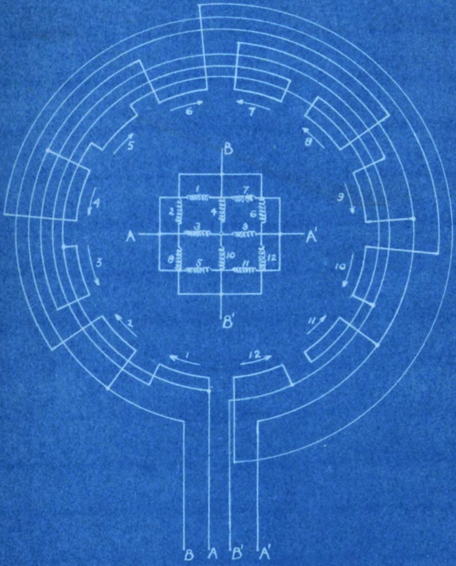
FIG. 5.



TWO PHASE SIX POLE

PARALLEL

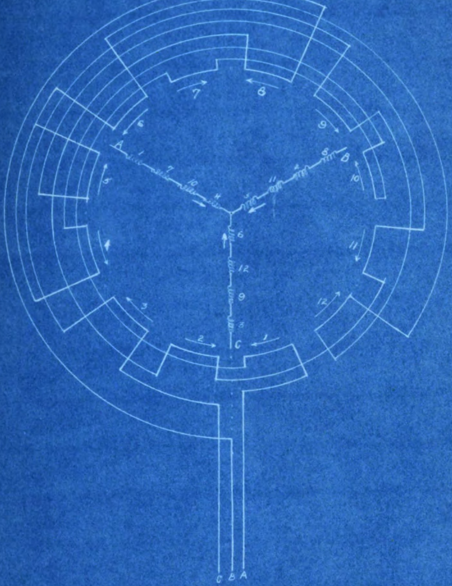
FIG. 6.



TWO PHASE SIX POLE

THREE PARALLEL

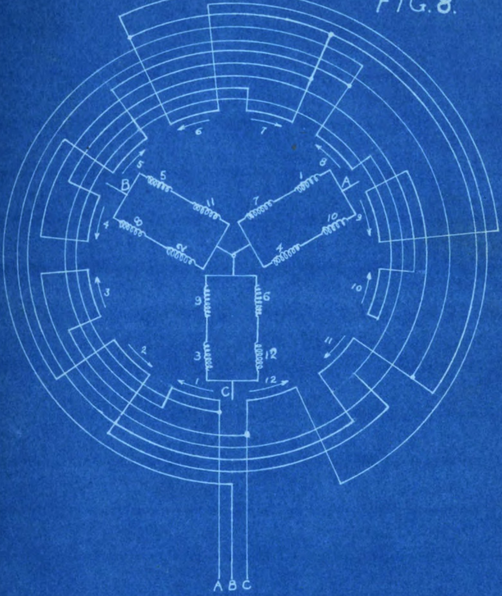
FIG. 7.



FOUR POLE THREE PHASE

SERIES STAR

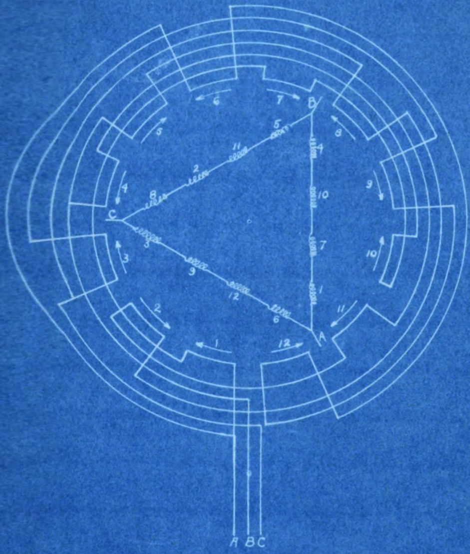
FIG. 8.



THREE PHASE FOUR POLE

PARALLEL STAR

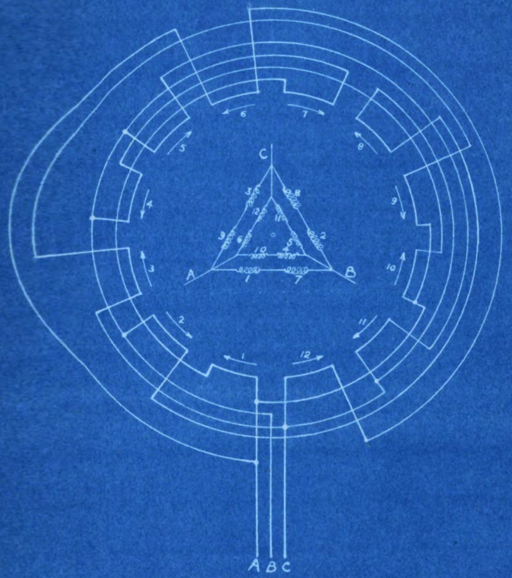
FIG. 9.



THREE PHASE FOUR POLE

SERIES DELTA

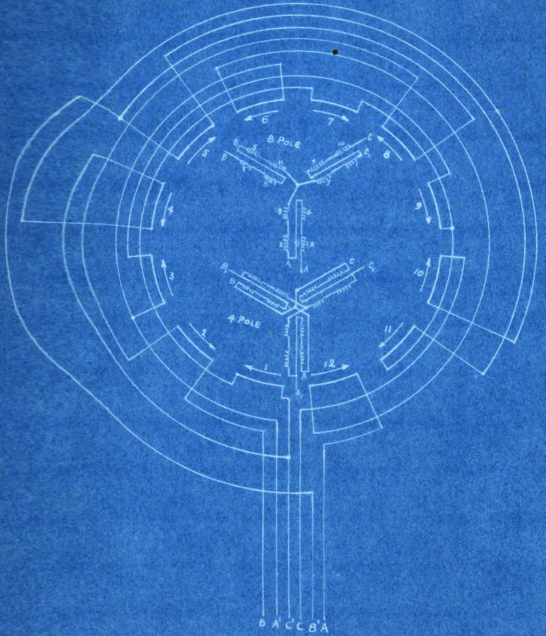
FIG. 10.



THREE PHASE FOUR POLE

PARALLEL DELTA

FIG. 11.



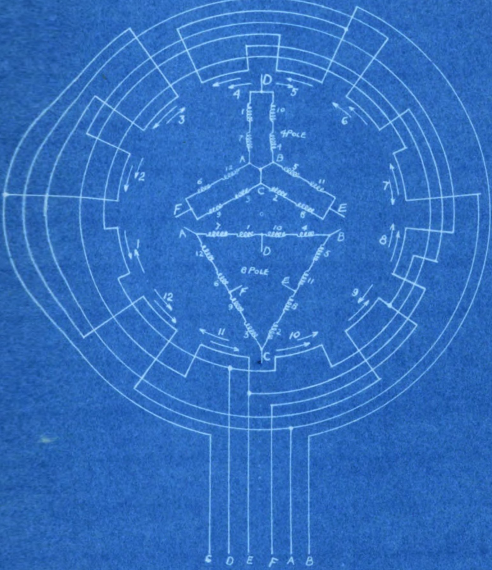
THREE PHASE FOUR-EIGHT POLE

Four pole: Parallel star. A, -- B, -- C, are leads. A -- B -- C are connected to-gether.

Eight pole: Series star. A -- B -- C are leads. A, -- B, -- C, are open.

Two speeds are obtainable by these connections.

FIG. 12.



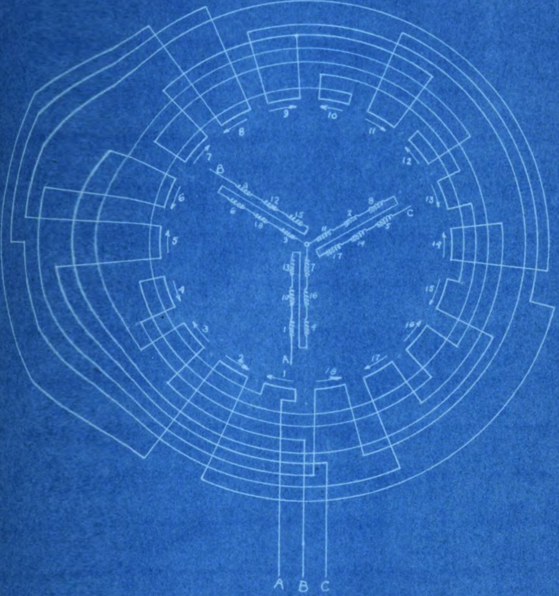
THREE PHASE FOUR-EIGHT POLE

Four poles: Parallel star. A -- B -- C are connected together and D -- E -- F are leads.

Eight poles: Series delta. A -- B -- C are leads and D -- E -- F are open.

Two speeds are obtainable by these connections.

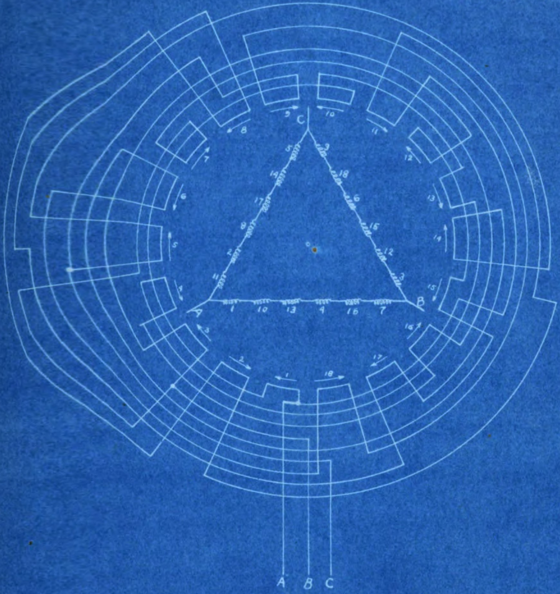
FIG. 13.



THREE PHASE SIX POLE

SERIES STAR

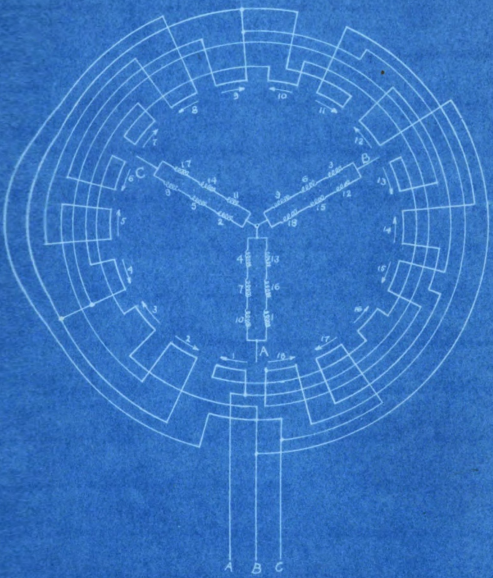
FIG. 14.



THREE PHASE SIX POLE

SERIES DELTA

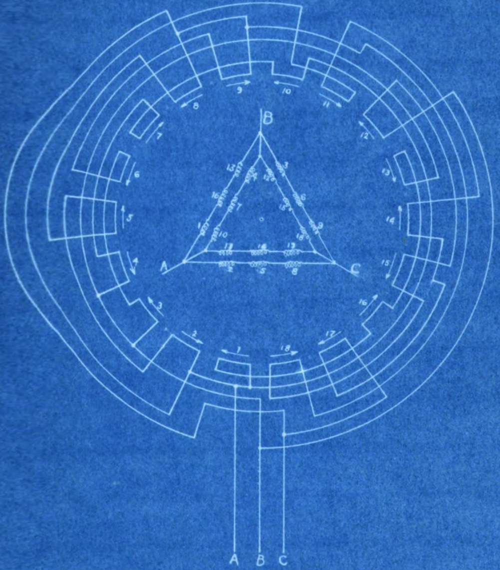
FIG. 15.



THREE PHASE SIX POLE

PARALLEL STAR

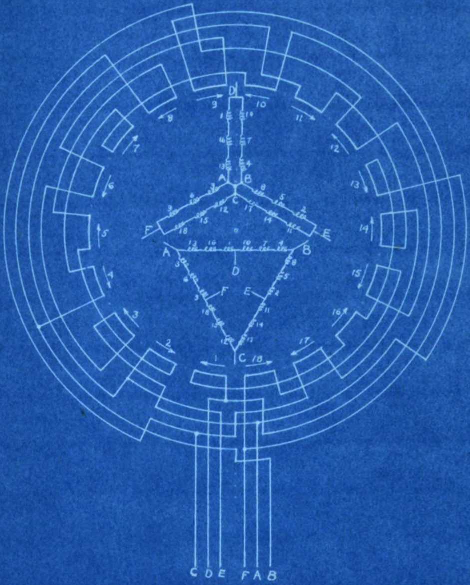
FIG. 16.



THREE PHASE SIX POLE

PARALLEL DELTA

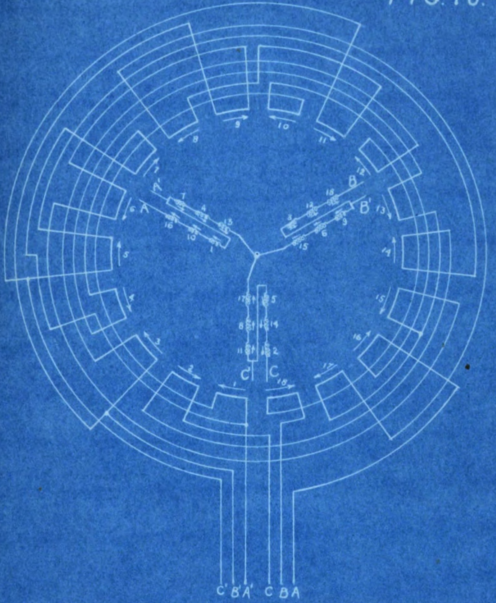
FIG. 17.



THREE PHASE SIX-TWELVE POLE

Six pole: Parallel star. D — E — F are leads and A — B — C
are connected to-gether.
Twelve pole: Series delta. A -- B -- C are leads and D -- E -- F
are open.
Two speeds are obtainable by these connections.

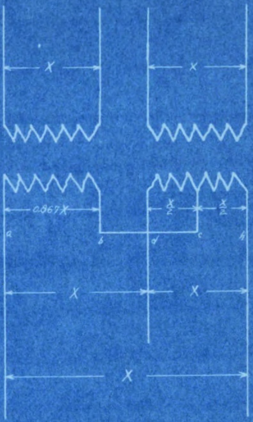
FIG. 18.



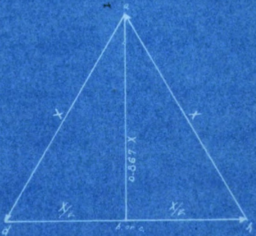
THREE PHASE SIX-TWELVE POLE

Six pole: Parallel star. A′ -- B′ -- C′ are leads and A -- B -- C
are connected to-gather.
Twelve pole: Series star. A -- B -- C are leads and A′ -- B′ -- C′
are open.
Two speeds are obtainable by these connections.

FIG. 19.



Schematic diagram.



Vector diagram showing voltage relations.

TWO-THREE PHASE SCOTT TRANSFORMATION