MULTI-HORSE POWER INDUCTION MOTORS

A Dissertation
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of
MASTER OF ENGINEERING
in
ADVANCED ELECTRICAL MACHINES
(Electrical Engineering)

by
PARAS NATH

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ROORKEE
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(INDIA)
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PARAS NATH.

CERTIFICATE

CERTIFIED that the dissertation entitled "~~OPERATION OF INDUCTION MOTORS WITH STATOR CONNECTED IN STAR AND IN DELTA WITH CHANGE IN TURNS~~" "MULTI- HORSE POWER INDUCTION MOTORS" which is being submitted by Paras Nath in partial fulfilment for the award of the Degree of Master of Engineering in Advanced Electrical Machines of the University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or Diploma.

This is further to certify that he has worked for a period of Seven months from May, 1967 to Nov. 1967 for preparing this dissertation for Master of Engineering Degree at the University.

29.XI.67

(J.L.JETHI)
READER
Electrical Engg.Deptt.,
University of Roorkee
Roorkee.

Roorkee
Dated November , 1967.

SYMBOLS

P.F	Power factor
H.P.	Horse Power
y	per unit winding connected in delta or internal delta connection.
HP_{Δ}	Horse power for delta connection
HP_{Δ} int.	Horse power for internal delta connection
HP_Y	Horse power for star connection
V_{120}	Voltage across terminal 1 and 2 at No load
$V_{12\ L}$	Voltage across terminal 1 & 2 at locked cond.
V_{230}	Voltage across terminal 2 & 3 at no load
$V_{23\ L}$	Voltage across terminal 2 & 3 at locked cond.
I_{Δ}	Full load current for delta connection
I_{Δ} int.	Full load current for int. delta
I_Y	Full load current for star connection.
V	Supply voltage
Z	Impedance
E	Phase voltage
q	Number of phase.
S	slip
X_m	Magnetizing reactance
X_1	Primary leakage reactance
X_2	Secondary leakage reactance
X	Total leakage reactance of Primary and Secondary under locked condition.

I_o	No load current
w	Total power input
R	Number of rotor slots
S	Number of stator slots
N	R.P.M.

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INTRODUCTION

A great and growing industry has developed around the subject of induction motor. In any industry there can be only one central fact, that is the existance of a demand or in other words a user, without whom the whole fabric of the organisation would collapse. It is therefore, fitting as well as being prudent to begin a practical investigation of the problems connected with the motor, by a consideration of the requirements, which the machines will be called upon to fulfil. Treating the user's requirements in this manner there are two main type of requirements with five headings in each, namely intermittent requirements and enforced requirements.

The Table No. 11 sets these requirements out, conveniently at the left hand side and places against each the range of alternative possibilities which each is likely to involve. It does not however, follow, that it is always possible for any two or more given requirements to be fulfilled. On the whole however, it is found that practically any normal requirement or group of requirements is capable of satisfactory interpretation, for where our knowledge has not been able to reveal a solution, the existing circumstances have been modified to suit. For any installation true requirements can be defined by a line, tending to be vertical between points A and B and passing between any two of the short vertical

CHAPTER I

INTRODUCTION

line which appear on each horizontal level. Though th-e true users' requirement can be classified into ten headings, the different line possible to draw to fulfil the above conditions are almost infinite. It accounts for the limitless number of different types and size of machines. A group, which is interpreted by manufacturer a standard range of induction motor, is that which covers outputs of, from 1 horse power to 200 horse power running at constant speeds of between 365 rpm and 3000 rpm . It meets all starting, all transmission and load condition, 2 phase and 3 phase supplies, frequency between 25 and 60 cycles, pressure from 200 to 600 volts, all forms of mechanical protection, all temperature requirements, all limitations to starting current, nearly all limitations to power factor and efficiency and its technology.

Of the many combinations of user's requirements with which it may be necessary to deal, the large majority can be covered by that class of A .C. motor in which the energy is transferred from the line to the rotor by transformer effect only, i.e., the class of induction motors. These machines are essentially of the constant speed type, providing what is usually termed a shunt speed characteristic i.e, in which speed is practically independent of the loads. The most important direction in which they fail to cover the full requirements is in the matter of speed and speed variation. The number of alternative economical running speed is limited. Speed variation is possible by methods, which is not only uneconomical but does not provide the most satisfactory type of speed characteristic. All machines in the class operate with a lagging power factor, drawing their magnetizing current from A.C. line, and to some extent, they thus also fail to cover the possible requirements under heading "Tarrif Restrictions".

They are characterised by very considerable popularity, a high degree of reliability cheapness, and absence of trouble . Induction motor represents standard range, and their characteristics satisfactorily meet the large proportion of the requirements.

In the requirement of starting conditions the standard range is liable to cover requirements completely, except in those cases where an arduous starting performance is coupled with a single phase supply. The better reliability of machine add a further advantage due to less probability of replacement.

Till now discussion is made about the user's demand, around which the business of motor manufacturer must pivot; and secondly the ability of induction motor in meeting this demand. Manufacturer in general designs induction motor for a definite operating conditions i.e., for the rating of Horse power, voltage, speed, phase, frequency keeping in view to fulfil the operating characteristic satisfactorily. The main considerations in the operation of an induction motor are starting torque, starting current, air gap clearance, power factor, efficiency, heating , maximum torque , or pull out torque, noise, mechanical vibration, temperature rise etc. The user selects the induction motor of specification according to the operating conditions required. In the industry , for which user's select the induction motor, any operating condition may likely to be changed. The most frequent changes ~~are~~ is in the voltage, horse power and speed. The change in any operating condition of induction motor affects the performance of induction motor, changes caused in performance may be undesirable. As for example, change in the supply voltage will change the horse power output, the efficiency and power factor, starting torque, starting currents and other characteristics, change in speed also changes the above characteristics. Change in Horse power rating i.e., the load on induction motor will change the efficiency power factor and other characteristics. Change involtage, speed and the horse power may be demanded simultaneously or one at a time, i.e., may be for short duration of time or for longer duration of time. Where motor is selected for certain use, motor is selected to suit average value of load, with a sufficient margin of overload capacity. The same motor is used for lighter as well as over load. The performance of induction motor that can be obtained will be best on full load condition with other operating conditions remaining same. So the lighter and over load condition may cause power factor and efficiency so poor that it becomes necessary to change the induction motor . But change in ~~dire~~induction motor need extra expenditure of money , to purchase a new motor or to keep motor in spare to suit different loads. S-imilarly change in voltages and speed may require another motor in spare.

The change in voltage speed and horse power simultaneously or either in any one can be made on the same induction machine with certain modification in the winding connection, without the sacrifice in operating performance, such as power factor and efficiency. The new connections on the same core with some turns can be made for new operating condition leaving the motor entirely normal in performances in all essential respect remaining the same as before.

Change in voltage can be met with a proper connections of stator, in series or parallel, delta or star connection. Change in speed can be met with change of pole connection and the change in horse power can be made with change in method of interconnection keeping voltage supply and other operating conditions same.

The interconnections that can be made are star, delta or internal delta.

The change in speed with single winding of stator can also be obtained with conventional and consequent type of connections. With series an parallel combination in star~~x~~ and delta, different speed, for constant torque - variable horse power , constant horse-power ~~and~~ - variable torque and variable torque - variable horse power can be obtained.

When only change in horse power is needed to suit the required change in load, then the change in method of inter connection is carried out.

W-ith the method of interconnections the change in horse power can be made only for a certain range, with satisfactory operating performance.

" Multi Horse power Induction motors'

The subject of work is "~~Operation of~~ Induction ~~Motors with Stator connected in S-tar and Delta with change in time~~ turns", so our main aim is to show the relation of horse power rating for the stator connected in delta, star and internal delta, then to perform the experiment and to verify the calculated value with the test value. There is a certain relation between the full load current , for star, delta and internal delta connected winding. That is to be ~~shown and~~ verified with experiment , change in connection also causes change in voltage induced in different part of winding, under no load and full load dondition, that is to be shown and verified with experiment; similarly the magnetizing current for different connections is to be compared by calculations and experiments .

A complete test of no load, blocked rotor tests, resistence, and load test are to be carried for star, delta and internal delta connections and the efficiency , Brake Horse power, starting torque, starting currents, full load torque are to be compared. Performance is being affected by saturation and harmonic effects. A discussion is to be made about these effects also. The complete performance of induction motor with stator, in star or delta with change of turn ratio is discussed in the follow chapters.

Chapter I Introduction.
Chapter II Analysis
Chapter III Horse Power Rating for Different connections.
Chapter IV Winding Connections
Chapter V Tests
Chapter VI Harmonics & its effect
Chapter VII Results
Chapter VIII Comments.

TABLE NO. 1.1

			A		
	Output	1 HP		200 H.P	
		output of	from 1/10th to 1000 H.P		
[illegible]	Speed &	Constant	Speed	multispeed	variable speed

TABLE NO. 1.1

A

Intermittant requirement.	Output	1 HP | 200 H.P output of | from 1/10th to 1000 H.P
	Speed & speed variation.	Constant | Speed | multispeed | variable speed 365 rpm | 3000 rpm Running speed lying | between 1000 rpm and 600 rpm
	Starting conditions.	Light load starting | full load starting | overload starting
	Transmission condition	belt drive | Rope drive Gear drive, chain drive, overload drive Horizontal spindle | Vertical spindle
	Load condition.	Continuous running | Intermittent running
Enforced requirement	Nature of supply.	A.C. , 1 phase, 2 phase 3 phase 25 cycle 60 cycle A frequency between 0 & 100 cycle 200 V 600 V
	Atmospheric condition.	A voltage between 100 V & 11000 volts
	Temp. & Altitude.	Different forms of mechanical protection
	Temp.& altitude	A temp. rise, on duty of between $25^{\circ}C$ and $50^{\circ}C$
	Supply regulation	various limitation in starting current and power factor
	Tarrif restriction	Limitation to desirable | Power factor and efficiency

B

CHAPTER II

ANALYSIS

ANALYSIS

A. GENERAL OUTLINE

The performance of an induction motor is made up of a number of different characteristics . It must be able to start its load without drawing from the supply circuit an abnormal amount of current. It must be able to carry its load, as long as it~~s~~ runs, with a reasonable temperature rise and at a reasonable power factor. It must have a good efficiency. It must have over load capacity of, from one and one half to two times normal full load torque with-out pulling out or stalling. ~~And~~ And it must have all these, without an appreciable amount of noise due to magnetic leakage or windage. Some of these characteristics may be favoured at the expenses of others as for example, it is possible to get a high power factor at the expense of having a very small clearance between stator and rotor , or it is possible to have a high efficiency at a cost of low starting torque and high starting current. To get a true comparison of the relative ted merits of two competitive ratings, all these points must be considered and given their due weight in view of the service in which it is intended to use the motor.

It is understood that all these characteristics are affected in various ways by the different ~~factors~~ features of the design, that is to say by the axial length of the iron core as compared to the rotor diameter, or by the number of slots or the kind and thickness of the laminated steel used and matters of this kind, but the thing which has the greatest effect and which can most easily be modified is the number of turns in the stator.

The main consideration in the operation of an induction motor are starting torque,starting current, air gap or clearance, power factor, efficiency , heating , maximum torque or pull out torque , noise and mechanical vibration. The motor with fewer number of turns will have relatively a higher starting torque and higher starting current , it will probably have a lower power factor wh ereas with larger number of turns it will have relatively lower starting current and torque, the efficiency depends on the relative value of iron and copper loss.

It will be noted that these changes are the sam-e as would occur if the voltage were raised or lowered on any motor. Increasing the number of turns in a winding has the same effect as lowering the voltage and vice versa.

Since the performance of the motor as regards torque and other characteristic is proportional to the voltage per turn in the winding. So it is necessary to know the number of turns and then cross section of copper wire to carry the amperes required to develop the desired horse power.

So to get an idea of all points, the following different items are considered. They are :

1. Diameter and length of laminated iron core necessary to get the horse power desired at the given speed and voltage.

2. Magnetic flux or field required to generate the line voltage

3. Number of turns of wire in series in the stator winding which, when cut by the rotating field will generate the line voltage.

4. Cross section of stator conductor to carry the current required to develop desired horse power at the power factor and efficiency that the design will probably give ~~give~~.

5. Number and size of stator slots, width and depth to accommodate winding (3) and (4) when insulated for the required voltage.

6. Magnetic densities in the stator teeth, rotor teeth, core and air gap due to magnetic field.

7. Magnetizing or no load current required to ~~get~~ set up the field mentioned in (2) with the number of turns in (3) with length of path required by (1) and (5).

8. Iron loss due to densities.

9. Iron loss due to primary slot opening.

10. Number and size of slots in rotor.

11. Rotor winding, squirrel cage or phase wound.

12. Figure rotor volts and Amps, if phase wound.

13. Figure slip or rotor copper loss.

14. Figure stator copper loss.

15. Estimate bearing friction and windage.

16. Figure leakage reactance for stator anound rotor slots and coil ends, also zig zag and ~~belt~~ belt or differential leakage.

17. From (7) and (16) figure power factor.

18. From (13) and (16) figure starting and maximum torque.

19. From output and (8), (9), (13), (14) and (15) figure efficiency.

Since the consideration for the moment assumes a given machine, which already exists, many of these things are already determined and some can be assumed. The facts that require checking in determining a new winding for new conditions of speed or horse power or voltage or phase or frequency, and which may be considered as fundamental are:

1. Is the core large enough to wind for the horse power and speed that are desired.

2. Is there cross section of iron enough below the slots to carry the magnetic field that is needed in the air gap to do the work desired.

3. How many turns are required in the stator winding.

4. What should be the cross section or size of the wire or conductor used in the stator widding ?

5. What should be the cross section of the bars in the rotor and what should be the cross section of the resistance rings at the ends of the rotor bars, assuming a squirrel cage rotor winding ?

6. Will the rotor diameter permit operating at the proposed r.p.m ?

Besides the factors discussed earlier characteristics are affected by type of winding and the method of interconnection. Hence characteristic can be modified by the change of interconnection of winding. Here for~~e~~ the given induction motor most of the necessary information as mentioned above are well known, along with number of turns on stator or primary winding. The only modification carried is in the type of interconnection for different winding for different number of poles. And then operating characteristic is to be calculated and experimentally verified.

B. ARMATURE WINDING AND TYPE OF CHANGE

The essential features of an electrical machine is the electric circuit or armature winding, in which working e.m.f. is induced. In induction motor, both stator and rotor are provided with winding. In poly phase induction motor mostly lap winding is used, due to certain advantage over wave and concentric winding. The problem of winding is to arrange and connect the coils in the several slots to obtain the required phase groupings. Generally double layer winding is employed. There are two common methods of interconnection of three phase winding of stator. They are namely (1) Star connection and (2) the delta connection. A third type of connection of winding may be employed, which is the combination of star and delta and is known as the interconnected delta. In general or the method of connection are first selected to fulfil the well known operating condition ~~of induction~~ of induction motor and then the design completed, and other performance of induction motor determined.

But change of connection may be made to use the same core and turn placed in the slot of stator for as many combinations of phase, voltage, pole, cycles and horse power as possible, leaving induction motor entirely normal and performances in all essential respects remains the same as before reconnection. Such changes, for example are represented by connecting the polar groups of a winding in series for 440 volts and in parallel for 220 volts. These are classified as "legitimate changes" .

A second type of change leaves the performance in some respects unchanged and alters it in other. These may be represented by operating a motor in star on 440 volts and in delta on 220 volts. In this change there is little change in efficiency or power factor .

The starting and maximum torques on 220 volts, however are only 75 % of their value on 440 volts. In such case the admisibility of the change depends ~~mymm~~ entirely on the work that motor is doing. If the torques at their altered values are sufficient to start and carry the driven load easily . There is no objection in operating the motor indefinitely as so reconnected, since the motor will not run any warmer than before and its efficiency and power factor may be better, Such changes may be classified as 'possible changes'.

A third type of changes leaves a motor operative in the sense of producing torque enough to do the work required but so alters its performance as to heating as efficiency or power factor, or insulation, that it is undesirable to leave the motor operating indefinitely in such a condition. This change is classified as makershift or 'undesirable changes'.

The change in type of connection with fixed supply voltage is also a type of change above mentioned in which some of performance remains unchanged, but some of the

Performances changes.

C. DISCUSSION ABOUT THE DIFFERENT OPERATING CONDITIONS

There are five main operating characteristics, namely, volts, phase, poles, cycles and horse power. Any change in the operating characteristics of a motor may be reduced to terms of a voltage change and that if the corresponding voltage be applied the operation under the new condition will be approximately the normal operating conditions under the original condition. A brief resume is in order to stating how each one of these may be considered as a voltage change. In other words if, for example, the horse power or phase of a motor is to be arbitrarily changed, what will be the new operating voltage to secure this result ? Taking these characteristics in order, a voltage change is self evident since every thing is to be reduced to voltage.

In the case of a change in the number of poles, if the voltage to be changed in the same direction and by the same amount as the change in speed. The torque will remain essentially constant, and the horse power will vary with the speed, being greater at higher speed and less at lower speed in exact proportion. However, there is not enough iron at the back of the slots to permit, of keeping the same total flux, and dividing it into fewer circuits, with ~~greater~~ greater flux per circuit, the voltage may be kept constant and the horse power will remain practically constant. The latter condition would mean that there is less total magnetic flux and less torque and higher speeds and greater total flux and greater torque at lower speeds, as must necessarily be expected since the horse power is constant ~~and~~ $\left(\text{horse power} = \frac{\text{torque x speed}}{5252}\right)$

A similar statement can be made for change of frequency.

There remain~~ing~~s only a change in horse power to be converted into a voltage change, and this is apparent from the fact that in any motor the horse power is proportional to the product of the voltage and current. Since the cross section of the copper conductor remains the same and hence the ampere remain the same, the only thing that can vary is the voltage, and it follows directly that to get more horse power, out of a motor require the application of a higher voltage and less horse power, will permit the use of a lower voltage.

From these considerations it appear that the effect of a change in any of the characteristics of the motor can be balanced by the proper change in the voltage The number of turns in the winding or connection of the groups may be changed.

As the effect of change in the operating voltage is equivalent to change in turn. Change in any operating condition is balanced by change in voltage. So the change in any operating condition can be balanced by change of turn. Hence ~~to~~ change in horse power can be ~~met~~ met by change in equivalent turn. The change in equivalent turn is accomplished by changing~~s~~ the type of interconnection. So merely change of interconnection for a given supply voltage changes the horse power rating. Frequency remaining same, speed of induction motor decreases when number of poles increases & vice versa. If the supply voltage is same,. ~~The~~ the lowering the number of poles increases speed, and hence decreases flux per pole. This causes decrease in torque. But horse power will remain constant due to relatively same increase in speed and decrease in torque (Because Horse power ~~ispmbportional~~ is proportional to torque and speed.)Horse power will remain constant if the pole ~~of p~~ i-s increased provided supply voltage again kept constant. If the supply of voltage increases in such a way that the proportional increase in voltage is equal to proportional increase in speed (due to decrease of number of poles) Then the flux will remain constant So the torque and as a result, horse power increases with increase of speed, approximately in same proportion. So ~~with~~ change in poles causes changes in torque or horse power, depending on the value of supply voltage, which is kept constant or changes proportionately. Change of method of connection (star, delta, internal delta) is equivalent to change in voltage. So winding connected for different number of poles, with different type of connection (star, delta or internal delta) gives different value of horse power, speed and torque.

Increase in number of poles increases the magnetizing current, hence reduces the power factor, and decrease in number of poles, decreases the magnetizing current, so increases the power factor. This change in pole will change the reactance ~~as~~ by saturation efect.

A polyphase winding may be connected so that the rotor will operate at either of two speeds, the higher speed being twice the lower speed . If the pole groups of each phase are connected, so that successive magnetic polarities are opposite, north and south at any instant, the higher speed will be developed, the winding is then said to be connected in the conventional manner. However, if the pole group of each phase are connected together, so that they create similar magnetic polarities all north or south at any instant, the lower speed will be developed the winding is then said to be connected in consequent pole manner. The poly phase induction motor must meet very rigid and exact standards of performance in modern industrial plants. This generally implies, that each electrical machine must have torque, horse power, and speed characteristics that match definite requirements of the mechanical application. For the purpose of standardization the multi speed motor is devided into three general groups. They are (1) Constant torque or variable horse power motor which develope approximately the same turning effect, or torque regardless of speed. (2) Constant horse power variable torque motor whose turning effect or torque, varies directly with the

Three

parallel combination of conventional and consequent type of connection, as follows :-

i. Const. Torque - Series delta for low speed two
parallel star for high speed.

ii. Const. Horse power- Two parallel star for low speed
Series delta for high speed.

iii. Variable torque - Series star for low speed two
parallel star for high speed.

The main principles which operate to fix the limits of the different combinations, such as series, parallel, series star, parallel, star , series delta, parallel delta, etc. possible with a single winding may be enumerated some what in the following manner:-

1. The mechanical output of a motor is limited by the cross section of copper available to carry current and by the cross section of iron available to carry magnetic flux.

2. An induction motor is also at all times an alternating current generator as well, and the voltage generated by its own rotating field cutting the conductor of its own stator coils must at all times very closely approximate the applied line voltage.

3. It is necessary that the pitch or throw of the coils bear reasonable physical selection to the number of poles that the machine has. For example in a

four pole motor the coils should throw some where near one fourth of the circumference of the stater bore, in six pole motor, somewhere near one sixth the circumference and so on.

4. All changes in operating conditions whether of horse power, voltage, phases, frequency or poles may be reduced to terms of change in voltage, and so considered.

5. An induction motor is similar to a transformer in that the number of turns in series in the winding must be varied in the same direction and by the same percentage as any changes in the voltage applied In addition to these principles, the following practical considerations must be remembered.

a. The new voltage, which is applied to a reconnected motor must not exceed the limiting value of the insulation which is on the coils.

b. In reconnecting for higher speeds the peripheral speed of the rotor must be kept down to a safe value so that the centrifugal forces does not damage the rotor core or winding mechanically.

c. In a wound rotor motor the rotor winding must be connected for the same number of poles as the stator winding.

d. In a squirrel cage motor if radical changes are made in the number of poles, a change may also be required in the short circuiting rings of the squirrel cage rotor winding in order to keep the proper starting torque.

e. In a pole-group winding the individual coils at ~~are~~ the beginning and end of the phase groups have usually heavier insulation then the inside coils of group. Where this is the case, when reconnecting for change in phase or poles, the coils with the heavier insulation should be shifted to their proper new places in the winding.

CHAPTER III

HORSE POWER RATING FOR DIFFERENT CONNECTION

H.P. RATING FOR DIFFERENT CONNECTION

A. BASIC PRINCIPLE

It is said that there are three methods of interconnection of 3 phase double layer winding. They are star connection, delta connection and internal delta connection, All three types of connection is shown in the Figure No.(3.1) Different type of internal delta connection can be made by changing the different, but equal number of coils in delta Voltage diagram for these different type of connection is shown in Figure No. (3.2a)

For the fixed ratio of full load torque to maximum torque, ~~aim~~ and for same supply voltage, The ratio of horse power for the 3 connection is given by

$$HP_{\Delta} : HP_{\Delta \text{ int.}} : HP_{Y} = 1 : \frac{1}{3-3Y+Y^2} : \frac{1}{3} \qquad \ldots(3.1)$$

Where Y is the per unit of winding, connected as delta is internal delta connection.

Taking the effect of saturation and harmonics it can be assumed that

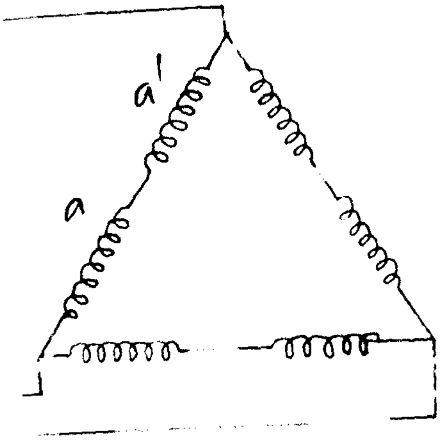


FIG 3·1(A)

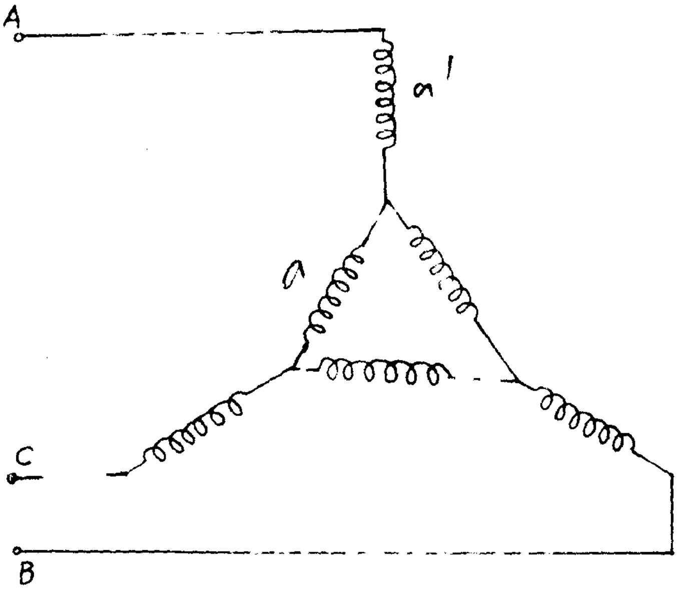


FIG 3·1 (B)

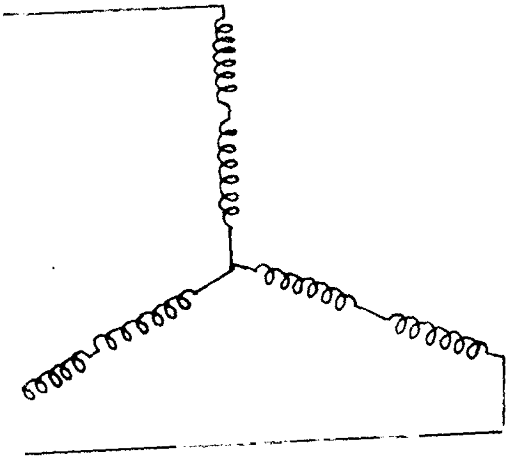


FIG 3·1 (C)

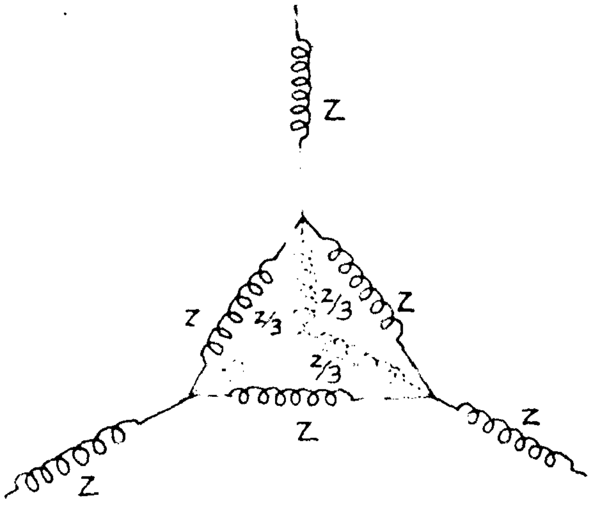


FIG 3·2 (B)

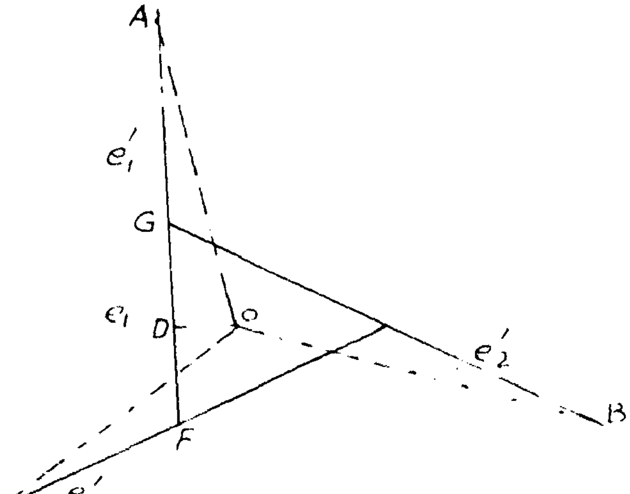


FIG 3·2 (A)

$$HP_{\Delta} : HP_{int\,\Delta} : HP_{Y} = 1 : \frac{1}{3.6-3.9Y+1.3Y^2} : \frac{1}{3.3} \qquad \ldots(3.2)$$

If the required horse power rating for the three case be

$$HP_{\Delta} : HP_{\Delta\,int.\,\Delta} : HP_{Y} = 1 : \frac{1}{X} : \frac{1}{3.3} \qquad \ldots.(3.3)$$

Then $$Y = \frac{3}{2} - \sqrt{0.77X - 0.52} \qquad \ldots.(3.4)$$

So knowing the required value of horse power X, the proper value of Y can be calculated by equation 3.4.

Another approximate rule in determining the ratings is that the ratio of horse power ratings for different connections is inversely proportional to the stator resistance between line terminals.

Let V = Line voltage

V_{120} = Voltage across terminals 1 and 2 at no load

V_{230} = Voltage across the terminal 2 and 3 at no load

V_{12L} = Voltage across terminal 1 and 2 at ~~loaded~~ Locked conditio

V_{23L} = Voltage across terminals 2 and 3 at ~~loaded~~ " conditio

Then approximately

$$V_{120} = \frac{V}{\sqrt{3}} \cdot \frac{1-Y}{\sqrt{1 - Y + \frac{Y^2}{3}}} \qquad \ldots(3.5)$$

$$V_{23O} = \frac{V}{\sqrt{3}} \cdot \frac{Y}{\sqrt{1 - Y + \frac{Y^2}{3}}} \quad \ldots(3.6)$$

$$V_{12}\,\ell = \frac{V}{\sqrt{3}} \quad \frac{1-Y}{2(1-2/3\ .Y)} \quad \sqrt{\frac{4 - \frac{14}{3}Y + \frac{13}{9}Y^2}{1 - Y + \frac{Y^2}{3}}}$$

$$\ldots(3.7)$$

$$V_{23}\,\ell = \frac{V}{\sqrt{3}} \quad \frac{Y}{2(3-2Y)} \quad \sqrt{\frac{21 - 24\,Y + 7\,Y^2}{1 - Y + \frac{Y^2}{3}}}$$

$$\ldots(3.8)$$

The ratio of full load currents neglecting saturation.

$$I_\Delta : I_{\Delta\,\text{int.}} : I_Y = 1 : \frac{1}{(3-1.267Y)\sqrt{1-Y + \frac{Y^2}{3}}} : 1/3$$

$$\ldots.(3.9)$$

and considering saturation, ratio of full load current is.

$$I_\Delta : I_{\Delta\,\text{int.}} : I_Y = 1 : \frac{1}{\sqrt{3.6 - 3.9Y + 1.3\,Y^2}\ (1.73-0.73Y)} : \frac{1}{3.}$$

$$\ldots(3.10)$$

Putting the value of Y in equation (1) and (2) Horse power rating is to be compared for star, delta and internal

Similarly putting the different possible value of Y in equation 3.5, 3.6 , 3.7 , 3.8 voltages can be calculated also similarly current can be calculated by equation 3.9 and 3.10.

Completing two layer winding for a particular number of poles (~~two~~ , four, six ~~or 8~~ pole) and connecting the same in the star, delta, ~~and~~ or internal delta for different values of y. The load test, no load test, Locked rotor test can be performed and characteristic can be determined, and also no load voltage, full load voltage, Load current, Horse power ~~,~~ rating, obtained by experimental result as well as by calculated value can be compared. The calculated value and experimental value is given in Chapter VI.

EXAMPLE

As for example, complete winding for 4 Pole, 6 pole ~~or 8~~ pole and connect it to star; delta and internal delta for y = 1/2 as shown in Figure 3·1(B). Supply voltage to stator equal to 250 volts, across AB, BC, and CA determine the value of $V_{12}0$,$V_{23}0$, $V_{12}l$ & $V_{23}l$
and also calculate V_{120}, V_{230}, V_{12l}, V_{23l}
by Equation No (3.5) to(3.8), compare the calculated and experimentally obtained value. Similarly measure the value of I_Y I_Δ and $I_{\Delta\ int}$, compare this value with calculated value.

The voltage across each component of stator is vector sum of

1. E.M.F. generated.
2. I z drop in that winding.

First consider the no load Condition ~~calculation~~ and neglect I_z drop. The vector diagram for interconnected delta in Figure (3.1 B will be as shown in Figure 3.2 A.

Let e = voltage induced in each winding

$$\therefore \text{Voltage } FG = \text{Gt-} ~~\text{in}~~ e \; ; \quad \therefore DG = \frac{1}{2} e$$

$$OD = \frac{1}{3} MD = \frac{1}{2} Mo$$

$$Mo = \frac{1}{\sqrt{3}} Gm = \frac{1}{\sqrt{3}} e$$

$$\therefore OD = \frac{1}{2\sqrt{3}} e = 0.289\, e \quad \text{———} \quad (3.11)$$

$$\therefore OA = \sqrt{AD^2 + OD^2} = \sqrt{(1.5\, e)^2 + (0.289\, e)^2}$$

$$= e \sqrt{2.25 + 0.0836} = e\sqrt{2.3336} = 1.527\, e$$

$$\ldots\ldots(3.12)$$

Let Line voltage = V = 256 volts

$$\therefore OA = V / \sqrt{3} = 256 / \sqrt{3} = 148 \text{ volts}$$

By equation (3.12)

$$e = V = V_1' = e' = \frac{OA}{1.527} = \frac{148}{1.527} = 96.8 \text{ volt}$$

Now resolve internal delta into equivalent Y as shown in Figure (3.2B)

Impedance per branch = Z/ 3

Iz drop in winding a' = 3/4 . Iz drop per phase

Iz drop in winding a = $\sqrt{3}$ x 1/4 . Iz drop/phase

The vector diagram for ~~current~~, induced voltage ~~and Iz drop~~ is shown in Figure 3.~~2~~ (A)~~,B,C~~).

First of all consider ideal case i.e. effect of saturation and harmonic is neglected.

For the connection of delta and internal delta the ratio of flux per pole changes with load, but approximately it can be assumed that changes in flux due to load is so small that changes in the flux due to load when compared for both connection can be neglected. The flux is proportional to the voltage. Therefore neglecting the change in flux due to load, the ratio of flux for both connection is equal to the ratio of induced voltage.

$\therefore$ Induced voltage in winding a'

Figure (3.1A) $= 1/2 \cdot$ Applied voltage

$= 256 / 2 = 128$ volts.

Induced voltage in a8

Figure (3.1B) $= 96.8$ volts.

$$\therefore \frac{\phi_A}{\phi_{A\ \mathrm{int.}}} = \frac{128}{96.8} = 1.323 \qquad \ldots.(3.13).$$

Now torque is proportional to flux and current and the current is proportional to flux. So finally torque is proportional to $(\mathrm{flux})^2$

$$\therefore \text{Ratio of Torque} = \frac{T_A}{T_{\mathrm{int}\,A}} = \left(\frac{\phi_A}{\phi_{A\ \mathrm{int}}} \right)^2$$

$$= (1.323)^2 = 1.75 \qquad \ldots(3.14).$$

Hence torque ~~per~~ Vs speed curve for connection given in Figure (1.B) in the ideal case can be obtained by deviding the torque for connection (a) by 1.75.

To take care of the saturation and harmonic effects approximately a further correction will be made, It can be assumed

$$\frac{T_A}{T_{A\ \mathrm{int.}}} = 1.3\left[(1.75)-1\right]+1 = 1.98 \qquad .(3.15)$$

~~Practical~~ predicted , and ~~ten~~ test results are compared on above lines. Also T_{max} / T_{fl} , Tss, N fl , I_s/ fl, Cos ϕ fl and efficiency on full load is compared.

Any deviation at low speed region would be due to the effect of harmonics, stsay load losses and the change in flux ratios.

BASIC RELATION

When the 3- phase of stator is connected for internal delta as shown in (Figure) the horse power rating of the motor depends on the basis of the rating :

a. $$H.P._{\Delta\ int.} = H.P._{\Delta} \times \frac{T_{fl}}{T_{max\ \Delta\ int.}}$$

b. $$H.P._{\Delta\ int.} = H.P_{\Delta} \times \frac{T_{fL}}{T_{s.s\ \Delta\ int.}}$$

c. $$H.P._{\Delta\ int.} = H.P_{\Delta} \times \frac{N_{fL}}{N_{syn.\ \Delta\ int.}}$$

d. $$H.P._{\Delta\ int.} = H.P_{\Delta} \times \frac{I_{fL}}{I_{fL\ \Delta\ int.}}$$

e. If the rating is limited by temperature rise, the motor should be rated, lighter. Under this basis, the full load point of the motor when connected in Y will be at the maximum at point for ratings under the heading 1 to 5.

Then find (1) Maximum torque (2) Starting torque (3) full load current , (4) full load speed (5) power factor (6) Efficiency.

The ratio of the rotor current in Figure 3.1(B) to that in Figure (3.1A) at the same slip is equal to the ratio of fluxes if ~~data ratio~~ saturation is neglected.

But when saturation is considered, then assumed approximately that

$$\frac{I_{\Delta}}{I_{\Delta\ \text{int.}}} = \sqrt{1.98} = 1.407 \qquad \ldots(3.16)$$

The equivalent turns in star for the connection shown in Figure 3 . 1(A) is $T_{ph} / \sqrt{3}$ and that for connection shown in Figure 3(1.B) for internal ~~dleta~~ delta connection is $(1-Y)\, T_{ph} + Y \dfrac{T_{ph}}{\sqrt{3}}$

$$\ldots.(3.17)$$

Therefore,

$$\frac{I_{\text{load comp. in } B\Delta}}{I_{\text{load comp. in } \Delta\ \text{int.}}} = 1.407 \, \frac{(1-Y)\, T_{ph} + Y \dfrac{T_{ph}}{\sqrt{3}}}{\dfrac{T_{ph}}{\sqrt{3}}}$$

$$\ldots.(3.18)$$

With the connection shown in Figure (3·1b) in order to bring the horse power of the motor back to horse power rating of delta connection the applied line voltage should be approximatly $V = 256 \times \sqrt{1.98} = 256 \times 1.407$

$= 361$ volts .

This is to be checked with the Test results

In general, due to phase displacement of the currents in the coils internal delta connection will introduce large harmonics. The harmonics in internal delta connection and other type of connections are discussed in Chapter VI. These harmonics will produce a dip in the Torque / speed curve, will reduce the starting and maximum torque and will increase stray load losses. However, it does improve the power factor at light loads.

The discussion made for the value of Y equal to X_L Y/2 but similarly we can discuss about the horse power, current, torque, ratio for delta and internal delta connection, for the different values of Y and ~~will~~ determined values can be compared. The value ~~calculat-ed~~ ~~and~~ obtained with test results are given in Chapter VII.

Now Before giving the actual test result, and showing ~~the test results obtained~~, the winding diagram, along with different connection for different number of poles is to be discussed.

$$= \frac{1.407\ (1-0.5)\ T_{ph} + \frac{0.5\ T_{ph}}{1.732}}{\frac{T_{ph}}{1.732}}$$

$$= \frac{1.407 \times 0.5 \times T_{ph} + \frac{0.5\ T_{ph}}{1.732}}{\frac{T_{ph}}{1.732}}$$

$$= \frac{1.732 \times 1.407 \times 0.5\ T_{ph} + 0.5\ Tph}{\frac{1.732}{Tm \,|\, 1.732}}$$

$$= 1.732 \times 1.407 \times 0.5 + 0.5$$

$$= 1.218 + 0.5 = 1.718$$

Assume that the exciting currents have the same ratio and hence the same phase relation .

$$\text{Then } \frac{I_{\lambda}}{I_{\lambda}\ \text{int.}} = 1.72$$

So the current / speed curve for connection$^{3'1}$ (b) can be obtained by deviding the current in connection Shown in figure^{3} (1.A) by 1.72.

The calculated ~~and~~ test results are to be plotted and compared.

CHAPTER IV

WINDING CONNECTION

WINDING CONNECTION

A. GENERAL OUT LINE

The primary function of every current carrying armature winding is to create magnetism . To accomplish this most effectively , the copper coils, constituting the armature winding, must be arranged in definite symmetrical patterns in the slots of the armature core and joined together in accordance with well established practice. Total number of coils needed is equal to total number of slots for double layer winding, but for single layer winding number of coils is equal to half ~~the number~~ of the total number of slots. In ~~he~~lap and wave winding all the coils are identical, however, when coils of any of the windings indicated are placed in the slots of the core , it is done with complete regularity, i.e, the procedure that is followed for one set or group of coils is repeated for every similar set or group of coils. When the individual coils are interconnected to form the completed a-c winding, it is necessary to join them together so that (1) the proper coils are grouped together to form pole phase sections. (2) The proper pole phase sections are combined to form the individual phases with the correct polarities (3) The individual phases are interconnected to form the proper poly phase connection.

The number of coils in a pole group is equal to the number of slots per pole per phase. The pole groups are gen~~ta~~erally connected in series, but may be connected in parallel to suit the voltage applied whenever it is needed to change the applied voltage. The pole groups are connected in series in such a way that the pole group of each phase are connected so that successive magnetic polarities are opposite North and South at any instant. In this case number of pole is equal to number of pole group per phase. All the coils in a pole group are joined in series because the coil construction and connection procedure automatically join together the coils in each section in this way.

The induction motor selected to perform the experiment is of the squirrel cage rotor type; of 2 H.P., andcoupled with a D.C. machine of the same horse power. This induction motor is designed to provide various types of connections with respect to number of poles in a three phase distribution winding. The stator of the induction motor has 36 slots wound with 36 coils in two layers. All the ends of the coils are brought out and numbered as shown on the connection board. The ends of the coils are indicated as 1-101, 2-102, 3-103, 4.104 ...... 36-136 . Each coil containing 38 turns of 21 S.W.G. super enamelled copper wire in series.

The machine can be connected for 2 poles, 4 poles, 6 poles, 8 poles. Then 3 phase can be made in star, delta or internal delta. Three types of pole changing connections can also made for 2/4, and 4/8 poles, for constant torque, constant horse power and variable torque and horse power.

We will give the connection diagram for 4 pole, 6 pole ~~and 8 pole~~ for delta star and internal delta connection. The possible number of internal delta for 4 pole winding is 3 , for 6 pole is 5. ~~and for 8 pole~~ is 7.

B. FOUR POLE THREE PHASE COIL CONNECTIONS

A winding of ~~suitable~~ double layer~~s~~ type for 4 pole will have following details :

No. of poles. = 4

No. of pole group per phase = 4

No. of pole phase group = 12

∴ No. of coils connected in series to form pole group = 36 / 12 = 3 coils.

Total electrical angle 360° ~~X~~ x 4 / 2 = 720°.

∴ Angle between any two slot = 720 / 36 = 20°

∴ Angle spread by 3 coils forming a pole phase group = 60°

∴ No. of slots per pole = 36/4 = 9

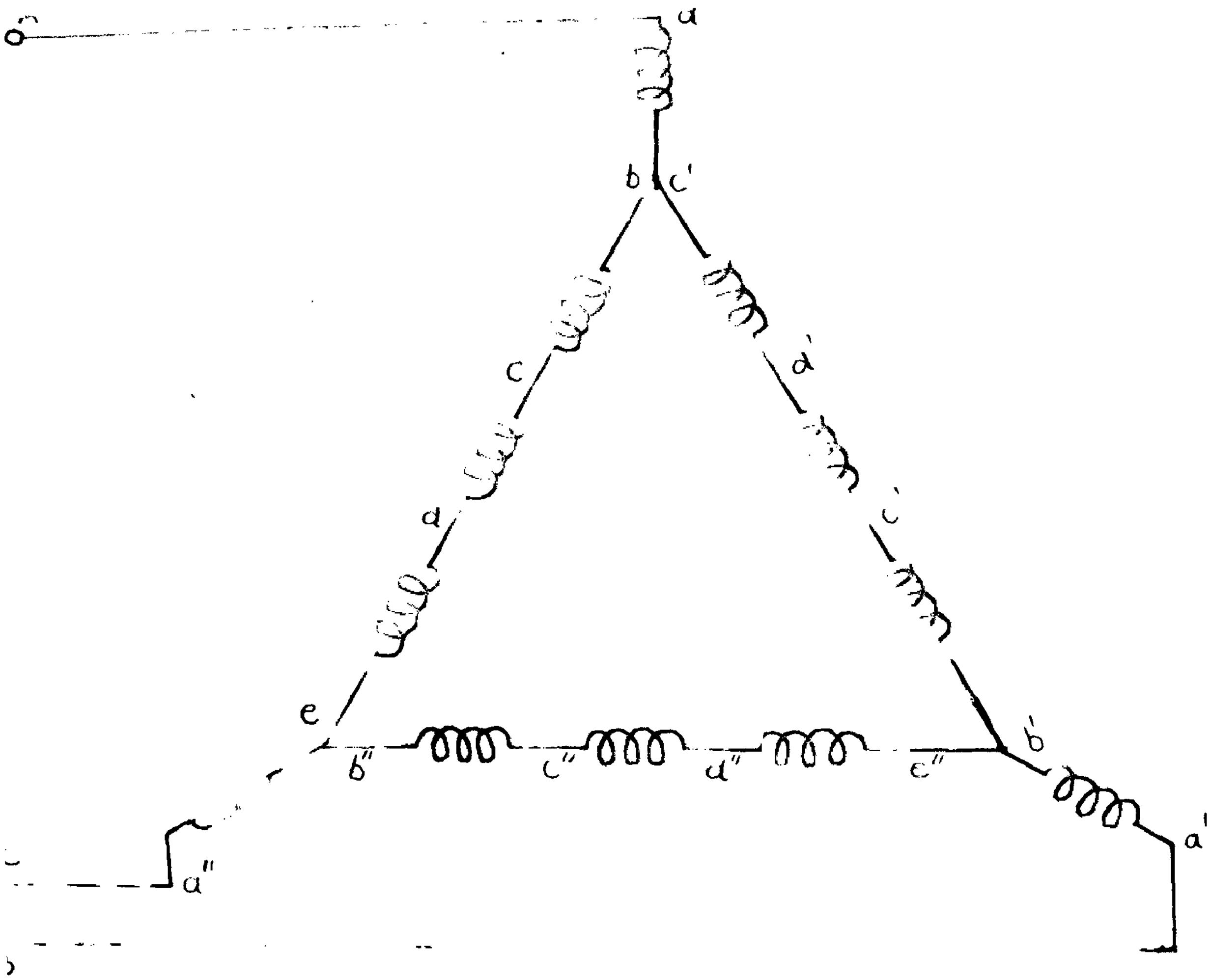

a
b
c'
c
d'
d
c'
e
b'
b"
c"
d"
e"
a'
a"

Fig 4.2

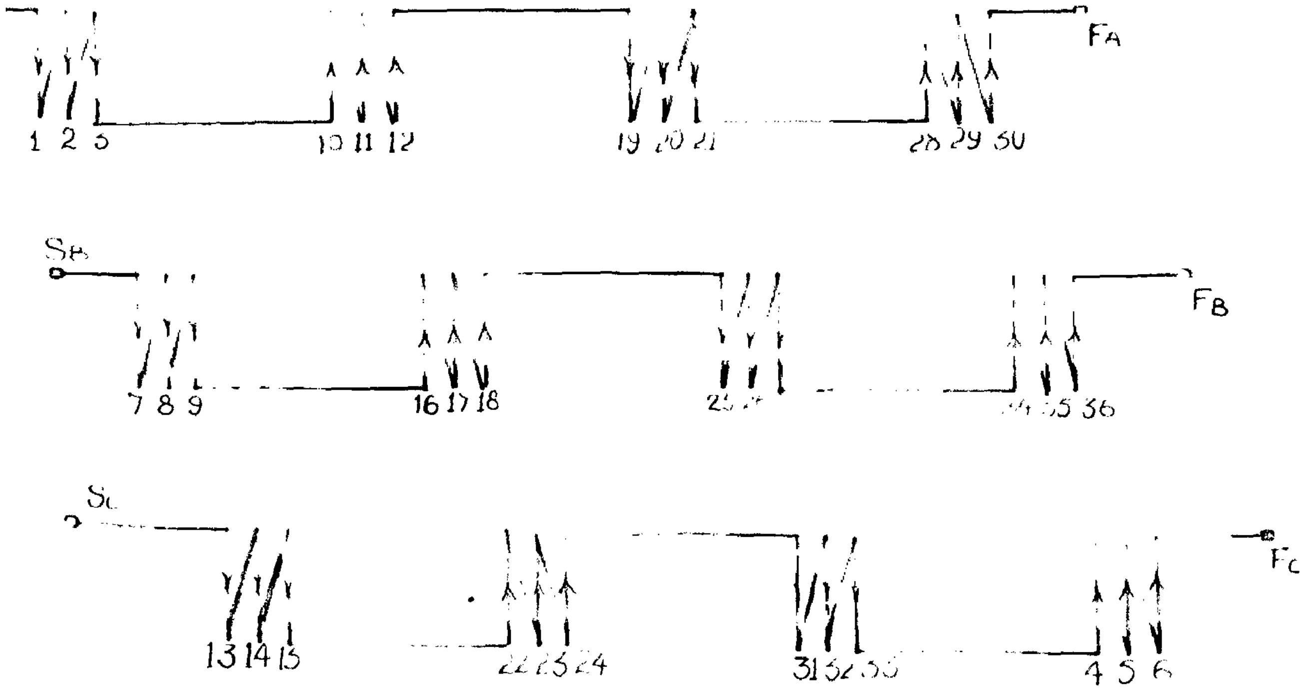

1 2 3
10 11 12
19 20 21
28 29 30
FA
SB
7 8 9
16 17 18
25
35 36
FB
SC
13 14 15
22 23 24
31 32 33
4 5 6
FC

Fig 4.1

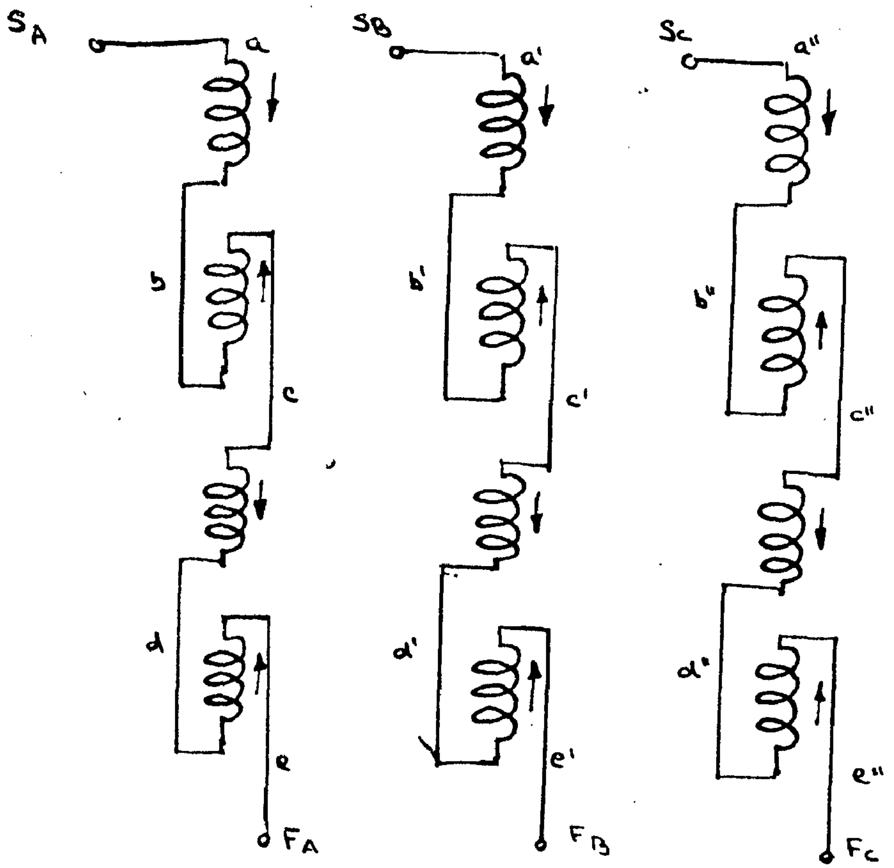


Fig 4.2

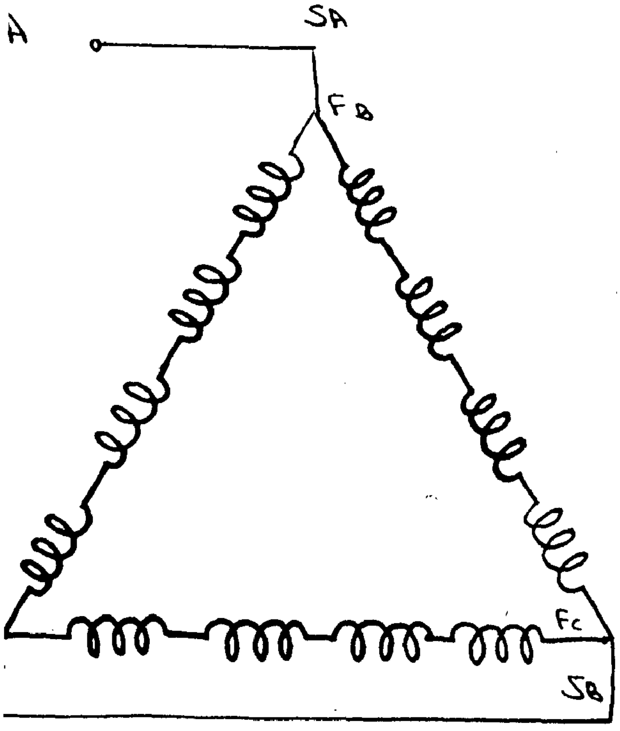


Fig 4.3

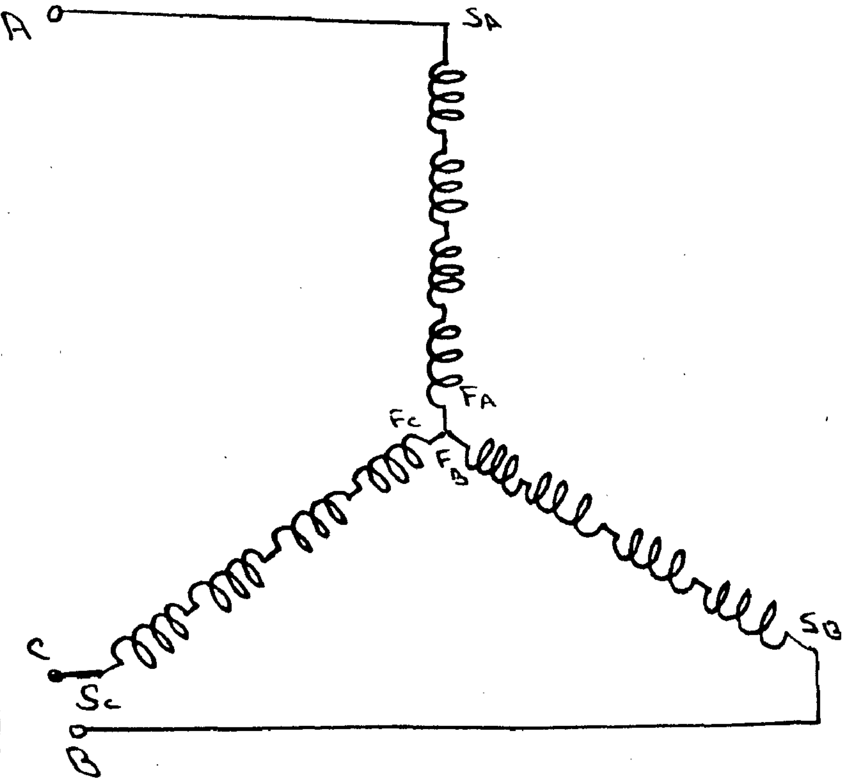


Fig 4.4

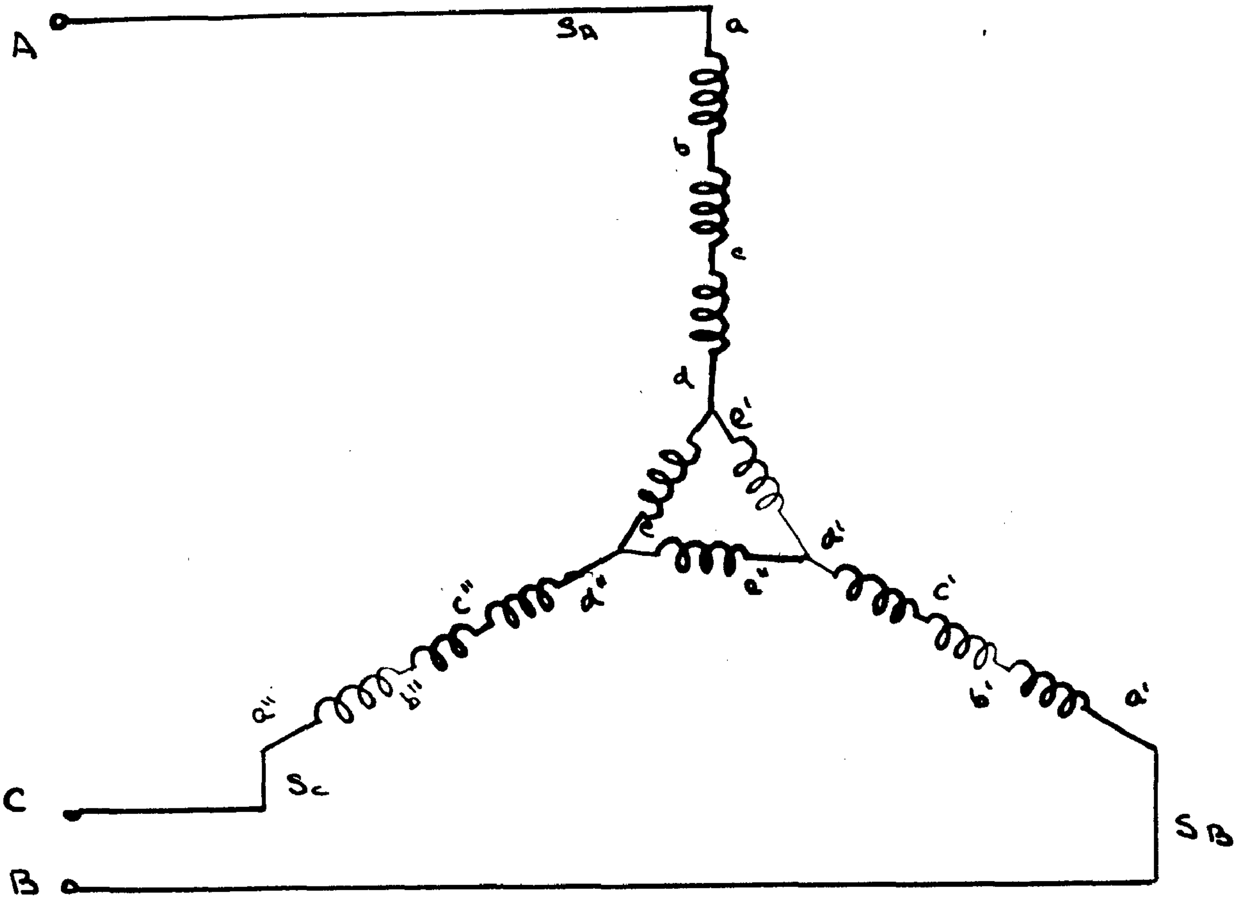


Fig 4.5

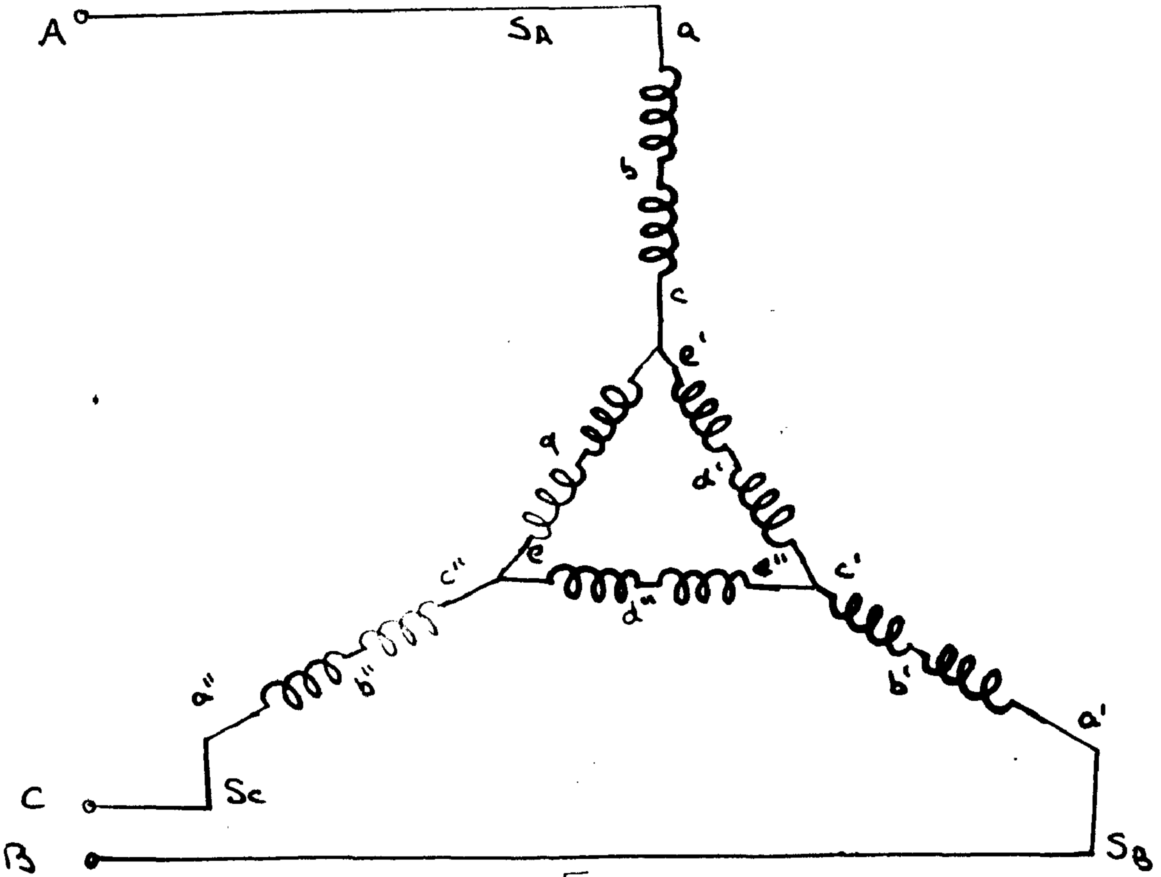


Fig 4.6

For full pitch coil winding span should be equal to 9 ~~star~~ slot.

To form 3 phase winding spaced 120° apart in spaces number of slots between two phase equal to 6 So if phase A start with slot 1 then phase B will start for slot 7, and phase (c) will start at slot (13).

The connection diagram with decrease of current is shown in (Figure 4.1 4.4.2).

Each phase is having four pole group, which is shown in Figure 4.2 4.4.2.

These three phase can be connected in delta, star and 3 internal delta connection. The delta and star connection is shown in Figure 4.3 & 4.4 respectively.

Three possible number of internal delta connection with one pole phase group in delta, 2 pole phase group in delta, 3 pole phase group in delta is shown in figure 4.5 ~~to~~ 4.6 & 4.7 respectively.

C. SIX POLE THREE PHASE COIL CONNECTION

A double layer winding for 6 pole will have following details.

Number of poles = 6

Number of pole groups per phase = 6

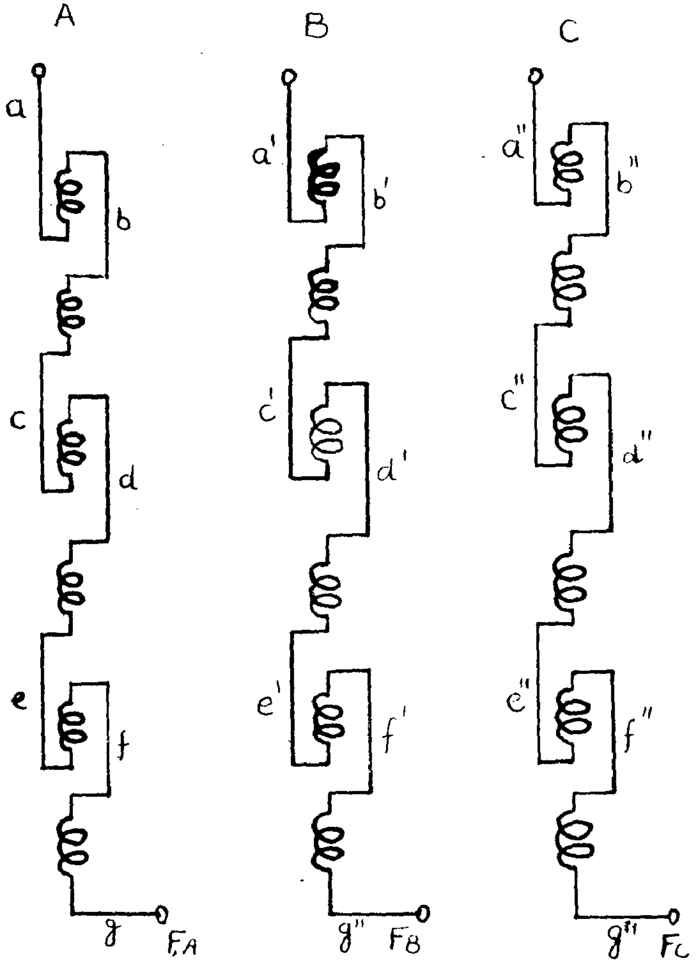

A
B
C
a
b
c
d
e
f
g
F_A
a'
b'
c'
d'
e'
f'
g''
F_B
a''
b''
c''
d''
e''
f''
g''
F_C

Fig 4·9

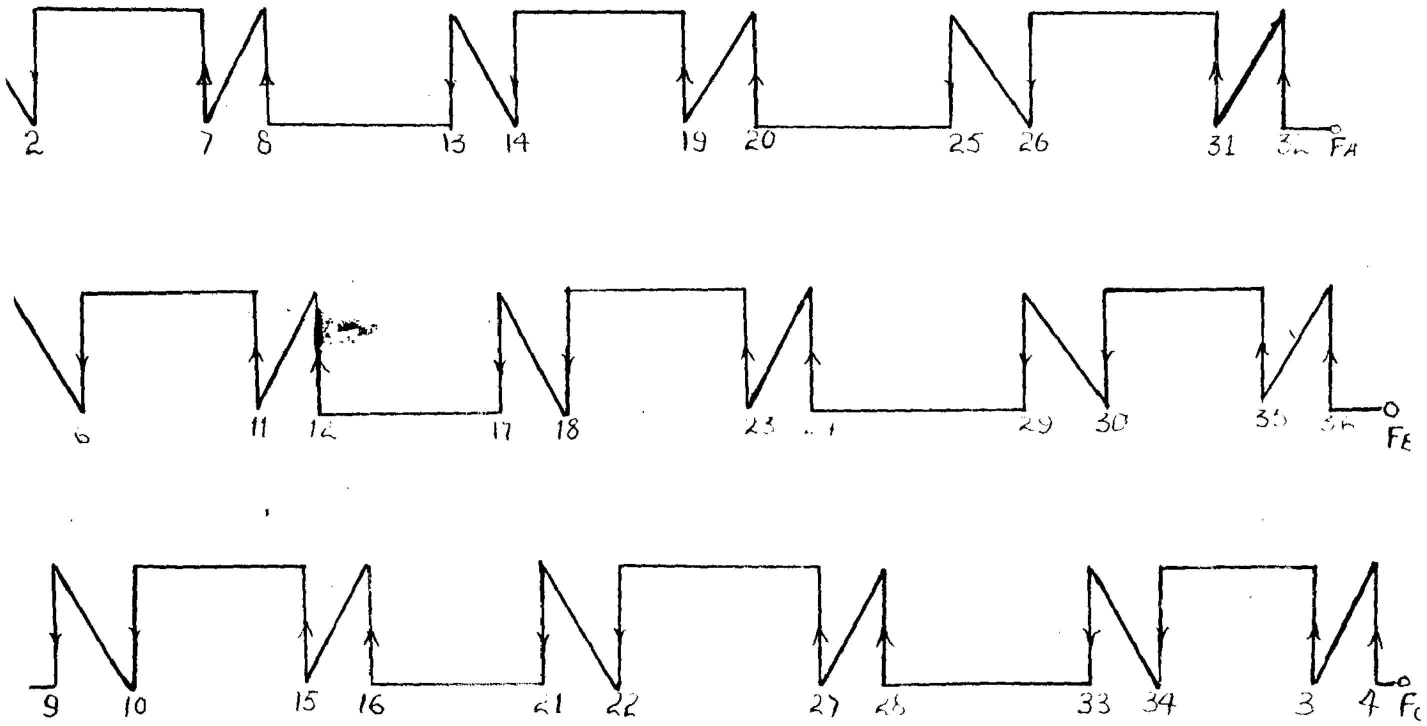

2
7
8
13
14
19
20
25
26
31
32
F_A
6
11
12
17
18
23
24
29
30
35
36
F_B
9
10
15
16
21
22
27
28
33
34
3
4
F_C

Fig 4·6

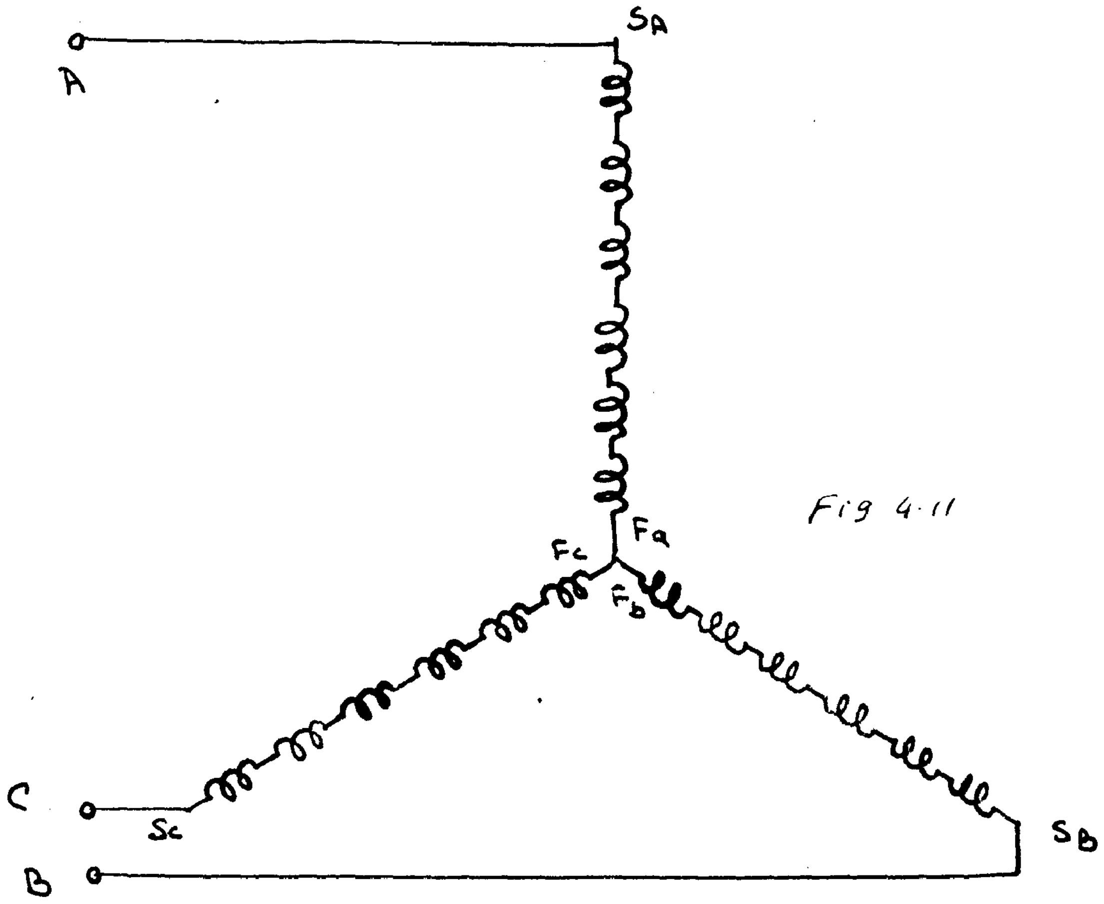


Fig 4·11

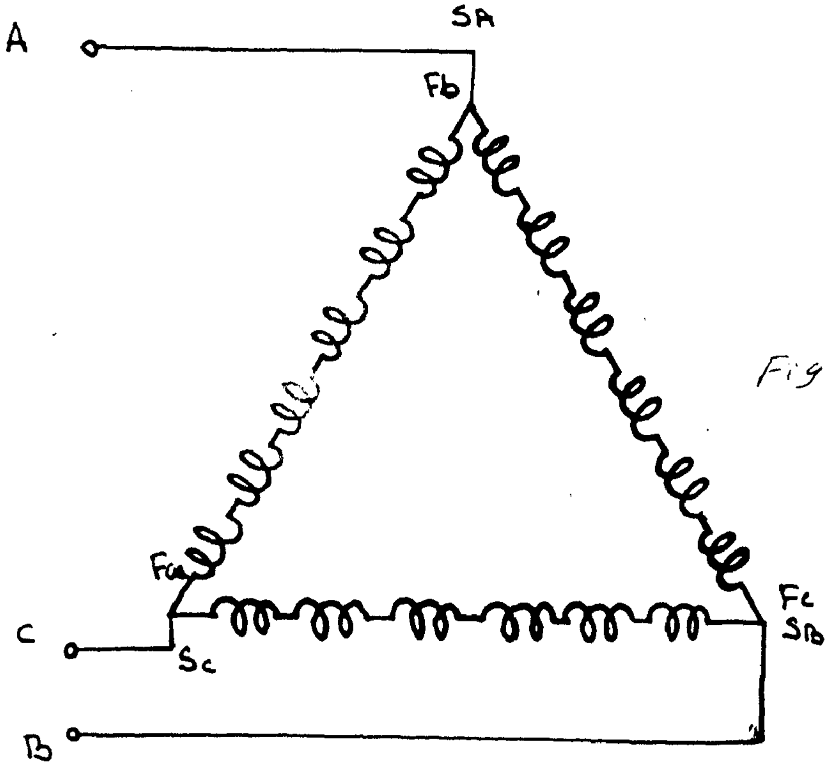


Fig 4·10

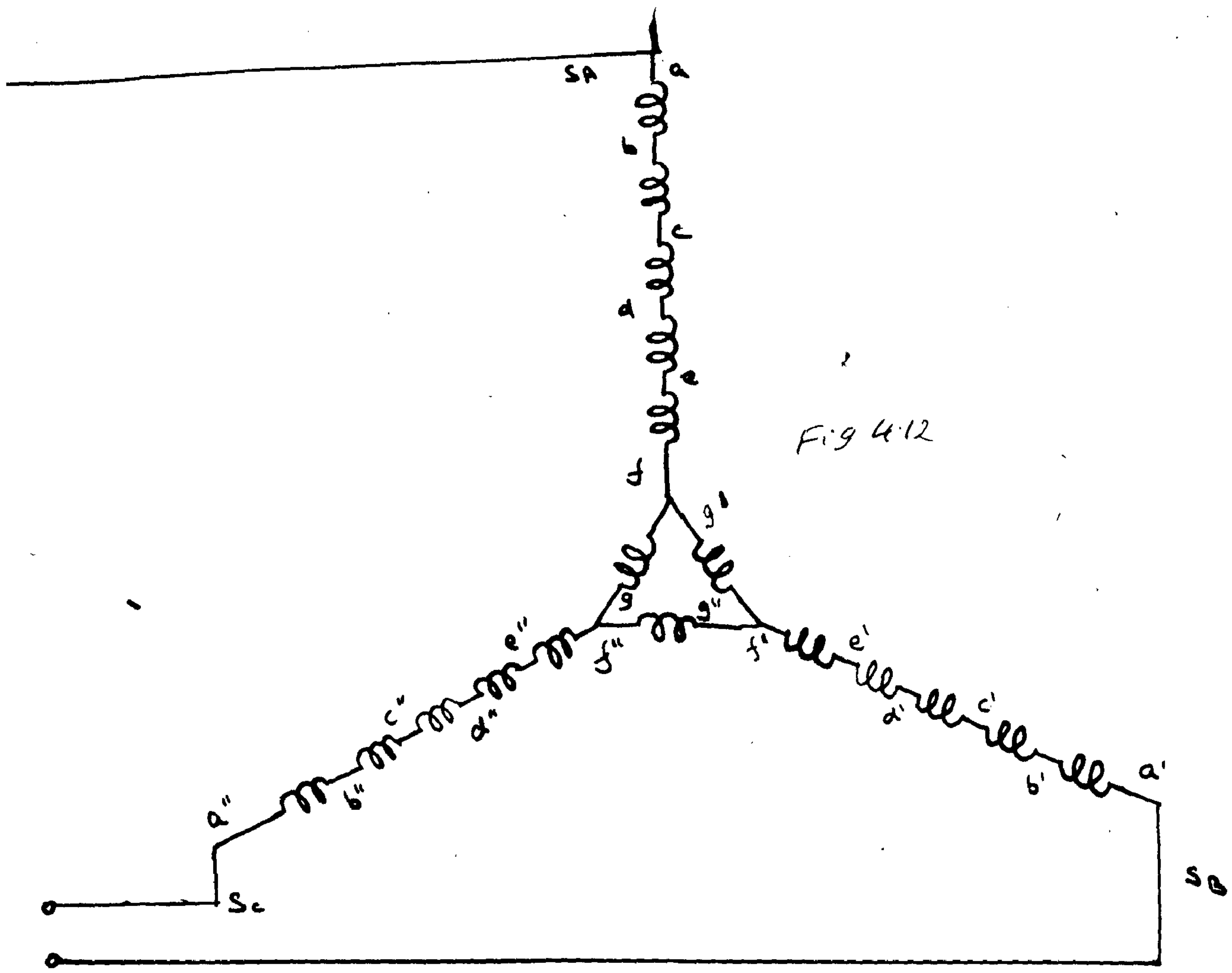


Fig 4.12

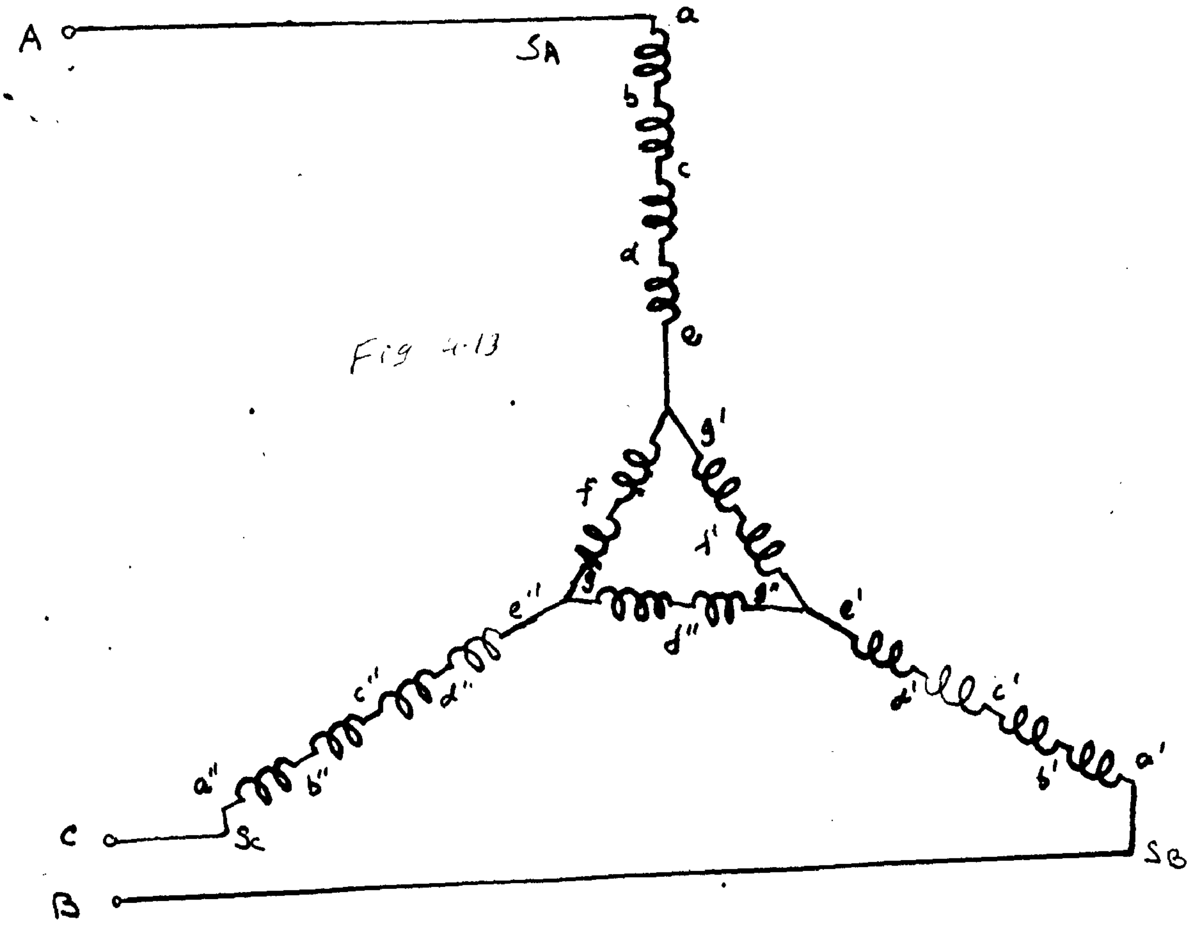
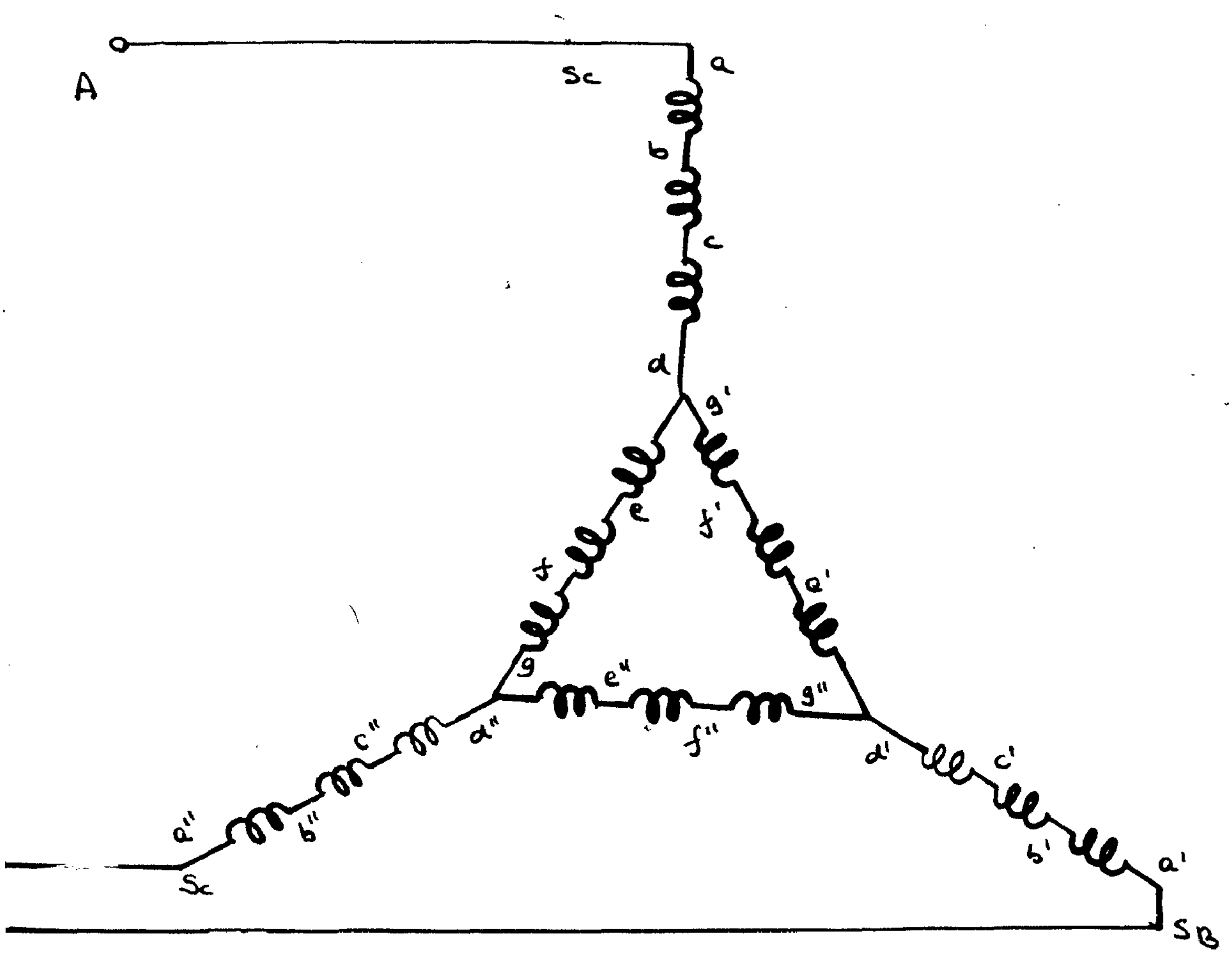


Fig 4.13


A
Sc
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b
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g'
e
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f
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g
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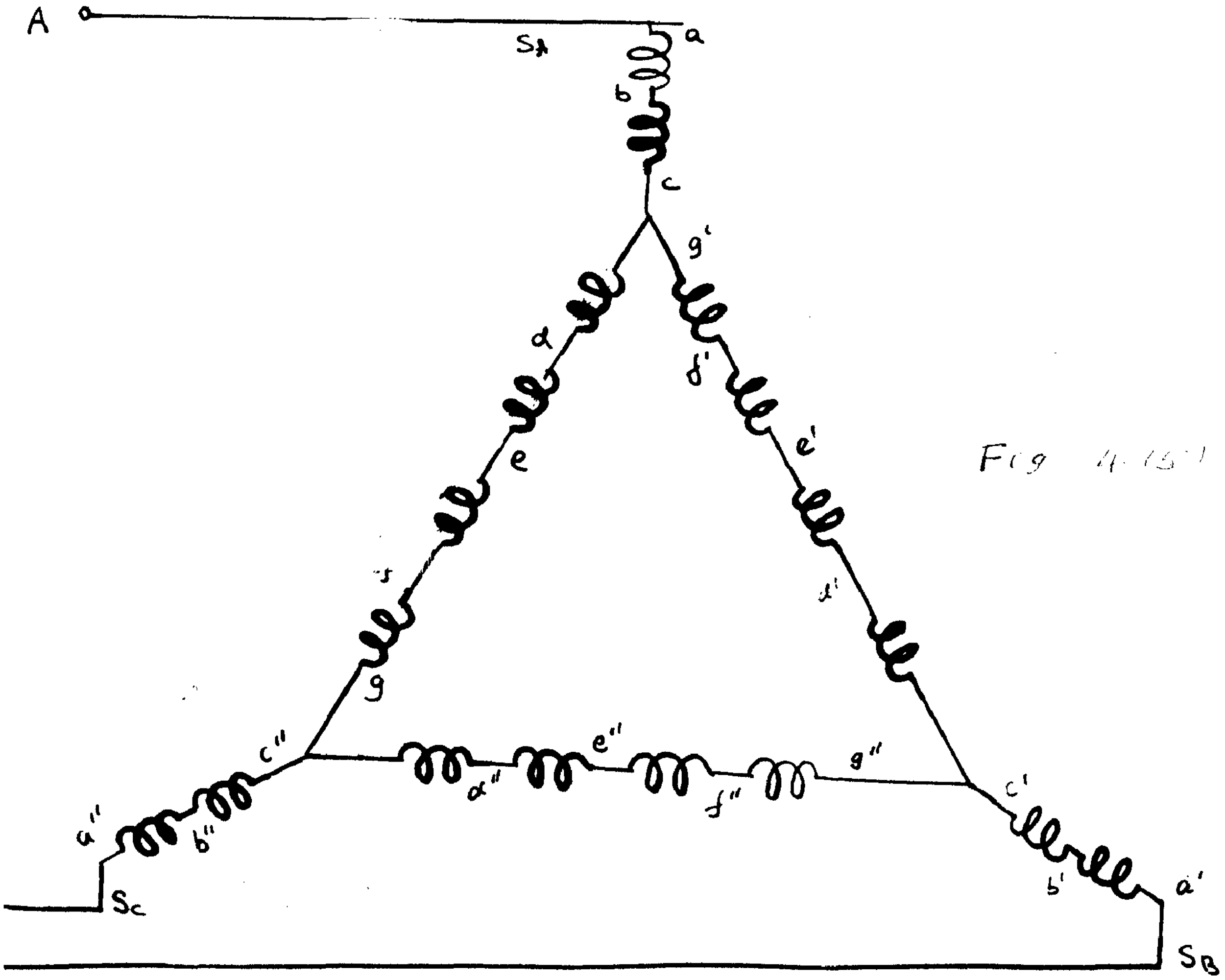
c''
c'
a''
b''
b'
a'
Sc
SB

Fig.4 (4)


A
Sa
a
b
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g'
d
d'
e
e'
f
f'
g
c''
e''
g''
c'
a''
d''
f''
b''
b'
a'
Sc
SB

Fig 4 (5)

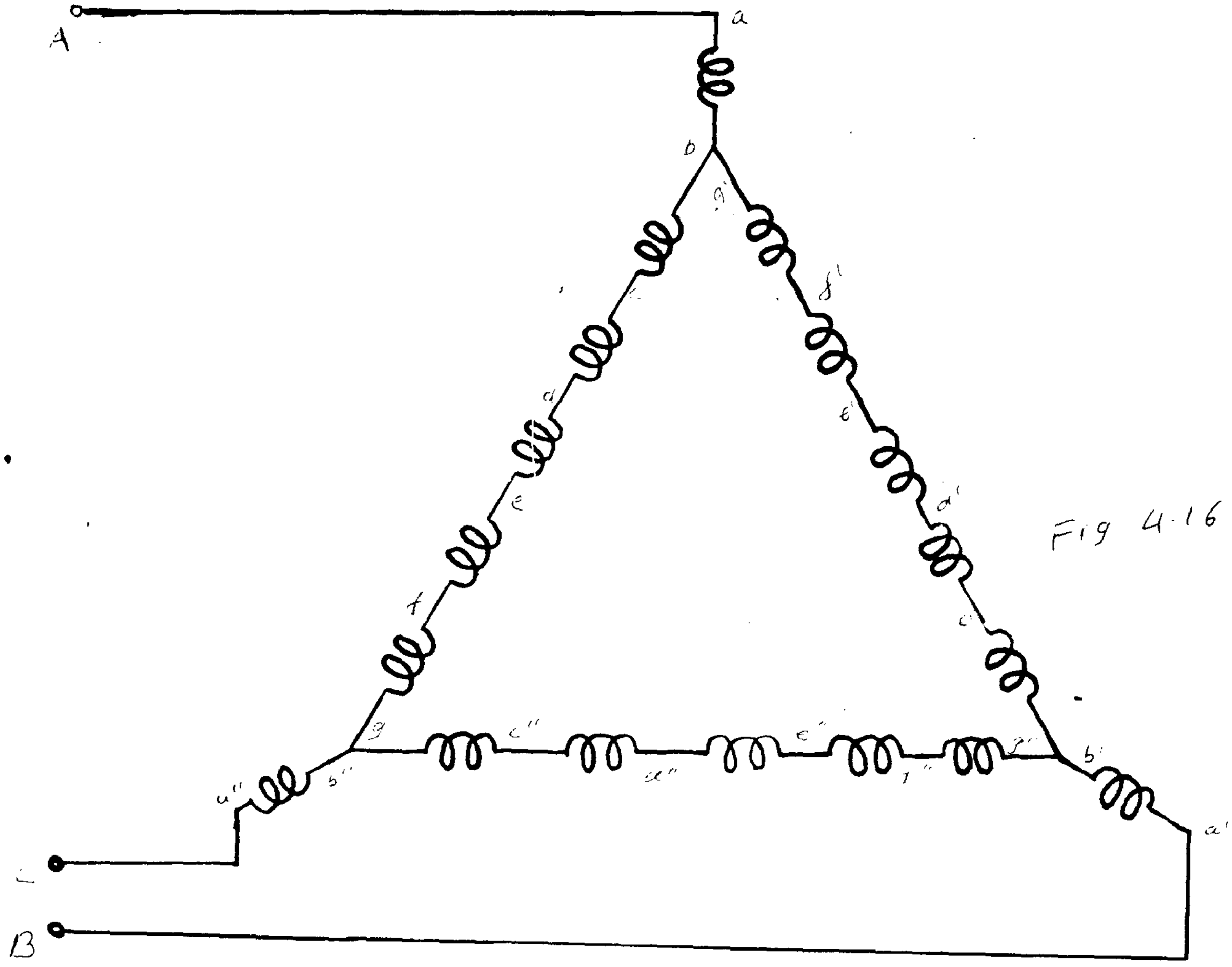


Fig 4.16

Number of total pole phase group = 18

No. of coils connected in series to
form a pole phase group = 36 / 18 = 2

Total electrical degree = $360^\circ \times 6/2$ = 1080°

Angle between any two slots = 1080/36 = 30°

Angle spread by 3 coils ~~froming~~ forming pole
phase group = $2 \times 30^\circ = 60^\circ$

No. of slots per pole 36 / 6 = 6

∴ For full pitch winding coil span = 6 slots.

To form 3 phase winding, spaced 120° apart in space, number of slot between two phase equal to 4. when Phase A starts from slot (1) then phase (B) starts from slot 5, and phase C starts with slot 9. The connection diagram ~~will~~ ~~dix~~ with ~~show~~ direction of current in pole phase group is shown in Figure No. 4·8 & 4.9 ~~&~~

Delta and star connection is shown in Figure 4·10 & 4·11 respectively.

In this 6 pole winding, there can be 5 possible types of internal delta connection. The internal delta connection with one pole phase group ; two pole phase group , three pole phase group, 4 pole phase group, 5 pole phase group in delta is shown in Figure 4·12, 4·13, 4·14 4·15 & 4·16 respectively.

CHAPTER V

TESTS

TESTS

A. General outline.

It is discussed in the previous Chapter that change of connection of stator winding of 3 phase induction motor causes a change of horse power output and an approximate relation of horse power when connected for delta, star and internal delta. To justify the expression it becomes necessary to have certain definite test on induction motor . Along with comparision of horse power rating, different other characteristics of induction motor, for the different connection, (delta, star or internal delta) for different number of poles must be compared so that relative advantage of different connection can be notified and hence can be utilized. The other characteristic, is to be compared are magnetizing current, power factor, starting torque, maximum torque, full load torque, the efficiency, over load capacity, speed-torque characteristic.

The machine selected for the test is of the squirrel cage type, whose all the dimensions are fixed. The only change that will be made is in the winding is for different number of poles and in connections, for delta, star and intermal delta, change in number of poles, changes magnetizing reactance. Magnetising reactance is inversely proportional to square of number of poles. So magnetizing current is also changes with change in number of poles. Similarly harmonics and saturation has got also some effect on some of the above mentioned characteristics.

Performance calculation can be made by two methods

1. on the basis of all the physical data, obtained by its original designer.

2. By test data.

Here the machine is not supplied with physical data by the manufacturer, so only way to know about the operating characteristics of induction motor is based on experiments.

Foremost necessity in calculating the performance is to know the circuit constants of induction motor They are resistance, reactance of primary (stator), secondary (rotor) and magnetizing branch of the machine, Some of these are fixed and some vary due to varition in operating condition of motor . Friction and windage loss can also be considered one of the ~~current~~ circuit constant for calculating the motor performances.

To calculate the circuit constants of induction motor, and the other performance under different operating conditions the following tests are commonly carried out:

1. No. load test.
2. Blocked rotor test
3. Resistance test
4. Load test
5. Turn ratio (for slip ring motor). test.
6. Temperature rise, test.
7. Insulation test.
8. Back to back test.

Among the above mentioned tests first four tests are most essential and sufficient for our purpose, to calculate the performance and to compare the different characteristics of induction motor. So only these tests are to be performed.

The circuit constant calculated by the test does not agree with actual value, because they are effected by certain factors, so they need some modification. As for example the value of X (reactance) and R_{b2}(Resistance) should be modified to allow the magnetic saturation and eddy currents. Before discussing about the modifications discussion about the different tests is being made.

1. No Load Test

This is one of the most informative tests, which gives the core and pulsation loss, friction and windage loss, magnetizing current, and no load power factor. Further any mechanical unbalance, noise faulty connections etc., are revealed. Magnetizing reactance can also be calculated.

To perform this test, a winding for proper number of poles (~~two~~, four or, six ~~or eight~~ poles) is made and connect~~ions~~ed in delta, star or internal delta connections are made to supply normal frequency, various voltage, and instrument including to measure the voltage, input power, and the current. Motor is run with its rotor in the normal running conditions i.e., short circuited when the motor has run enough for its bearing to show distress if faulty, the applied voltage is raised to about 25 % over normal and input power and current observed. The slip is measured. It is difficult to accurately measure speed due to very low slip. The readings are taken at lower values of voltages down to that at which the current starts again to rise.

When the voltage is decreased current decreases, when voltage comes to nearly 25 % the normal voltage current increases, similar is the case with power input. The slip and power factor increases with decrease of voltage, upto 50 %, if the normal voltage increase is small, but after that increase in slip and power factor is very quick .

Here the power-voltage curve is parabolic in shape. These power ~~output~~ input is to supply the core and pulsation loss, windage, friction loss and stator copper loss, which is small comparatively. Knowing the value of stator resistance, copper loss can be calculated. The parabolic curve when extended downward cuts the power axis curve at some point to voltage supplied. The value of power input is equal to friction and windage loss. This is also obtained by drawing a curve of power input with respect to V^2 which is a straight line and extending it to y axis, the intersept on y axis at $V^2 = 0$ gives the value of friction and windage loss. This loss is assumed fixed when friction and windage loss and stator copper loss at normal voltage is deducted from power input, then rest gives the value of core and pulsation loss. The core and pulsation loss can be assumed constant, actually speaking core loss which includes hysterisss and eddy current loss varies with slip under loading condition. Pulsation loss also depends on relat~~ion~~ve ~~of~~ speed of rotor with respect to stator and number of type of slots. For a given machine this can also be assumed constant.

Also by knowing no load slip and measuring no load slip of motor total high frequency losses (Pulsation losses) pulus friction and windage losses can be calculated from the formula.

High frequency loss + ~~to~~ friction and windage loss

$$= q \frac{E^2 S}{R_2} \quad \text{Watts.}$$

Where E is the unit phase voltage, q is number of phase, R_2 is secondary reactance in ohms per phase and S is the slip ~~of~~ at no load.

The value of the no load current at rated voltage and frequency fixes the starting point of the circle diagram. The magnetizing reactance may be calculated by the formula

$$X_m = \frac{E}{I_o} - X_1$$

The primary leakage reactance X_1 is determined from the locked rotor test data.

2. Locked Rotor Test

This locked rotor test in induction motor is analogous to the short circuit test of a transformer. The rotor is held stationary and short circuited under its normal running condition. Though this test consequently reveals no mechanical defects, but is of importance as furnishing the shoot circuit current and power factor which, with the no load current and power factor, enables the current diagram to be drawn. In addition the $I^2 R$ loss measured by the test are necessary for the estimation of efficiency by loss summation.

To perform the experiment, the stator is supplied with a low voltage of normal frequency, to avoid excessive current. The voltage is raised in steps, with a readings of current and power input, untill the current reaches not more than twice normal. The readings are taken quickly to avoid over heating.

The position in which the rotor is champed may affect the current, if so, the variation are noted when the rotor is locked in various positions and a mean position found.

Alternatively the rotor may be allowed to rotate very slowly during the progress of the test. Here the pow er curve is practically a parabola and is equal to copper los-s of stator and rotor. . Flux is very less at the usual short circuit test voltage. So the core loss as a whole will thus be quite small. In particular the pulsation losses naturally vanish and the mechanical losses are absent.

Here impedance falls with the higher currents. This is due to the reduced leakage reactance consequent upon the saturation of the teeth. For the same reason the parasitic eddy current losses in the conductor are some what reduced , so that the effective resistance may also fall. Hence at higher current values the current is no longer proportional to the applied voltages, but increases more rapidly at a power factor probably higher than at current in the region of the full load magnitude.

The motor impedance per phase is determined from the volts, amperes, and watts readings. The total resistance component for a three phase motor is $R = W / 3 I^2$

(Ohms per phase)

Where I = per phase current , W = Total input watts,

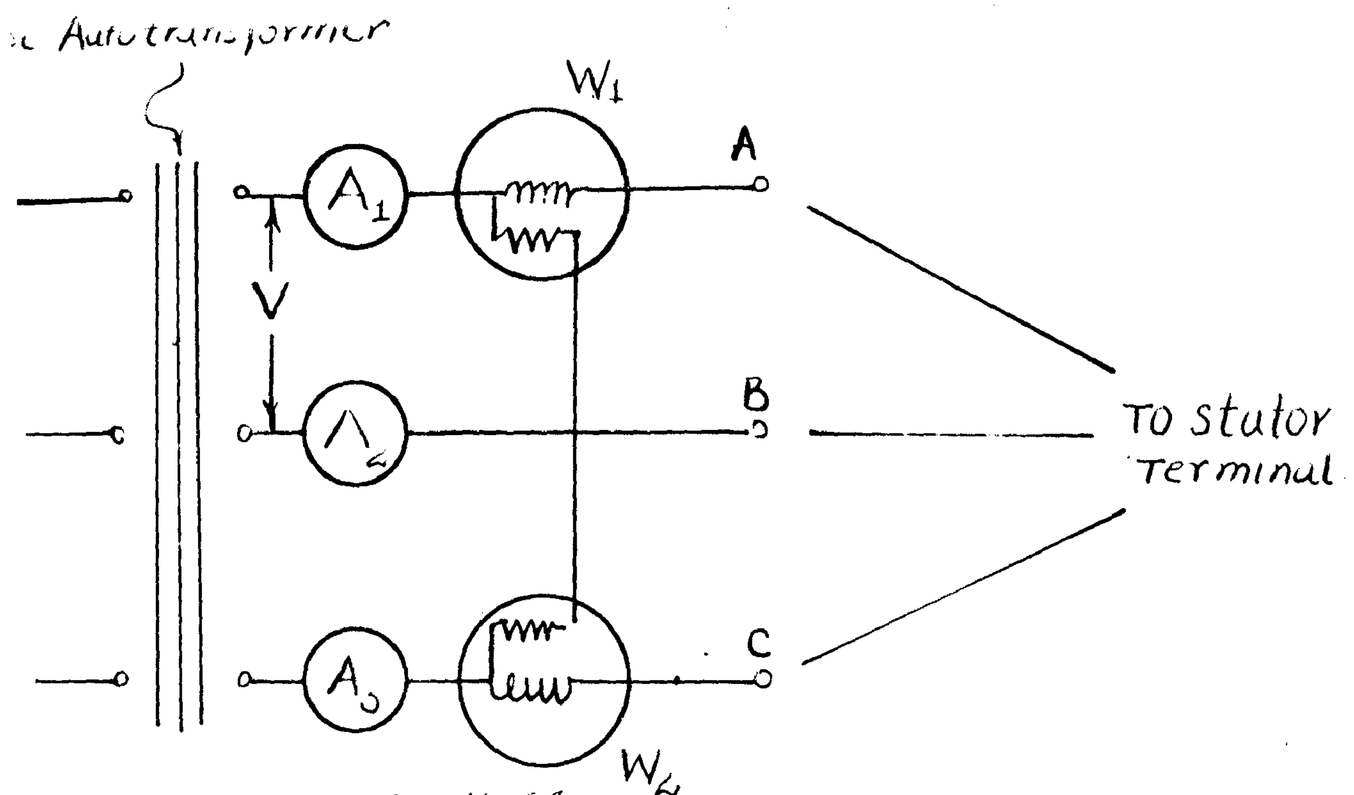


Fig No 5.1

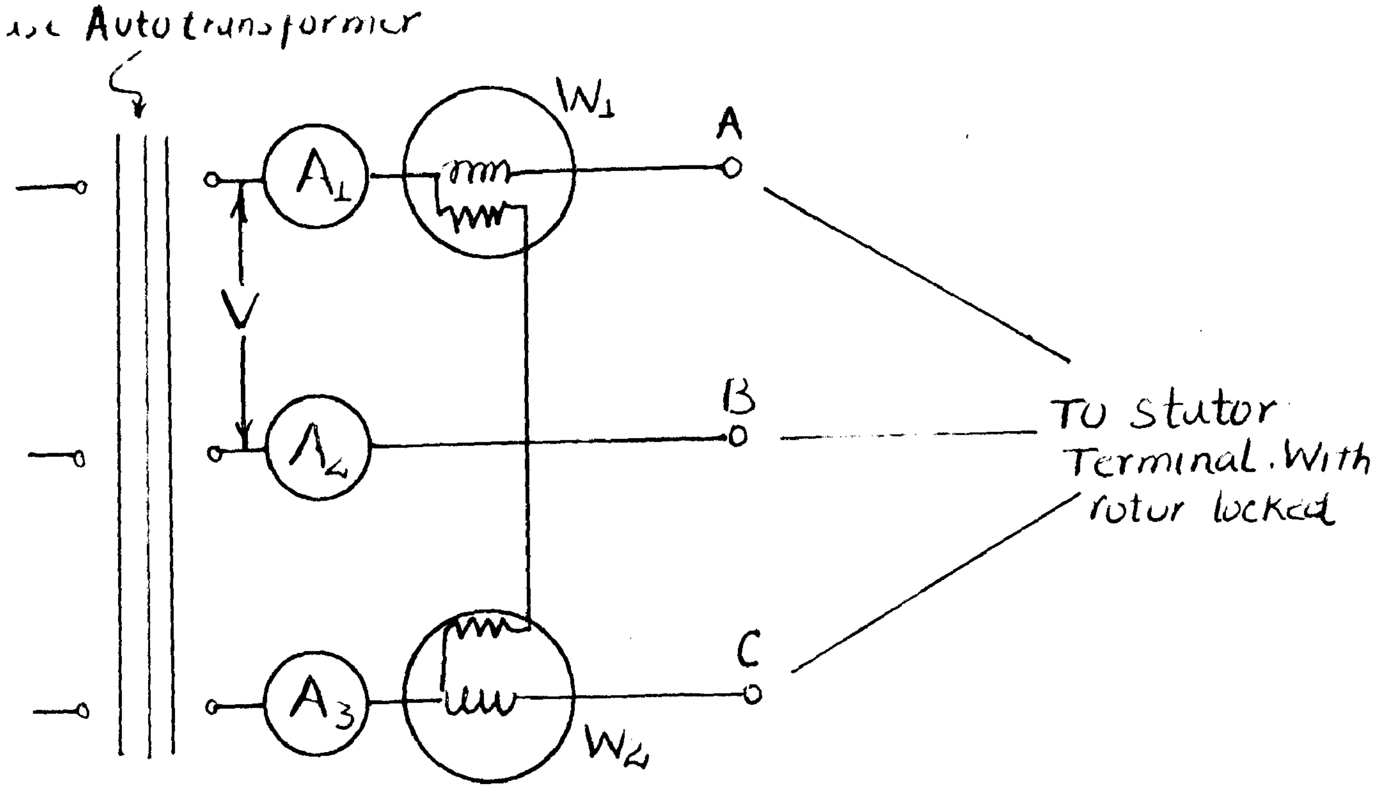


Fig. No 5.2

and the reactance component is

$$X_t = \sqrt{\frac{E^2_{ph}}{I^2} - R^2} \qquad \text{(Ohms per phase)}$$

Where E_{ph} = phase voltage.

The test value of reactance X_t from above equation is a little smaller than the true value of reactance, because the formula assumes the line current to flow through the primary and secondary impedance in series, whereas actually the magnetizing component of the current flow in the primary winding only. A small correction factor must be applied to X_t, therefore to obtain the reactance 'X' for use in equivalent circuit calculations.

Normally the primary and secondary leakage reactance value X_1 and X_2 are assumed equal each having the value of X/2.

The Figure No. shows the circuit diagram for the experiment.

3. Resistance Test

The primary resistance is measured with direct current a current about one quarter of full load value being preferably used and readings being taken quickly to avoid errors due to temperature changes during the test. The resistance calculated is corrected for Temperature 75°C when test is carried out at room temperature.

Substracting the primary resistance at the temperature of test from the resistance component of the total impedance, gives the effective secondary resistance at stand still.

4. Load Test

This is the most important test for the induction motor, because with this test quantities for pull out torque or starting torque are to be furnished, these may also be investigated, and with test ~~and~~ efficiency, brake horse power power factor, torque, and slip can be determined at various loads.

For this test an absorption brake or a coupled calibrated d.c. generator may be used to load the machine. The motor is operated on normal voltage and frequency at loads between zero and 50 percent or 100 percent over load, readings being taken of voltage, current in all phases, total power and slip.

A curve for speed, power factor, efficiency, brake horse power, torque and slip to a base of percentage normal full load current is to be drawn. The torque-current curve which can be drawn will be fairly straight as ~~as~~ is brake horse power curve, Since the speed is nearly constant. As current increases from no load value, the power factor rises to a maximum near full load. Power factor will fall again to short circuit value if the load is increased and the motor stalls. The efficiency is zero at no load, but

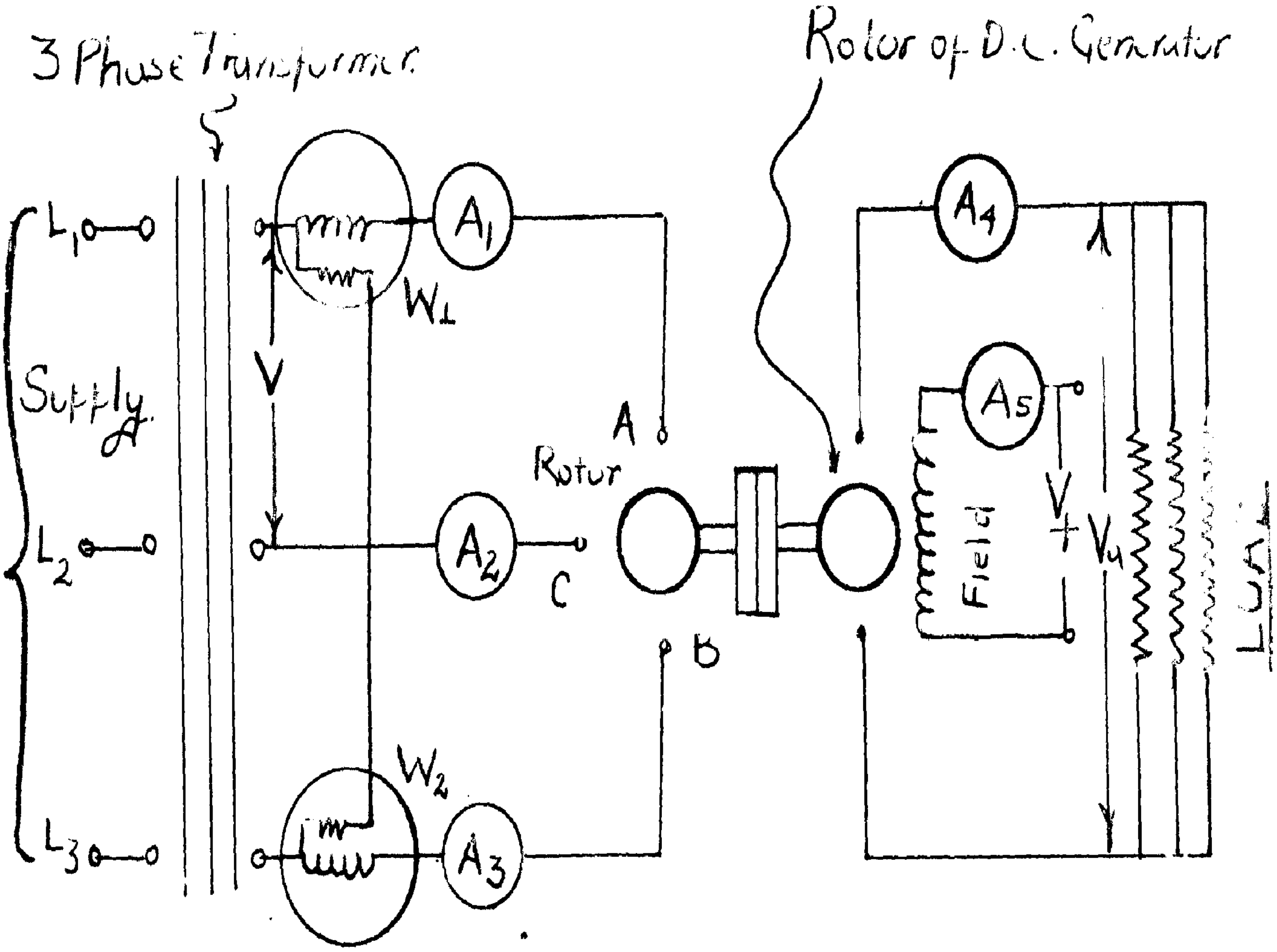

3 Phase Transformer
Rotor of D.C. Generator
L1
L2
L3
Supply
W1
W2
A1
A2
A3
A4
A5
V
A
B
C
Rotor
Field
V4
LOAD

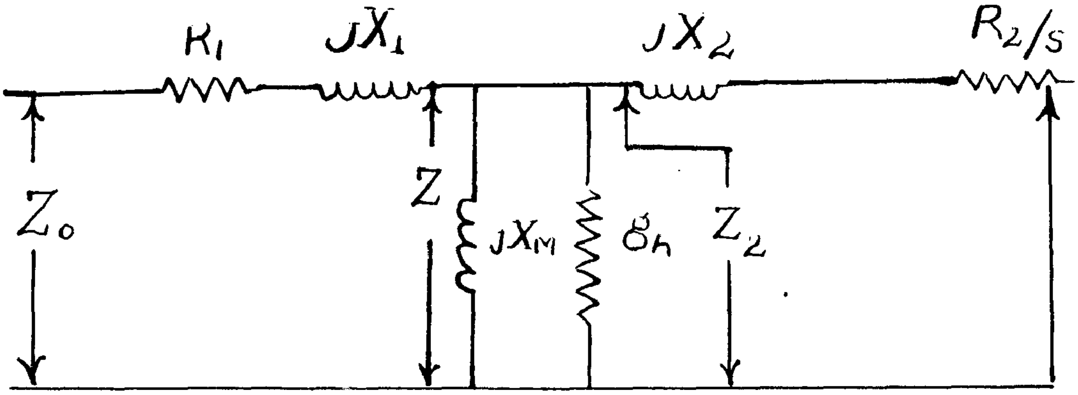
Fig No 53

will
with rise to a maximum , where roughly the I^2R losses equal to the no load losses. Thereafter the efficiency falls because the losses increases more rapidly than the output. The circuit diagram for the experiment is shown in Figure No. 5.3 .

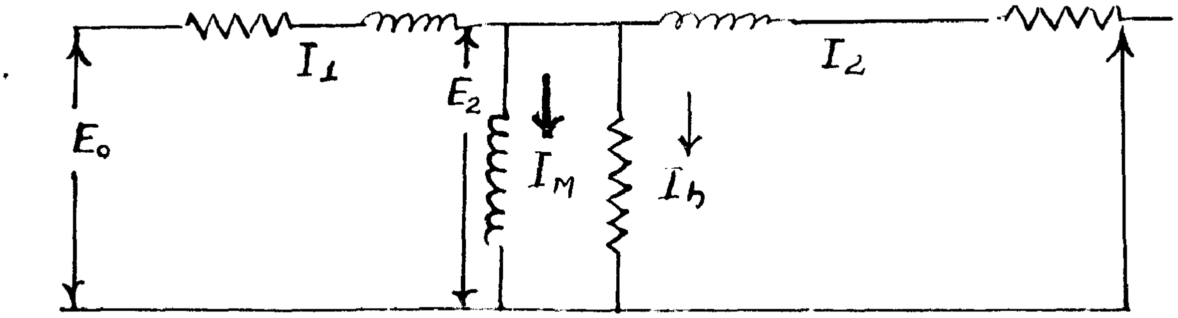
5. Correction for the Circuit Constants

Although the performance of a poly phase induction motor can be easily visualized by the phasor or circle diagram, it is not convenient to make exact or repetitive calculations by these graphical methods. For this purpose the equivalent circuit offers a far more convenient and versatile method of analysis. The exact equivalent circuit due to 'Steinmetz' normally used for this purpose is shown in Figure No. 5.4 .

The constant of the equivalent circuit can be determined by a no load test, locked rotor test. D.C. resistance test. In practice so called constant of the equivalent circuit or circuit impedances vary somewhat with changes in motor current, speed, voltage, temperature, etc. The variation can be taken care of by introducing, appropriately modified values for each condition of operation. Usually the resistance of stator winding corrected for 75°C. Also lower values of motor reactance taken under full voltage starting condition , when the current is high and the leakage path is saturated, then at full speed when the current is low. Similarly non uniform current distribution in the rotor conductor causes the secondary resistance to be



Impedances.



Voltages and currents.

FIG. NO.(5.4) EQUIVALENT CIRCUIT OF POLYPHASE INDUCTION MOTOR.

higher and the secondary reactance to be lower, at stand still than they are at full speed. All these variations are recognised in practice by using test or calculated values appropriate for the particular condition.

Instead of varying the circuit constants to take an account of all conditions it is often preferable to make circuit calculat~~ed~~ion with fixed values of the circuit constants, and then to correct the results, if necessary by suitable formulae. A correction formulae have been developed that make it easy to determine the effect of any moderate change in the impedance values without re calculating the whole circuit.

Circuit Calculations

For calculations of circuit constant from the test data the following formulas are important.

1. $$X_t = \frac{f}{f_t} \sqrt{\frac{E}{3\,I_k^2} - \left(\frac{W}{3\,I^2}\right)}$$

Where E = Line voltage (Y connection)

2. $$X = X_t \left[1 + \frac{X_m \cdot X_t}{4\,B_o}\right] + {}^{\wedge}\, x$$

3. $$X1 = X_2 = 0.5\ X$$

4. $$\triangle X = R_t - R_2$$

5. $W_H + W F = W_{RL} - 3 I_m^2 R_1$

(W_s = Stray load loss is equal to 0.01 to 0.02 times rated output at full load, and varies as the square of the load current at other loads).

6. $X_m = \frac{E_o}{I_m} - X_1$

If values of torque , currents etc., are desired for considerable overloads, or to through out the accelerating range, the values of R_2 and X should be modified to allow for magnetic saturation and eddy currents. Curves for reactance against current obtained by locked rotor tests over the desired range of values, and a value of R_t and corresponding values of Λx obtained by locked rotor tests at different frequencies are desirable for this purpose, especially for closed slot or double squirrel cage rotor.

β. GENERALIZED CIRCUIT CALCULATIONS

To facilitate the derivation of formulae and chart from which any desired characteristics of a polyphase motor can be determined, it is convenient to make use of the following symbols :-

$a = \frac{I_m}{\cancel{E_o} I_1}$ = Ratio of no load current to primary current.

$b = \frac{I_1 x}{E_o}$ = Ratio of apparent leakage drop at assumed load to impressed primary voltage.

$c = \frac{I_1 R_1}{E_o}$ = Ratio of primary resistance drop to impressed voltage.

$d = \frac{I_1 R_2}{E_o}$ = Ratio of secondary resistance drop based on the primary current to impressed voltage.

$h = \frac{\text{Core loss}}{\text{Volt-Amp-input}}$ = ratio of core loss watts per phase to volt - Amp input per phase at the load under consideration.

Also let

$$K = \frac{d}{S} = \frac{R_2}{S.Z_o} = \frac{R}{Z_o}$$

= ratio of apparent percent secondary resistance drop to percent slip.

$$ab = \frac{I_m X}{E_o} = \frac{X}{X_m + X} = \text{The leakage factor.}$$

C· CALCULATION IN THE REGION OF STAND STILL

For In the calculation near the region of stand still following correction will be done for the calculation of parameter.

a. $X = X_t \left(1 + \frac{ab}{4} \right)$ approximately.

b. Apparent secondary resistant R_t, approximately measured in the locked rotor test is smaller then the true value by the factor $(1 - ab)$.

c. Starting torque is less than the torque that would be obtained if the magnetizing current were zero by the factor

$$\left(1 + \frac{ab}{4}\right)^{2} (1-ab) = \left(1 - \frac{ab}{2} \right) \text{ approximately}$$

D. CALCULATION IN THE REGION OF FULL LOAD

For this case (a) $K \simeq \cancel{b}\,1 + \frac{a^2 - b^2}{2} + h - c + 2a^2b^2$

This equation is useful in making performance calculations from the test results, for there is no suitable means of directly measuring R_2, and a knowledge of this is essential for the start of equivalent circuit calculation for a definite value of slip. Measurement of R_2 by stand still impedance test involves large errors due to iron losses and eddy current, and on slip ring motors its measurement with direct current applied across the rings involves transformer ratio calculations which may lead to error.

The normal procedure in testing is, therefore to operate the motor under load, and take simultaneous readings of line current and slip, establishing a slip-current curve. The usual primary resistance, running light and blocked rotor tests determining the value of a, c, h and b for any assumed value of primary current I_1 substituting values in above this gives the value of K, which in conjunction with the test S versus I_1 curve gives R_2 from the identity

$R_2 = K s Zo$. A check may be obtained by repeating the calculations for several values of current and the same value of R_2 should be found in all cases.

b. $$\frac{I_2}{I_1} \cong 0.98 - \frac{a^2}{2} - \frac{ab}{2}$$

This equation is convenient for determinating the actual secondary copper loss, and hence the torque and rotor heating, for any slip, when the usual no load test data are available.

c. $$\frac{E_2}{E_o} = 1 - \left(\frac{ab}{2} + \frac{3b^2}{8} + c \right) + a^2b^2$$

This is conveneint for determining the actual secondary flux densities and the air gap flux under load condition. At no load, the per unit primary reactance drop is ab/2, so that, assuming the core loss to vary as E_2^2, the ratio of actual core loss under load to that as no load is

d. $$\frac{E_2^2}{E_o^2 (1-ab/2)^2} = (1 + ab) (E_2^2 / E_o)$$

$$= 1 - \frac{3b^2}{4} - 2c \quad \text{approximately.}$$

This equation does not make any allowances for stray load losses, which are due to the leakage fluxes produced by the load currents. It gives the same value for, core loss as found by the formal solution of the equivalent circuit of Figure 5·4 .

E POWER FACTOR DETERMINATION

$$\text{Power factor} = 1 - \frac{(a+b)^2}{2} + 3\,a^2 b^2$$

This equation indicates clearly the symmetrical way in which a and b determine the power fac tors, but, i.e., is not accurate enough for most performance calculations. Other relations obtainable from the above equation shows an effect on power factor of an increase in frequency at constant line current and voltage is practically the same as the effect of an equal percent increase in line current as constant voltage and frequency. Also an increase in voltage with fixed frequency and current has exactly the same effect on power factor as an eqqal percent decrease in current with voltage and frequency constant.

F CALCULATION IN THE REGION OF MAXIMUM TORQUE

Neglecting the effect of magnetizing current

a. $$\frac{R_2(1-s)}{s} = \sqrt{(R_1 + R_2)^2 + (X_1 + X_2)^2}$$

Whence maximum output is

b. Maximum output $= \dfrac{q\ E_o^{\,2}}{2\ (R_1 + R_2) + \sqrt{(R_1 + R_2)^2 + X^2}}$ Watts.

and it occurs at a value of slip.

b. S at maximum output $= \dfrac{R_2}{R_2 + \sqrt{(R_1 + R_2)^2 + X^2}}$

d. Maximum torque occurs when

$$\frac{R_2}{S} = \sqrt{R_1^{\,2} + X^2}$$

The maximum torque in synchro watt is

e. Maximum torque $= \dfrac{q\ E_o^{\,2}}{2\ (\ R_1 + \sqrt{R_1^2 + X^2}\ )}$

Occurring at slip

f. $S = \dfrac{R_2}{\sqrt{R_1^{\,2} + X^2}}$

Considering the effect of magnetizing current.

g. $T_{max} = \dfrac{q\ E_o^{\,2}}{2\ (R_1 + X)} \left(1 - \dfrac{3ab}{4} + \dfrac{a^2b^2}{4} - \dfrac{bh}{4} + ac - \dfrac{c^2}{2b^2} \right)$

This is similar to equation e, except for the factor

$$\left(1 - 3\frac{ab}{4} + \frac{a^2\ b^2}{4} - - - - - \right)$$

Therefore reduction of the maximum torque due to magnetising current.

The value of K at maximum torque is

$$(h) \quad K = 0.707 - \frac{ab}{8} + \frac{a^2b^2}{2} + \frac{5bh}{8} - \frac{c}{3b} + \frac{3aC}{8} + \frac{5\,C^2}{16\,bh} + \ldots\ldots$$

For this slip at maximum torque is found to be

$$s = \frac{I_1 R_2}{K\,Z_o} = \frac{b\,R_2}{K\,x}$$

$$= \frac{R_2}{X}\left[1 + \frac{ab}{4} - \frac{C}{16b} - \frac{a^2b^2}{4} - \frac{aC}{a} - \frac{C^2}{8\,b^2}\right]$$

or approximately

$$(i) \quad S = \frac{R_2}{x}\left(1 + \frac{ab}{4} \right)$$

The power factor at maximum torque is approximately

$$j. \quad p.f = 0.707 - \frac{7\,ab}{10} + \frac{3C}{8\,b}$$

by a similar procedure, the maximum output is found out by

$$k. \quad \text{Maximum output} = \frac{q\,E_o^2}{2\left[R_1 + R_2 + \sqrt{(R_1 + R_2)^2 + X^2}\right]}\left(1 - \frac{3ab}{4}\right)$$

Synchro watt.

G SUMMARY OF FORMULAE

For convenience, the foregoing formulae may be expressed in terms of the apparent value of leakage reactance Xt found in the locked rotor test (They are summarized here) -

The true value of equivalent circuit reactance is

a. $X = \left(1 + \frac{ab}{4} \right) X_t$. Ohms.

The stand still current is

b. $$I_s = \frac{E_0}{\sqrt{\left[R_1 + (1 - ab) R_2 \right]^2 + X_t^2}}$$

and the stand still torque is

c. $$Ts = 7.0\, h \frac{K_1 K_e\, q\, (1-ab)\, I_s^2 R_2}{N_s} \text{ ft. lb.}$$

Where K is an empirical constant of the order of 0.9 which allows for non fundamental secondary losses, and K_e is a factor greater than one to allow for the deep bar effect in the rotor conductors.

The relation between K_e and R_2 and the apparent secondary resistance R_t , determined by impedance test

d. $R_t = K_e (1-ab) R_2$

The maximum torque is

e. $$T_m = \frac{q(1-ab)\,E_o^2}{2\left(R_1 + \sqrt{R_1^2 + X_t^2}\right)}$$ Synchro watts.

The slip at maximum torque is

f. $$S\,m\,T = \frac{R_2}{\sqrt{R_1^2 + X_t^2}}$$

The maximum output is

g. $$W_m = \frac{q\,(1 - ab)\;E_o^2}{2\;R_1 + R_2 + \sqrt{(R_1 + R_2)^2 + X_t^2}}$$

Synchro watts.

The slip at maximum output is

h. $$S_{mo} = \frac{R_2}{R_2 + \sqrt{(R_1 + R_2)^2 + X_t^2}}$$ numeric

i. The ratio of I_m / I_s $$= \frac{(1-ab)}{2}\left[1 - \frac{R_1}{X_t} + \frac{R_2}{2X_t^2}(R_2 + 2R_1)\right]$$

< 0.5 numeric

The power factor is given by

j. $$\text{p.f.} = 1 - \frac{(a + b)^2}{2} + 3\,a^2b^2$$

CHAPTER VI

HARMONICS AND ITS EFFECTS

HARMONICS AND ITS EFFECT

A. GENERAL OUTLINE

Superimposed upon the currents and forces due to the fundamental sine wave field of an induction motor, there are many smaller currents and forces produced by the myriad of Harmonics fields that are also present. The parasitic magnetic fields are attributed to m.m.f. harmonics originating in (a) windings (b) the slotting (c) saturation (d) gap length irregularity . Minor causes include (e) over hang leakage, fields (f) Axial leakage of main flux In some cases (g) unbalance of or (h) Harmonics in the 3 phase supply voltage will produce the trouble. The most important causes are a,b,c & d inherent in the machine. The effects include elastic deformation i.e. shaft vibrations parasitic torque, vibration and noise. The current flowing in the winding produces harmonic that may contain only space harmonics, or space harmonics with time harmonics, in m.m.f. , and so in flux and flux density is produced , because of rectangular shape of m.m.f. wave, and due to variation of currents respect to time.

The harmonic so produced in m.m.f. flux and flux density wave can be minimized by (a) distributed type of winding (b) chording winding(c) proper selection of phase belt of coil (a) by skewing, (b) by proper connection whether star, delta or internal delta. Even some of the harmonic can be eliminated completely. Discussion of winding changes the space of m.m.f. , flux and flux density wave from rectangular to trapezoidal so net reduction in harmonics . But it decreases the resultant magnitude. Factor which is substituted to express ~~the~~ its effect is known as distribution factor and expressed by formula $K_{dn} = \dfrac{\text{Sin } q/2 \cdot n\alpha}{q \text{ Sin } n/2 \alpha}$

Where q = no. of slots per pole per phase.

α = Angular spacing between two slots.

Effect of chording causes the difference of phase between the voltage induced at two sides of coil, so makes shape of m.m.f. , flux, flux density rectangular but of unequal length about the axis, i.e., contains even harmonics

The resultant voltage induced is being reduced by chording i.e., by fractional ~~plates~~ pitch winding but decreases some of harmonics . By proper chording, any particular harmonic can be eliminated completely. Generally 3rd, 5th, and seventh harmonic causes unwanted affects, so they are eliminated. Third harmonics is eliminated by polyphase connections. So to reduce 5th and 7th harmonic pitch of coil is kept between 140° to 160°. The factor which reduces the resultant magnitude of e.m.f. is known as pitch factor and expressed by Cos $\psi/2$.

When ψ is the electrical angle by which pitch is shortened.

Proper value of phase belt is necessary to reduce the harmonics . For three phase winding the value of phase belt is 60°.

In the case of induction motor, skewing of the slot has the same result as the increasing the effective reluctance of the air gap towards pole tips. This skew reduces the magnitude of the harmonics, specially 5th harmonics.

Presence of slot in stator and rotor also introduces harmonics in the m.m.f. wave. The harmonics depends upon the number of slots per pole and also on slot opening. The order of these harmonics are

$$\left(\frac{S}{P} - 1\right), \left(\frac{S}{P} + 1\right) . \left(\frac{R}{P} - 1\right), \left(\frac{R}{P} + 1\right)$$

Irregularities of air gap caused by stator and rotor slots, also introduces harmonics known as Permeance harmonics, they can be represented by

$$P_g = P_0 + P_1 \text{ Cos } \left[(R-S)x - RNt \right] + P\ S \text{ Cos } Sx + PR$$

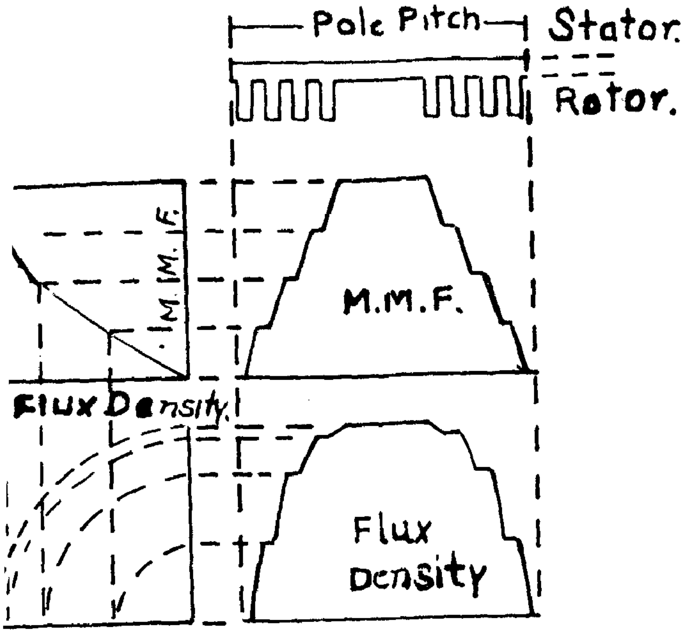
$$\text{Cos } R\ (x - Nt)$$

Where $P_1 = \dfrac{P_R \ . \ P_S}{2\ P_0}$

P_0 = Average permeance

P_R = half amplitude of permeance variation due to rotor slot opening.

x = angular position of the rotor, measured in mechanical radian.



No 63 M.M.F. AND FLUX-DENSITY. TRIBUTION WITH CYLINDRICAL ROTOR.

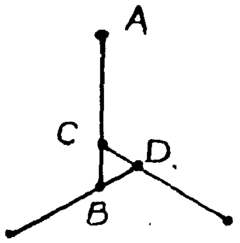


FIG NO 61 INTERCONNECTED DELTA.

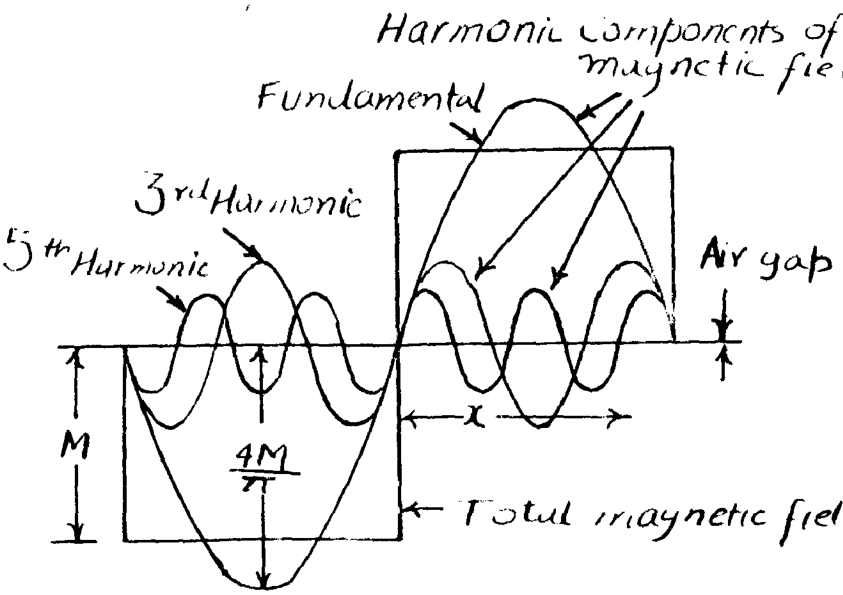
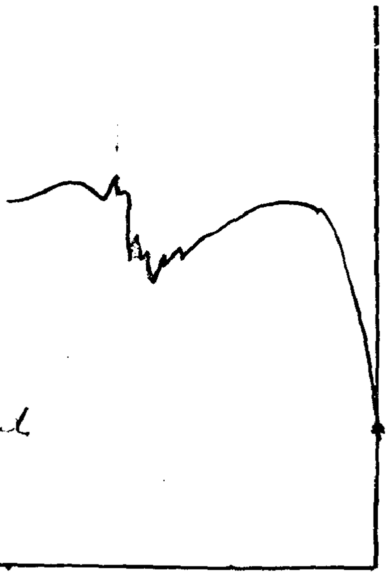


FIG. NO. 64 HARMONICS OF FLUX WAVE DUE TO FULL PITCH COIL.



TORQUE CURVE FOR 36 STATOR SLOTS & 44 ROTOR SLOTS

Fig 62

N = Rotor speed in mech. radiansper second.

t = time, in second.

R = number of rotor slots.

Among this, $\left[(R-S)x - RNt\right]$ is unimportant, this correspond to a field of small number of poles 2 (R-S). The term $\left[(R+S)x - RNt\right]$ is unimportant, as its number of poles is too great to produce any large torque or force variations.

The term Cos Sx and Cos $Rx - RNt$ are the short pitch permeance, ripples due to the stator and rotor slot openings.

B. COMPLEX MAGNETIZATION OR EFFECT OF SATURATION.

When the flux density of induction motor is on straight line portion of the B-H curve, then the shape of the space wave of the flux density or flux is similar to m.m.f. wave. But when flux density reaches its saturation value then the magnitude of harmonics is reduced and space wave of flux becomes sinusoidal , when flux density is on a straight line portion of belt curve, then the sinusoidal impressed voltage, produces sinusoidal flux and sinusoidal magnetizing current, but when saturation takes place then permeability of iron portion reduces with degree of saturation. Final effect is that sinusoidal impressed voltage produce sinusoidal flux or flux density even for saturated condition, but the shape of magnetizing current becomes peaked one. Con-

Containing 3rd, 5th, 7th and other harmonics. The magnitude depends upon the degree of saturation. To induce a sine wave of flux peaked wave of magnitising current, and to induce a flat wave of flux, sine wave of magnetizing current is necessary. So a flat topped wave magnetizing current induced a flux wave which is still more flat topped, specially if high magnetic flux densities are reached.

A sine wave of flux causes a sine wave of reactive e.m.f. to be included in the ~~induced in~~ the winding, but a flat topped flux wave causes a peaked wave of induced voltage to be set up and vice versa.

The 3rd , seventh, eleventh etc., harmonics induces peaked e.m.f. waves for dimpled flux wave and vice versa while fifth, ninth, thirtith etc., harmonics give rise to e.m.f. wave which are dimpled when the flux wave is dimpled and peaked when the flux wave are peaked.

(C) EFFECT OF WAVE FORM OF APPLIED VOLTAGE MAGNETIZING CURVE

When harmonics are present in the applied voltage wave, they give rise to corresponding harmonics in the flux wave, these may be either peaking or dimpling according to the order and phase of the e.m.f. harmonics. When a voltage harmonics is of such a nature as to peak the resultant flux wave, the r.m.s. value of magnetizing current is increased very greatly if high flux densities are reached. If , on the otherhand the voltage harmonic is such as to flatten the flux wave, then the machine value of the magnetizing current is reduced but not to the same extent as it was increased in the former case.

D. EFFECT OF RESISTANCES, INDUCTANCES, CAPACITANCE

The effect of resistance, in the circuit is thus to distortion flux wave, the rate of growth of the flux being greater than its rate of decay.

Where as conditional inductance cause a flattening of the flux wave in Iron, series capacitance causes a peaking of the flux wave in to unsymmetrical shape.

E. HARMONICS IN POLY PHASE SYSTEMS

In balanced 3 phase system, connected in star, even if 3rd harmonic occurs, it cancels out in between the line. But 5th , 7th harmonic may be present in between line. For 3 phase delta connection, for balanced case 3rd harmonic voltage constitutes a short circuit, path, so 3rd harmonic current flux such that 3rd harmonic voltage is cancelled by 3rd harmonic voltage drop, so 3rd harmonic voltage disappear harmonic voltage drop, So 3rd harmonic voltage does appear between line.

In general if n be the order of the harmonic and let $n = 6a \pm 1$ where a is any integer. Then when ais odd, the harmonic is reversed in relative phase, when a f appears in tve line voltage and a when a is even it appears in the line voltage, unchanged. This rule apply to all harmonic except the third and those multiple of three, All these disappearing entirely in the line voltge, assuming a three wire system with an insultated neutral. The properties of the variations harmonics ~~ix~~ are summarized in the following table .

	Phase sequence	Phase of harmonic in Line voltage.
Fundamental	Positive	Unchanged
3rd	Zero	-
5th	Negative	Reversed
7th	Positive	Reversed
9th	Zero	-
11th	Negative	Unchanged
13th	Positive	Unchanged.

In general, the third harmonic and any harmonic the order of which ais a multiple of three gives rise to the phenomenon of the oscillating neutral, but none of the other harmonics shows this effect; no matter whether the circuit is earthed or insulated.

F. HARMONIC IN DELTA CONNECTION

In the case of delta connected load each leg is supplied with line voltage, The latter may contain various harmonics, but in a balanced system the tripplen harmonics are absent. The wave form of the current in each load circuit takes its character from the line voltage, the harmonics being reproduced unchanged in the case or resistance, damped down in the case of a constant inductive reactance and magnified in the case of a capacitive reactance, For balanced case third harmonic current flows in closed delta, but no 5th, 7th and other harmonic current can flow in closed delta. Auxiliary magnetization of iron core at 3rd harmonics frequency tends to restore the flux wave to its original wave shape, the flat shape of the flux wave being greatly reduced, but not theoritically eliminate. The effect of lack of phase balance is to cause small harmonics p.d.'s to appear at different points in the closed delta .

G. HARMONIC IN INTERCONNECTED DELTA CONNECTION

The interconnected delta enables a star arrangement of conductance to be employed, while ensuring a stable neutral potential. The connections are shown in Figure which represents three iron cored choking coils, each of which must have an intermediate tapping. The voltages are imagined to be of such a magnitude as to bring about a certain amount of saturation in the iron . Assuming balanced line voltages, there can be no third harmonic voltage between lines and so no third harmonic current is derived from the source of supply. Due to the resulting defeciency in the third harmonic magnetizing current, the flux wave is flat topped, containing a third harmonic in phase This induces a third harmonic emf in each winding. The portion of the winding represented by AC has no their harmonic current flowing in it, and therefore the point C oscilates, in potential with respect to neutral at third harmonic frequency. In the same way the points B & D oscillates in potential with an equal amplitude. The whole area BCD therefore oscilates, theoretically, with respect to neutral potential. Third harmonic emf's are therefore, induced in BC , CD and D B. Just as in the other portions of the winding, and the delta constants a closed circuit for the third harmonic currents a third harmonic circulating current is therefore, set up and this magnetizes the three iron cores at third harmonic frequency, thus repairing the deficiency of the magnetizing current drawn from the supply. The flux wave is therefore restored to very nearly its normal shape. It cannot, theoretically, be made ~~quasi~~ quite sinusoidal, for in that event. There would be no third harmonic flux . Consequently no third harmonic circulating current would flow and no compensating action would take place.

The third harmonic component of flux is however, practically eliminated, so that the potential oscillation of the inter connected delta is also practically eliminated, and stable conditions are maintained . No third harmonic potential difference's are discessible in the closed delta itself, since the voltage drop occurs simultaneously with the induction of the third harmonic e.m.f.

G. EFFECT OF HARMONICS

Uptill now we have discussed the possibilities of different harmonics in m.m. f wave, magnetizing current mand e.m.f. induced, which are generally ~~on generating~~ originating in (a) winding (b) slotting (c) saturation (d) gap length irregularity along with the method of elimination of different harmonics. For three phase induction motor 3rd harmonic are generally eliminated completely by connection, But 5th, and 7th and other harmonics remain present. With suitable method these higher order harmonics can be minimised, even a particular harmonic can be eliminated completely. But generally higher harmonics remains present. The harmonic originated in different ~~points~~ parts have different characteristics, but all has got objectionable effect in the form of Asynchronous crawling, synchronous crowling, stand still locking, noise and vibration and formation of voltage ripple. Besides these they effect the power factor efficien

1. Asynchronous Crawling:

Space harmonics of the winding m.m.f. create revolvinv field which induce secondary currents and produce torques, similar to these of the fundamental, but have more poles, and therefore, lower synchronous speeds. As the motor accelerates through the synchronous speeds of one of these harmonics, the harmonics torque reverses causing a dip in the resultant motor torque speed curve, unless minimized by good design, the consequent Asynchronous crawling may be seriously impair the motor's starting ability.

At speeds above their respective synchronous values, the forward harmonics produce braking torque as the backward harmonics do at all forward speed . They cause stray load losses and increase the motor heating.

Forward mmenoting slot and phase betlt harmonicsdue to stator winding produce magnetic fields of (S+P) and (2q +1) P points of poles, whose m.m.f is in direct proportion to primary current just as fundamental m.m.f 's. The speed at which braking torque starts is at P / S+P or =/2q +1 times fundamental synchronous speed.

The back-ward revolving harmonics with (S -P) and (2q-1)P parts of poles are similar in all respects, except that their synchronous speeds are reached when the motor is driven backward at speeds $P/S-P$ or $1/2q-1$ times fundamental. Permeance harmonics with $(P-R+S)$ pair of poles and $(P+R-S)$ pairs of poles, and rotor harmonics with $R-P$ and $R+P$ pairs of poles also produce Asynchronous crawling.

This asynchronous crawling can be minimized by reducing the magnitude harmonics, by chrowding the pitch, interspacing and skewing the slot.

ii. Synchronous Crawling:

If any two of the seperate harmonic fields have the same number of poles, pulsating torque will be produced as they slip, past each other. When their speeds coincides the two like fields with synchronize and a corresponding locking or synchronous crawling" torque will be observed.

When fundamental or principal phase belt harmonic field with pole $2P(2q-1)$ and $2P(2q+1)$ revolving backward and forward at speed $w/P(2q-1)$ and $w/P(2q+1)$ respectively in pole number and speed with the permeance harmonic field's poles $2(P-R+S)$ and $2(P+R-S)$ pole revolving at speed $w-RN/P-R+S$ and $W+RN/P+R-S$, synchronous crowling will occur at corresponding speed.

This tendency can be avoided by employing proper winding pitch and number of rotor and stator slots.

iii. Stand Still Locking

When the either of number of poles and direction of rotation of permeance harmonics is similarto pole direction of fundamental and phase belt harmonics, there will be two independently produced fields revolving in synchronism, with a phase displacement RQ that varies with the relative positions of stator and rotor teeth. In such a case, locking will occur when two similar field are in space phase opposit on and the stand still torque will vary up and do not through a wide range as the rotor is slowly turned one rotor tooth pitch. This will occur for fundamental field ~~is~~

$P + R - S = P$

or $R - S = 0$ and for harmonic field if

$P + R - S = (2q + 1) P$ or $P - R + S = (2q - 1)P$

or $S - R - P = (2q - 1) P$ or $R - S - P = (2q - 1) P$

giving $R - S = \pm 2 q P$

Taking into account the nth harmonic of rotor permeance, the nth harmonic of stator permeance variation and the kth harmonic of the phase belt variation, any slot combination having $mR - nS = \pm 2 K q P$, will have a locking fendency at stand still. Locking is also caused by stator and rotor ~~stator~~ ~~and rotor~~ slot harmonics, this occurs when $mR - NS = \pm KS$ or $\pm KR$.

Locking tendency can be minimised by proper selection of fractional slot winding and skewing of rotor and rotor slots

iv. Magnetic Noise and Vibrations:

If two harmonic field, with number of poles, differencing by 2 coexists in the air gap, they will produce unbalanced radial magnetic forces, and consequent radial vibration of the rotor as a whole. Also symmetrical radial forces of high frequency are produced by superposition of rotating magnetic fields of different pole number . These phenomena create stator vibration and magnetic noise.

v. Unbalanced Magnetic Pull

In the extreme case when the stator and rotor slot number differ by only ($R-S = \pm 1$) The radial magnetic pull during the stationary period is a maximum at the point of tooth opposite slot, and a minimum at the opposite end of the same diameter, where tooth is opposite tooth. This is so because the zigzag leakage flux is largest when both slot is opposite and this leakeage flux has a much higher air gap density then the fundamental flux during starting, when the stator and rotor currents are each many times as large as the no load magnetizing current. Around the periphery between the two extreme, the magnetic /pull varies gradually, forming a two-node force wave . The force wave rotates at a speed R times then the speed of the rotor itself, since it moves forward (or backward if $R < S$) a whole revolution for each advance of the rotor through 1/R revolution.

The total force on stator or rotor, for $R-S = 1$ is given by $F = \frac{\pi D^2 P_0 P_1}{2} X \cos (R \omega t + \theta)$.
This is an alternating radial force at rotor tooth frequency which therefore tends to bend the rotor shaft and cause oscillation of the shaft in clearance of sleeve bearing. If the shaft is sufficiently stiff, and the bearing clearance is small, the force will cause some vibration and noise during the stationary period, but will not materially affect full speed operation.

The phenomena of unbalanced pulls and consequent torque dip occur at a speed corresponding to the critical speed of the shaft whenever a harmonic field with two more or less poles then the fundamental field exists. This will happen, as shown above when $R-S = 1$, and also when $R-S = -2P-1$, $-2P+1$, -1, $2P-1$, $2P+1$,

Smaller torque drops and accompanying noise will occur at other speeds with any odd value of R-S , since there will then be harmonic field with poles differing by 2.

terminals. And these voltages will produce currents in the supply lines, which will induce high frequency. Voltage in any adjacent circuits, giving telephase interference.

For the selected squirrel cage induction motor for the test, with 36 stator and 44 rotor slot, torque curve will be of the nature shown in Figure 6-2 . The characteristic of the motor is starting noiseless. A rather strong saddle, also, in this case caused by the number of rotor slots, is to be noted as - 136 = - n/p . Further saddles of -90 and + 79 , somewhat weaker ones at -40, ; -300 , + 275 very weak ones at 150 and -180 rpm.

vii. E-ffect of Harmonics on Power Factor

Effect of harmonics is to decrease the value of maximum power factor that can be obtained in the absence of harmonics. In fact whenever the e.m.f. and current waves are dissimilar in shape, a power factor of unity is impossible even although the circuit may possess nothing but resistance. The special case of resonance ~~in one~~ also, if the e.m.f. wave be complex is character (i.e., if it contains harmonics), the current wave will not be similar to it; and maximum power factor obtainable is less than unity.

So when every +ve e.m.f. wave contains, harmonic, which does not present in the current wave or vice versa,

vi. Voltage Ripples:

As discussed when magnetic circuit is saturated then magnetizing current will have a peaked wave form, and its impedance drop will accordingly include 3rd, 5th, 7th harmonics, besides the fundamental voltage component. The connecting three single phase transformers in Y or Δ , the triple frequency currents can be eliminated from the power lines , but with Y connection, there will be a third harmonic voltage between the line terminal and ground. This voltage is also eliminated by delta connection, allowing triple frequency current which are required to maintain a sinusoidal flux wave form, to flow in the delta, In the case of induction motor presence of air gap make the motor current flux relation much more nearly linear.

If the motor with open stator slots and a squirrel cage rotor with relatively large number of slots, without skew. In this case, stator harmonic flux induces large high frequency secondary currents whose 'armature reaction' oppose the stator m.m.f. reducing the stator harmonic fluxes to a small value. Since the rotor slots per stator harmonic pole are few in number, the space wave forms of the harmonic armature reaction will be very riged. This is, torque, low order harmonics of the slot harmonic field will be created and these in turn will induce high frequency voltage in the stator winding thus giving rise to voltage ripples at the primary

The maximum power factor obtainable is less then unity. The effects on power factors depends on the magnitude and order of harmonics.

CHAPTER VII

RESULTS

RESULTS

A. CALCULA-TED VALUE

The relation of horse power for star, delta and internal delta with different values of y , for four poles and six poles is given by the samé emperical formula.

Without considering harmonic and saturation effect :-

$$H.P_{\Delta} : H.P_{\Delta\ int.} : H.P._{Y} = 1 : \frac{1}{3.6-3y+y^2} : \frac{1}{3} \qquad ...(7.1)$$

and considering harmonic and saturation effect:-

$$H.P_{\Delta} : H.P._{\Delta\ int.} : H.P._{Y} = 1 : \frac{1}{3.6-3.9y+1.3y^2} : \frac{1}{3.3} \qquad ....(7.2)$$

Substituting the value of y, equal to 0.25, 0.5, 0.75 for 4 Pole winding and equal to 0.166, .333, 0.5, 0.667, .833 the numerical relation willbe as shown in table 7.1.

The relation of load current for delta internal delta with different values of y and star is given by { } same emperical formula. wi

TABLE No. 7.1

	y	$HP_\Delta : HP_{\Delta\,int.} : HP_Y$	
		without considering harmonic & saturation effect.	Considering harmonic and saturation effect.
a. **For 4 Pole.**			
i. int. Δ with one coil in delta	0.25	1 : 0.433 : 0.333	1 : .3698 : .32
ii. with 2 coil in Δ	0.5	1:.572 : .333	1 : .507 : .32
iii. with 3 coil in Δ	0.75	1:.762 : .333	1 : .711 : .32
(b) **For 6 Pole**			
iv. int. Δ with 1 coil in Δ	.166	1:.396 : .333	1 : .335 : .32
v. with 2 coil in Δ	.333	1:.474 : .333	1 : .409 : .32
vi. with 3 coil in Δ	.50	1:.572 : .333	1 : .507 : .32
vii. with 4 coil in Δ	.667	1:.692 : .333	1 : .634 : .32
viii. with 5 coil in Δ	. 833	1:.841 : .333	1 : .798 : .32

without consideration of harmonic and saturation effect:-

$$I_\Delta : I_{\Delta\,int.} : I_Y = 1 : \frac{1}{(3-1.267y)\sqrt{1-y+y^2/3}} : \frac{1}{3} \qquad ..(7.3)$$

considering saturation and harmonics effect:

$$I_\Delta : I_{\Delta\,int.} : I_Y = 1 : \frac{1}{\sqrt{3.6-3.9y+1.3y^2}\;(1.73-0.73y)} : \frac{1}{3.3} \qquad ...(7.4)$$

Substituting the value of y the numerical relation will be as shown in Table 7.2.

TABLE NO. 7.2

THEORETICAL RELATION FOR LOAD CURRENT

Value of y	$I_\Delta : I_{\Delta\,int.} : I_Y$ without considering saturation & harmonic effect.	$I_\Delta : I_{\Delta\,int.} : I_Y$ considering saturation & harmonic effect.
For four Pole		
0.25	1 : 0.42 : 0.333	1 : .393 : 0.32
0.5	1 : 0.556 : 0.333	1 : .505 : 0.32
0.75	1 : 0.738 : 0.333	1 : .714 : 0.32
For Six Pole		
0.166	1 : 0.391 : 0.333	1 : .36 : 0.32
0.333	1 : 0.464 : 0.333	1 : .431 : 0.32
0.5	1 : 0.556 : 0.333	1 : .522 : 0.32
0.667	1 : 0.672 : 0.333	1 : .641 : 0.32
0.833	1 : 0.80 : 0.333	1 : .797 : 0.32

The value of V_{SAFB} and V_{FAFB} on no load and locked rotor condition can be given by the derivative from the above relation

V_{SAFB} at no load = V_{120} = voltage across terminals 1 &2

V_{FAFB} at no load = V_{230} = voltage across terminals 2&3

V_{SAFB} at locked condi. = V_{12L} = voltage across terminal 1 &2

V_{FAFB} at locked condi. = $V_{23\,L}$ = voltage across terminal 2 &3

$$V_{120} = \frac{V}{\sqrt{3}} \times \frac{1-y}{\sqrt{1-y+y^2/3}} \qquad \ldots(7.5)$$

$$V_{230} = \frac{V}{\sqrt{3}} \cdot \frac{y}{\sqrt{1-y+y^2/3}} \qquad \ldots\ldots(7.6)$$

$$V_{12\ L} = \frac{V}{\sqrt{3}} \cdot \frac{1-y}{2(1-\frac{2y}{3})} \cdot \sqrt{\frac{4-\frac{14}{3}y+\frac{13}{9}y^2}{1-y+\frac{y^2}{3}}} \qquad \ldots\ldots(7.7)$$

$$V_{23\ L} = \frac{V}{3} \cdot \frac{y}{2(3-2y)} \sqrt{\frac{21-24y+7y^2}{1-y+\frac{y^2}{3}}} \qquad \ldots(7.8)$$

Where V = Line voltage.

Substituting the different value of y the value of voltages will be as shown in Table 7.3.

TABLE NO. 7.3

y	V_{120}	$V_{12\ L}$	V_{230}	$V_{23\ L}$
0.25	126.26	66.51	42.08	206.701
0.5	96.76	55.42	96.76	317.2
0.75	55.86	36.95	16.75	331.0
0.166	134.18	69.28	26.86	148.37
0.333	117.46	63.34	58.73	254.33
0.5	96.76	55.42	96.76	317.2
0.667	71.0	44.34	142.0	337.03
0.833	39.04	27.71	195.0	375.0

B. EXPERIMENTAL RESULTS

To perform the experiment the stator winding is made for 4 pole and 6 pole , the connection made for star, delta and internal delta for the value of y equal to 0.25, .50 and 0.75 ~~and~~ for 4 pole and y equal to 0.166, 0.333 , 0.5 , 0.667 , 0.833 for 6 pole , after that for each connection no load, and blocked rotor test and load test performed according to procedure discussed in previous chapter. The observed data of load test with calculated value of efficiency, B.H.P, torque and P.F. is shown for 4 pole in Table 7.4 (a to e) and for 6 pole in Table 7.5 (a to g) . The no load test data for 4 pole is shown in Table 7.5 (a to e) and for 6 pole in Table 7.6 (a to g) The blocked rotor test data for four pole is shown in table 7.7. (a to e) and for 6 pole in Table 7.8 (a to g).

The curves for B.H.P. , slip , speed, torque, for 4 pole and 6 pole winding is shown in graph nos. 2 to 6 and 8 to 14 respectively. These graphs show the performance for delta, star, and internal delta (for different value of y) connected stator winding . The curves for slip versus torque is shown in Graph No. 16 and 17, for 4 pole and 6 pole respectively.

By the experimental data of no load and blocked rotor test, circle diagram is constructed and maximum torque , starting current , starting torque are determined. The ratio of maximum torque to full load torque, starting torque to full load torque and starting current to full load current for delta star and internal delta connected winding of 4 pole and 6 pole is shown in Table No. 7.9.

TABLE NO. 7.9.

y =	$\frac{T_{max.}}{T_{fl.}}$	$\frac{T_s}{T_{fL}}$	$\frac{I_{ss}}{I_{fL}}$
For 4 Pole.			
0	2.69	2.3	5.36
0.25	2.76	1.67	5.08
0.50	3.39	2.29	5.425
0.75	3.3	2.3	6.78
1.00	3.23	2.75	7.2
For 6 pole			
0	4.52	4.01	5.22
.166	2.268	.77	4.98
.333	2.2	1.645	3.94
.50	2.38	1.86	3.19
.667	2.57	2.29	4.22
0.833	2.862	2.59	4.27
1	3.11	2.654	4.43

By the help of this table it will become easier to say which connection will give best performance, i.e., ~~bette~~r, minimum load current with better efficiency and power factor for a particular value of Horse power. The horse power for which load current, efficiency and power factor are determined from 0.2 to 2.4 Horse power with an increment of 0.02 horse power connection for the best performance for 2,1.6, 1.2, 1.0 , 0.8 , 0.4 Horse power is discussed in next chapter.

$I_\Delta / I_{\Delta\ int.}$ & $T_\Delta / T_{\Delta\ int.}$

The table No. 14 shows the ratio of /~~current~~ for delta and internal delta and torque for delta and internal delta.

C. RELATIVE PERFORMANCE OF DIFFERENT CONNECTION

After performing the experiment and calculation, performance curve is drawn, which is shown in Fig. 2 to 6 and 8 to 14. These curves indicates difference shape for delta star and internal delta connected winding of 4 pole and 6 pole, These curves indicates that there is a limit of Horse power to be obtained with each connection. The relation of Horse power is given numerically in Table No. 7.1. With the help of table No. 7.1. and performance graph No. 2 to 6 and 8 to 14, the load current, power factor, and efficiency for different horse power can be determined for delta, star and internal delta connection of 4 pole and 6 pole winding. These values are shown in Table 7.10 (a to e) and 7.11(a to g) for 4 pole and 6 pole connection respectively. Graphs are drawn to show the relation of load current, power factor and efficiency with respect to horse power for delta star and internal delta connected winding of 4 and 6 pole windings in graph No. 18 to 23. By these graphs, for different horse power, value of load current power factor and efficiency for 4 pole and 6 pole is obtained which is shown in Table No. 7.12 and 7.13, along with the value of slip. The value of T_{max}/T_{fl}, T_s/T_{fl}, I_s/I_{fL} is shown in Table No. ~~7.14.~~ 7.9

CHAPTER VIII

COMMENTS

COMMENTS

After drawing the performance graph No. 18 to 23, and making table No. 7.12 and 7.13, it become very easy to select the connection for any particular value of horse power to give best performance. Hence we will discuss here about the best connection for 2 Horse power, 1.8 horse power, 1.2 horse power, 0.8 horse power and 0.4 horse power.

For 2 Horse Power

For 4 pole in delta connection, the load current is 5.0, 4 amp, efficiency 77.5 % and power factor 0.895, slip 0.075 , For four pole winding this horse power cannot be obtained with star connection, as is seen from graph 2 . The load current for internal delta increases ~~with~~ as the value of y decreases, only slight change in Power factor and efficiency and slip increases with decrease of y. Taking all considerations, four pole delta connection is best connection for this. For the 6 pole, winding, 2 Horse power cannot be obtained with star connectio-n and internal delta with value of y equal to upto 0.5. Now only delta connection and internal delta with y = 0.833 gives better performance among them. Load current is less in delta, than in internal delta, efficiency is also 80% in delta compared to 73% of internal delta, The power factor is ~~best~~ less in delta, but not so inferior, slip is also very less. So for 6 pole winding, the delta connection is to be selected. So for 2 Horse power we are getting two connection i.e. delta of 4 pole winding and 6 pole winding.

1.6. Horse Power:

For 4 Pole

This much horse power can be possible with delta connection and internal delta of $y = 0.75$, other connections shows high load current, poor efficiency, high value of slip and comparatively lower value of $T_{max}/T_{f.L}$, $T_{start}/T_{f.L}$. Among these two connections, load current of delta is 3.85 Amp, efficiency 80 %, power factor .875, and slip 0.0528, compare to internal delta connection, with $I = 4.45$, efficiency = 69% and power factor = 0.87, and slip = 0.1025. So ~~for~~ delta connection is best among all.

For 6 pole:

In this case 1.6 Horse power is not possible with star, connection, and internal delta of value upto $y = 0.5$, because slip is very high, current is high and efficiency very poor. So the selection is from delta, ~~connection~~ & internal delta of $y = 0.833$, 0.677. The variation of load current is small, but variation in efficiency and slip is more, so delta connection is best among them, but internal delta with yequal to .833 also gives better performance.

1.2 Horse Power.

For 4 Pole

1.2 horse power is not possible with star connection and internal delta with y equal to 0.25. Among the delta, and internal delta with y = 0.75 and 0.5, The load current in delta is small, than others efficiency is same for delta and internal delta with y = 0.75, which is more than for internal delta with y = 0.5 Power factor is better for internal delta, but ~~efficiency~~ slip is high for the internal delta. The selection is to be made from delta and internal delta with y=0.75.

The best connection for 1.2 horse power in 4 pole winding is then internal delta with y = 0.75 due to its better power factor.

6 Pole:

1.2 horse power is not possible with star and internal delta with y = 0.166 . Among the rest connection, internal delta with y ± 0.667, needs **minimum** current but slip is high, efficiency less. Internal delta with y = 0.833 needs comparatively less current than delta with better power factor, but with smaller efficiency and higher slip . But difference of efficiency, power factor current and slip is not more so either of these can be selected.

0.8 Horse Power.

4 Pole:

0.8 horse power is possible with all connection, but the efficiency is very poor for star connections and also slip is very high. Among the rest, internal delta with y = 0.75 , needs smallest current and gives maximum efficiency, and best power factorwith comparatively good slip, So best connection is internal delta with y = 0.75.

6 Pole

0.8 horse power is possible with all type of connection. Here star connections needs, smallest value of current with better efficiency and power factor, but slip is very high on the whole. Internal delta with y = 0.333 , 0.166 are better due to comparatively less current and good efficiency and power factor so selection is to be made from either of the two.

0.4 Horse Power

4 Pole

0.4 horse power is possible with all connection, the current required by different connections are different. The smallest current is required by star connections but it gives very poor efficiency and power factor, delta connection needs maximum current, with poor efficiency and power factor. Only internal delta gives better efficency and power factor with comparatively low current. Among them internal delta with y = 0.25. Due to less current internal delta with y = 0.25 is better than internal delta with y =.75 but due to other view points latter one is better.

6. Pole

In 6 Pole connection 0.4 horse power is possible with all connection. The delta connection needs current more than other winding, also its efficiency / power factor is poor. Star connection needs less current than other with comparatively good efficiency and better power factor . But slip is very high. Among the internal delta, internal delta with y=0.25 needs current less than all, with efficiency and power factor more than others with comparatively better slip. So selection is to be made -from star connection and internal delta connection, due ~~D-ue~~ to better efficiency, and slip) latter one is better.

We have discussed the selection of connection for 2, 1.8 , 1.2 , 0.8 and 0.4 horse power only. But by table 7.12 and 7.13 connection for any value of horse power in between (0.2 to 2.4) can be selected to ~~be~~ give~~n~~ best per-formance.

Here experiment was performed on a small squirrel cage induction motor, and Table No. 7.12 and 7.13 formed for 4 pole and 6 pole winding. A similar table can be formed for any type of induction motor, after experiment. Then for the required horse power, best connection can be selected to give best performance.

The connection which gives better performence for 0.2 to 2 horse power is shown below for 4 pole and 6 pole connections.

4 Pole connection.

H.P.	
2.4	Delta
2.2	Delta
1.8	Delta
1.6	Delta
1.4	Delta
1.2	Internal delta with y = 0.75 , Delta
1.0	Internal delta with y = 0.75
0.8	Internal delta with y = 0.75 and y = 0.25
0.6	Internal delta with y = 0.75 and y = 0.25
0.4	Internal delta with y = 0.75 , y=0.25 & Star
0.2	Internal delta with y = 0.75 , y = 0.25

6 Pole connection

2	Delta
1.8	Delta, Internal delta with y=0.833
1.6	Internal delta with y = 0.833, Delta
1.4	Internal delta with y = 0.833, y =.667,y=.5
1.2	Internal delta with y =.5, y = .667
1.0	Internal delta y = 0.667,y=.333,y=.5

0.8	Internal delta , $y = 0.166$, $y = .333$, $y = .667$
0.6	Internal delta $y = .166$, $y = .333$
0.4	Internal delta with $y = .166$ and star
0.2	Star connection.

In the industry , load on motor remains constant for certain period and but it may be different for certain another period. In that case the proper selection of connection is chosen to give better performance. So induction motor may have 6 or 9 or 12 terminal to provide proper internal delta winding with switch gear device to change ~~to~~ the ~~circuit~~ Connection . But switch gear system should not be expensive. So according to load, switch gears relay system connects the supply for proper internal delta connection.

TABLE NO. 7.4 (a)

4 POLE STAR CONNECTION - LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	Current Amp.	Power input watts.	R.P.M.	D. C. GENERATOR Armature Volts V_a	Current I_a	$I_a R_a$ volts	E_b volts	$E_b \cdot I_a$ watts.	Const. loss watts	Brake power output watts.	Slip	Efficiency %	Torque Syn.Watt	B.H.P. Hp	Power factor.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
~~[illegible]~~	~~x255x~~			~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~												
256	255	146			0.2	130	1475	24.5							0.019				0.1273
256	255	146			1.5	352	1400	250	1.3	5.3	255.3	331.5	125.1	456.6	0.067	8.96	488	0.614	0.53
256	255	146			1.8	458	1350	242	1.73	7.1	249.1	430.0	125.1	555.0	0.10	81.5	617	0.745	.575
256	255	146			2.4	582	1300	229	2.14	8.73	237.93	508.0	125.1	633	0.133	77.6	731	0.85	0.547
256	255	146			3.03	736	1240	213	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~								
256	255	146			3.03	736	1240	213	2.53	10.62	223.62	565.0	125.1	690	0.173	60	835	0.926	0.547

TABLE NO. 7.4 (b)

4 POLE INTERNAL DELTA WITH ONE COIL IN DELTA (y = 0.25)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	255	165	120	41.2	0.3	170	1480	24.8	0		24.8	140.2	125.1		0.0125				0.1277
256	254	165	125	40.5	1	368	1460	278	0.5	2.042	280.042	276.08	125.1	265.3	0.027	72.1	271.6	0.356	0.83
256	255	167	127	41.2	1.2	530	1450	272	1	4.08	276.08	514.0	125.1	401.18	0.0325	75.8	414	0.538	0.996
256	254	162.5	124	40	2.33	882	1400	257	1.94	7.925	261.925	687.0	125.1	639.1	0.067	72.4	684	0.857	0.854
256	253	160	123	38.8	3.45	1338	1285	235	2.79	11.41	246.41		125.1	812.1	0.1425	60.7	947.5	1.089	0.902

TABLE NO. 7.4 (c)

4 POLE INTERNAL DELTA WITH TWO COILS IN DELTA (y = 0.5)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	254	189	96	94	0.5	166	1480	25.6		0	25.6		0		.0125				
256	254	188	95	93	1.1	350	1480	274	0.5	2.044	276.04	138	125.0	163.0	.0125	46.6	165	.2186	.717
256	254	186	94	93	1.8	674	1450	265	1.48	6.05	271.48	402	125.0	527	.0325	68.1	544	.706	.845
256	254	186	94	92	2.66	1034	1410	256	2.43	9.93	265.93	647	125.0	772	.06	74.7	830	1.034	.848
256	253	181	92	89.5	3.85	1424	1365	238	3.24	13.24	251	813	125.0	938	.089	65.9	1030	1.258	.835
256	253	178	92	87	5.36	1167	970	206	3.7	13.27	219.27	730	125.0	855	.353	43.4	1324	1.147	.491

TABLE NO. 7.4(d)

4 POLE INTERNAL DELTA WITH 3 COILS IN DELTA (y = 0.75)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	254	220	56.2	163.5	0.8	283	1495	26							0.003				
256	255	220	56	163	1.5	502	1475	270	1.0	4.08	274.08	274.08	125.1	395.18	.019	79.7	407.5	.535	.755
256	255	218	55.5	162	2.15	808	1450	262	1.95	7.96	269.96	525	125.1	650.1	.0325	80.3	672	.872	.857
256	255	217	55.2	161	2.93	1130	1425	251	2.86	11.7	266.70	762	125.1	887.1	.049	78.4	933	1.189	.87
256	255	213	54.7	156	4.62	1766	1360	230	4.39	17.96	247.96	1085	125.1	1210.1	.0925	68.5	1333	1.622	.863
256	252	210	55.5	151	6.46	2380	1250	207	5.26	21.50	228.5	1202	125.1	1327.1	.167	55.75	1594	1.78	.83

TABLE NO. 7.4(e)

4 POLE DELTA CONNECTION

1	2	3	4	5	6	7	8	9	1.	11	12	13	14	15	16	17	18	19	20
256	255				1.2	180	1495	25.2							0.0025				
256	254				1.4	532	1485	270	0.5	2.45	272.45	137.4	125	162.4	0.0026	30.52	1638	0.2178	.856
256	253				2.51	940	1450	258	2.44	9.96	267.96	600	125	725	.033	77.2	750	.971	.845
256	253				3.77	1472	1415	245	4.05	16.54	261.54	1060	125	1185	.056	80.6	1256	1.59	.853
256	254				4.62	1844	1390	234	5.14	21.0	255	1312	125	1437	.0725	77.8	1550	1.925	.9
256	253				5.96	2340	1350	218	6.46	26.40	244.40	1574	125	1699	.10	73.9	1886	.256	.886
256	252				7.2	2880	1300	202	7.63	31.18	233.18	1780	125	1905	.1325	66.2	2190	2.55	.9
256	252				9.16	3530	1175	179	8.5	~~216.2~~ 37.2	216.2	1836	125	1960	0.217	56.1	2510	2.628	.87

TABLE NO. 7.5 (a)

6 POLE STAR CONNECTION - LOAD TEST

V	V_{SASB}	V_{SAFA}	V_{SAFB}	V_{FAFB}	Current	Power input.	R.P.M.	D.C. Generator Armature					Slip	Brake power output	Efficiency	Torque	B.H.P.	Power factor	Fb . I_a
								volts V_a	current I_a	I R volts	Fb volts	Const. loss watts.							
volt	volt	volt	volt	volt	Amp.	watts								watts	%	Syn.Wat.	HP		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	253.5	14.5			0.5	130	980	192	0				0.02					0.586	
256	235.5	14.5			1.25	426	960	172	1.45	5.92	177.92	125.1	0.04	383.3	90	391	0.513	0.768	258.2
256	254	14.5			1.8	692	930	162	2.55	10.425	172.425	125.1	0.07	582.1	84.2	675	0.779	0.807	457
256	254	14.5			2.35	876	900	154	3.2	13.06	167.06	125.1	0.1	660.1	75.3	733	0.855	0.841	535
256	253	14.5			3.54	1278	810	132	4.2	16.8	148.8	125.1	0.14	733.1	57.4	854	0.963	0.814	608

TABLE NO. 7.5(b)

6 POLE INTERNAL DELTA WITH ONE COIL IN DELTA (y =0.166)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	252	157	134	25.3	6.8	125	996	20	0									.352	
256	252	157	133	24.8	1.25	360	975	174	1.2	4.92	178.92	125.1	.025	339.9	94.4	349	.456	.649	214.8
256	253	156	133	24.3	1.75	620	950	166	2.3	9.4	175.4	125.1	.05	528	85.2	557	.708	.799	403
256	253	155	133	23.5	2.76	1032	900	150	3.8	15.52	165.52	125.1	.1	754	73.2	838	1.012	.843	629
256	252	154	132	22.5	3.98	1429	820	131	4.68	~~1x4x68~~ 19.15	150.15	125.1	.18	828 .1	58.0	~~888xxx~~ 1010	1.112	.812	703

TABLE NO. 7.5 (c)

6 Pole Internal Delta with 2 coils in delta (y = 0.333)

V	V_{SASB}	V_{SAFA}	V_{SAFB}	~~Curr~~ V_{FAFB}	Current	Power input	R.P.M.	D.C. Generator Armature Volts	Current	I_aR_a	Eb	Const. loss	Slip	Brake power output	Efficiency	Torque	B.H.P.	Power factor	[illegible]
volts	volts	volts	volts	volts	Amps.	watts		Va	I_a	volts	volts	watts		watts	%	syn.watt	HP		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	254	171.0	117.0	54.5	1.1	138	996	20	0				0.004					0.283	
256	252	169.0	117	53.5	1.7	534	965	168	1.93	7.83	175.83	125.1	0.035	462.3	84.4	478	0.618	0.708	337.2
256	251	167.5	116.5	52.6	2.41	850	935	147	3.27	13.36	170.36	125.1	0.065	692.6	81.4	741	0.927	0.796	361.5
256	251	166	116.5	51.3	3.2	1164	900	146	4.35	17.77	163.77	125.1	0.100	837.1	71.8	929	1.123	0.820	712.0
256	250	164	116	41.5	4.26	1544	835	130	5.23	21.4	151.4	125.1	0.165	918.1	59.1	1110	1.232	0.817	793
256	250	157	116	44.5	5.12	1792	730	110	5.33	21.8	131.8	125.1	0.270	828.0	46.25	1135	1.111	0.789	703

TABLE NO. 7.5(d)

6 Pole Internal Delta with 3 coils in delta (y = 0.5)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	251	186	96	90	1.3	163	1000	20										0.283	
256	252.5	186	97	89	2.14	594.	955	164	2.68	10.9	174.9	125.1	0.045	593.1	98.3	622	0.797	0.626	468
256	249	182	96	86	3.25	864	905	149	4.45	18.2	167.2	125.1	0.095	868.1	91.1	948	1.165	0.599	743
256	249	181	96	86	3.85	1136	890	141	5.2	21.24	162.24	125.1	0.110	970.1	85.3	1091	1.3	0.665	845
256	251	178	96	84	4.8	1450	825	127	6.0	24.5	151.5	125.1	0.175	1033.1	71.3	1253	1.386	0.681	908
256	251	169	94	81	5.7	1748	745	110	6.15	25.12	135.12	125.1	0.255	975.1	55.75	1304	1.307	0.692	850

TABLE NO. 7.5 (e)

6 POLE INTERNAL DELTA WITH 4 COILS IN DELTA (y = 0.667)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Eb , I_a 20
256	252	205	74	132	1.7	156	990	20	-	-	20	-	-	[illegible]				0.207	0
256	250	204	73	132.5	2.2	620	960	167	2.3	9.4	176.4	125.1	0.04	531.1	85.6	553	.712	0.635	406
256	251	203	74	132.0	2.75	902	950	159	3.6	14.7	173.71	125.1	0.05	750.1	83.3	789	1.005	0.740	625
256	251	202	74	131	3.54	1250	925	146	5.0	20.44	166.44	125.1	0.075	95[illegible].1	76.0	1027	1.273	0.790	825
256	251	201	74	128	4.58	1664	895	134.5	6.49	26.56	161.00	125.1	0.105	1171.1	70.3	1308	1.57	0.819	1046
256	251	198	74	126.5	5.47	1992	850	124	7.3	29.4	153.4	125.1	0.150	1245.1	62.6	1146.5	1.67	0.821	1120
256	251	195	73	124	6.25	2280	780	110	7.45	34.5	144.5	125.1	0.220	1201.1	52.8	1557	1.61	0.823	1076

TABLE NO. 7.5 (f)

6 POLE INTERNAL DELTA WITH 5 COILS IN DELTA (y = 0.833)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	252	228	40.4	187.5	2.03	263	997	20	-	-	20	125.1	0.003				-	0.298	0
256	253	227.5	40.5	188	2.59	716	980	168	2.7	11.04	179	125.1	0.02	608.1	85.0	627.5	0.817	0.[illegible]23	483
256	252	226	40.4	186	3.24	965	965	159	4.23	17.32	176.32	125.1	0.035	871.1	90.25	902.5	1.17	0.738	746
256	252	227	40.5	185	3.66	1250	955	153.5	5.07	20.7	174.8	125.1	0.045	1006.1	80.5	1055	1.35	0.770	881
256	250	224.5	41	182.5	4.53	1614	925	141	6.63	27.12	168.12	125.1	0.075	1239.1	76.8	1340	1.66	0.803	1114
256	250	224	41.5	181	5.4[illegible]	1990	905	129	7.96	32.94	161.94	125.1	0.095	1413.1	71.1	1545	1.895	0.825	1288
256	250	222	42	177.5	6.95	2550	860	110	9.4	38.42	148.42	125.1	0.140	1520.1	59.7	1766	2.09	0.827	1395

TABLE NO. 7.5 (g)

6 POLE DELTA CONNECTIONS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
256	253				1.5	196	995	20	-				0.005					.286	
256	252				2.56	293	985	181	0.4	1.634	182.639	125.1	0.015	198.1	67.6	201	.2654	.258	73.1
256	252				2.97	653	984	172	2.36	9.64	181.64	125.1	0.016	553.1	84.8	562.5	.7425	.426	428.0
256	251				3.73	1120	970	161	4.56	18.63	179.63	125.1	0.030	943.1	84.2	973	1.265	.677	818
256	251				4.65	1585	950	147	6.8	27.8	174.8	125.1	0.050	1315.1	83.1	1384	1.763	.769	1190
256	251				5.7	2030	930	134	8.7	35.56	169.56	125.1	0.070	1600.1	78.75	1720	2.244	.803	1475
256	250				6.18	2230	920	126	9.57	39.1	165.1	125.1	0.080	1703.1	76.4	1852	2.282	.814	1578

4 POLE STAR CONNECTION

TABLE 7.5 (a)

NO LOAD TEST

V volts	$V_{JA\,JB}$ volts	$V_{SA\,SB}$ volts	I Amps	W Watts	RPM
280	270	158	0.8	145	1435
250	254	145	0.75	135	1435
220	212	123	0.5	135	1420
160	155	90	0.6	134	1400
100	90	87	1.1	155	1250

Table 7.6 (a)

SHORT CIRCUIT TEST

V volts	$V_{SA\,SB}$ volts	$V_{JA\,JB}$ volts	I Amps	W watts
25	24	14	0.2	100
50	49.5	29.5	1.2	70
75	75	45	1.75	126
100	100	57.6	2.37	232
150	148	86	3.55	374

4 POLE INTERNAL DELTA WITH ONE COIL IN DELTA

TABLE 7.5 (b)

NO LOAD TEST

V volts	V_{JAJB} volts	V_{SASA} volts	V_{JAJB} volts	V_{SASB} volts	I Amps	W Watts	RPM	SLIP
280	277	180	137	44.5	0.82	168	1450	0.033
256	253	164	124	40.5	0.675	150	1450	0.033
220	218	142	102	35.3	0.6	146	1440	0.04
180	155.5	112	73	25.5	0.675	138	1420	0.055
100	93	69.2	45.3	15.5	1.065	148	1330	0.114
90	88	55.4	44.3	11.5	2.375	240	550	0.634

Table 7.6 (b)

SHORT CIRCUIT TEST

V volts	V_{JASB} volts	V_{JASA} volts	$V_{[illegible]}$ volts	$V_{[illegible]}$ volts	I Amps	W Watts.
25	25	16	13	0	0.4	10
50	49.6	31.8	25.4	2.5	1.4	90
75	75	46.6	37.7	7.0	2.2	132
100	100	63.1	51.4	12.5	2.95	212

4 POLE INTERNAL DELTA WITH TWO COILS IN DELTA

TABLE 7.5(c)
NO LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W Watts	RPM
280	278	208	105	103	0.85	180	1450
256	254	189	95	93	0.8	160	1450
220	217	161	83	81	0.7	140	1450
160	156.5	118	60	58.2	0.695	140	1430
100	97	73	36	35.5	1.025	130	1385
80	79	56	28.6	27.7	1.55	160	1230

Table 7.6(c)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps	W Watts
25	24.8	17	10.5	4	0.8	20
50	50	34.4	20.6	14.5	1.8	86
75	74	50.5	30.4	21	2.75	210
100	100	70	41	29	3.7	400

4 POLE INTERNAL DELTA WITH ~~XXX~~ FOUR COILS IN DELTA

TABLE 7.5 (d)
NO LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amp.	W watts	RPM
280	278	239	63	178	1.1	208	1450
256	253	218	55.5	161	1.035	161	1450
220	17	187	47.6	139	0.9	155	1430
180	156	136	34.5	101	0.85	138	1420
100	98	84	21.4	64	1.0	134	1400
70	68	54.3	14.5	40.2	1.93	170	1170

TABLE 7.6(d)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amp.	W watts.
25	25	19.8	3	13.6	1.2	24
50	49.5	39	13	26.0	2.42	170
75	74	58.5	19.5	32.6	3.04	400
100	100	80	26.5	53.5	4.03	544

4 POLE DELTA CONNECTION

TABLE 7.5 (e)
NO LOAD TEST

V volts	V_{SASB} volts	I Amps.	W Watts	RPM
280	278	1.3	212	1440
256	254.5	1.25	195	1440
220	218	1.1	190	1440
160	156	0.9	144	1435
100	99	0.8	138	1410
70	69	1.3	136	1330
55	535	2.2	166	1160

TABLE 7.6 (e)
SHORT CIRCUIT TEST

V Volts	V_{SASB} Volts	I Amps	W Watts
25	24.7	1.75	40
50	49.7	3.57	190
75	74.5	5.46	416
100	100	7.16	780

6 POLE STAR CONNECTION

TABLE 7.7(a)
NO LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	I Amps.	W Watts.	RPM	SLIP
280	279	170	0.9	145	970	0.03
240	239	146	0.85	125	970	0.03
180	199	123	0.75	105	970	0.03
160	157	86	0.625	80	965	0.035
120	120	75	0.6	76	950	0.05
80	80	49	0.6	80	860	0.14
72	72	44	1.05	94	800	0.2

TABLE 7.8 (a)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	V_{SAFA} volts	I Amps.	W watts
50	49	30.3	1.2	50
75	74	45.3	1.8	136
100	98	67	2.4	250
125	124	76	3.03	406
150	148	91	3.59	592
175	177	108	4.25	862

6 POLE INTERNAL DELTA WITH ONE COIL IN DELTA

TABLE 7.7.(b)
NO LOAD TEST

V volts.	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W watts	RPM	SLIP
280	277	171	144	27	1.05	125	980	0.02
255	236	146	126	23	0.9	168	975	0.025
200	193	124	106	19.5	0.85	136	975	0.025
160	157	93	84	15	0.7	100	970	0.30
120	118	74	64	11.5	0.65	84	970	0.05
80	73	47	40	4	0.875	88	880	0.12

TABLE 7.8 (b)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	W Watts	I Amps
50	49.6	30	27	0.0	62	0.51
75	74	43.6	39.5	2.0	200	[illegible]
100	98	59	53.5	3.0	200	0.61

6 POLE INTERNAL DELTA WITH TWO COILS IN DELTA

TABLE 7.7.(c)
NO LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W Watts	RPM	SLIP
280	270	180	125	63	1.2	153	975	0.025
255	255	171	115	57.5	1.075	152	975	0.026
220	220	148	93	50	0.915	150	975	0.025
160	160	103	73	35.7	0.75	110	975	0.025
100	97.5	67	44	31.3	0.65	84	960	0.05
70	70	44	30	10.5	1.35	120	700	0.3

TABLE 7.8 (c)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W Watts.
50	50	31.5	21.5	9	1.35	90
75	74	46	32	14.5	2.1	180
100	98	35	42.6	19	2.9	310
125	124	79	61.5	17.5	[illegible]	[illegible]
150	149	95	73	21.3	[illegible]	510

6 POLE INTERNAL DELTA WITH 3 COILS IN DELTA

TABLE 7.7.(d)
NO LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps	W watts	RPM	SLIP
280	260	207	108	1 0	1.57	170	975	0.025
256	255	188	98	91	1.425	160	975	0.025
220	219	160	84	78	1.225	150	975	0.025
160	156	116	61	56	0.9	108	965	0.05
100	98	73	37.5	34.5	0.8	91	950	0.05
60	58.	38.5	22.5	17.5	1.47	110	725	0.275

Table 7.8.(d)
SHORT CIRCUIT TEST.

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} Volts	I Amps	W watts
50	49	33	21.3	12	2.75	86
75	74	49	31.6	18.3	5.58	220
100	96	66	42	24	7.36	390

6 POLE INTERNAL DELTA WITH 4 COILS IN DELTA

TABLE 7.7.(e)
NO LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W watts	RPM	SLIP
280	276	225	80	145	1.86	185	985	0.015
256	252	205	74	134	1.7	170	975	0.025
220	290	178	64	117	2.9	150	970	0.03
160	157	113	45	84	2.15	120	965	0.035
100	97	80	28	51.3	1.7	87	960	0.04
57	57	44.8	16.5	28.8	2.5	42	840	0.16

TABLE 7.8.(e)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W Watts
25	24.4	18.3	6	3	1.11	20
50	48.6	36.2	17	20	2.28	110
75	73	54	25.6	22.5	3.39	270
100	99	75	25	39.5	4.58	570

6 POLE INTERNAL DELTA WITH 5 COILS IN DELTA

TABLE 7.7.(f)
N-O LOAD TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W watts	RPM	SLIP
280	277	253	45	207	2.2	210	970	0.03
256	254	230	41	188	2	170	970	0.03
220	117	197	35.3	161	1.75	160	970	0.03
160	126	142	25.3	118	1.2	130	970	0.03
100	97	88	16	74	0.8	85	960	0.04
70	69.5	61.	11.5	50	0.9	80	930	0.07
47.5	47.5	40.5	5	33	1.8	100	715	0.285

TABLE 7.8.(f)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	V_{SAFA} volts	V_{SAFB} volts	V_{FAFB} volts	I Amps.	W Watts.
25	25	21	2	16	1.4	30
50	49	42.5	10	22.5	2.97	144
75	74	64	16	40.6	4.2	330
100	100	85	21.4	64	5.6	636

6 POLE DELTA CONNECTION

TABLE 7.7.(g)
N-O LOAD TEST

V volts	V_{SASB} volts	I Amp	W watts	RPM	SLIP
280	278	5.46	240	980	0.02
256	252	4.89	200	980	0.02
220	219	4.25	172	950	0.05
160	157	3.08	140	950	0.05
100	98	2.12	80	950	0.05
75	74	1.9	73	950	0.05

TABLE 7.8.(g)
SHORT CIRCUIT TEST

V volts	V_{SASB} volts	I Amps	W watts
25	24.5	1.75	30
50	49.3	3.65	90
75	74.3	5.5	440
100	99	7.3	820

TABLE NO. 7.10 (a)

4 POLE STAR CONNECTION.

considering saturation and harmonic effect.		Power factor	Efficiency %
Horse power Hp	Current. Amps.		
1	2	3	4
0.16	0.4	0.45	35
0.32	0.75	0.675	57.5
0.426	0.973	0.765	68
0.48	1.15	0.80	73.5
0.64	1.575	0.6	52.5

TABLE NO. 7.10 (b)

4 POLE INTERNAL DELTA WITH ONE COIL IN DELTA

(y = 0.25)

1	2	3	4
0.1849	0.65	0.7555	32.5
0.3698	1.0	0.800	68.75
0.493	1.25	0.825	75.00
0.554	1.425	0.835	76.00
0.74	1.9 0	0.86	74.5

TABLE NO. 7.10 (c)

4 POLE INTERNAL DELTA WITH TWO COILS IN DELTA

(y = 0.5)

1	2	3	4
0.2533	1.1	0.73	46.3
0.507	1.5	0.80	65.0
0.676	1.8	0.81	65.0
0.6135	1.75	0.83	68.75
1.014	2.675	0.85	74.5

TABLE NO. 7.10 (d)

4 POLE INTERNAL DELTA WITH THREE COILS IN DELTA

(y = 0.75)

1	2	3	4
0.3535	1.2	0.82	70.0
0.71	1.925	0.865	82.5
0.948	2.375	0.87	82.0
1.066	2.75	0.87	80.9
1.422	3.8	0.87	73.0

TABLE NO. 7.10 (e)

6 POLE DELTA CONNECTIONS

1	2	3	4
0.5	1.775	0.67	50
1.0	2.55	0.81	71
1.333	3.075	0.84	80.75
1.5	3.525	0.865	80.75
2.0	4.825	0.895	77.5

TABLE NO. 7.10 ([illegible])

6 POLE STAR CONNECTION

1	2	3	4
0.16	0.65	0.61	87.75
0.32	0.61	0.58	86.5
0.4266	0.75	0.665	89.2
0.48	1.175	0.785	90.25
0.64	1.10	0.77	90.5

TABLE NO. 7.11 (b)

6 POLE INTERNAL DELTA WITH ONE COIL IN DELTA

(y = 0.166)

1	2	3	4
0.1675	0.925	0.545	83.50
0.335	1.1	0.615	95.0
0.447	1.275	0.6725	94.0
0.5025	1.4	0.7125	91.25
0.67	1.7	0.79	86.85

TABLE NO. 7.11 (c)

6 POLE INTERNAL DELTA WITH TWO COILS IN DELTA

(y = 0.333)

1	2	3	4
0.2045	0.95	0.475	77.0
0.409	1.35	0.6175	86.25
0.546	1.60	0.685	86.50
0.614	1.80	0.7275	86.5
0.818	2.2	0.78	83.0

TABLE NO. 7.11 (d)

6 POLE INTERNAL DELTA WITH THREE COILS IN DELTA

(y = 0.5)

1	2	3	4
0.2535	1.0	0.385	85.0
0.507	1.45	0.48	93.0
0.675	1.85	0.54	95.5
0.76	2.2	0.575	96.0
1.014	2.8	0.625	95.9

TABLE NO. 7.11 (e)

6 POLE INTERNAL DELTA WITH FOUR COILS IN DELTA

(y = 0.667)

1	2	3	4
0.317	1.35	0.5125	83.5
0.634	2.025	0.6425	86.25
0.951	2.75	0.74	83.5
1.268	3.4	0.785	79.55

TABLE NO. 7.11 (f)

6 POLE INTERNAL DELTA WITH 5 COILS IN DELTA

(y = 0.833)

1	2	3	4
0.399	1.75	0.525	82.25
0.798	2.525	0.66	85.0
1.064	3.075	0.72	83.25
1.98	3.35	0.745	82.0
1.596	4.25	0.795	78.0

TABLE NO. 7.11 (g)

6 POLE DELTA CONNECTIONS

1	2	3	4
0.5	2.6	0.58	75
1.0	3.4	0.67	85.5
1.33	3.9	0.7125	84.75
1.50	4.2	0.735	84.0
2.00	5.25	0.795	80

TABLE NO. 7.12

FOUR POLE WINDING

H.P.	y = 1				y = 0.75				y = 0.5				y = 0.25				y = 0			
Hp	I Amps	η %	P.F.	Slip	I Amp	η %	P.F.	Slip	I Amp	η %	P.F.	Slip	I Amp	η %	P.F.	Slip	I Amp	η %	P.F.	Slip
2.4	>5.5	73	.91	.11	>>5	50	.84	5	>>>5	55	.95		>>>5	38	.95		>>>>5	0	.95	
2.0	5.04	77.5	.895	.075	5.8	59	.86		>5	68	.93		>5	45	.95		>5	0	0.94	
1.8	4.4	79	.89	.065	5.1	64	.865	.177	>5	74	.87		>5	49	.92		>5	0	0.92	
1.6	3.85	80	.875	.0525	4.45	69	.87	.1025	>5	77.5	.905		>5	53	.91		>5	0	0.91	
1.5	3.45	80	.865	.0455	4.1	71.5	.87	.085	>5	78	.90		>5	56	.91		>5	0	0.91	
1.4	3.35	79.75	.855	.045	3.725	73.5	.87	.0725	5.1	78.5	.9	.11	>5	58.75	.905		>5	0	0.90	
1.2	2.95	78	.833	.0375	3.05	78.	.87	.055	4.?5	77.	.90	.0775	4.4	64	.9		4.7	0	0.89	
1.0	2.55	74.5	.8	.03	2.5	82	.87	.0375	3.2	74.0	.875	.0575	2.95	69.25	.88	.12	33.	15	0.89	.21
0.8	2.225	69	.75	.025	2.05	82.5	.865	.03	2.35	69.5	.83	.043	2.1	73.5	.87	.0625	2.125	36	0.855	.125
0.6	1.925	65.5	.67	.0175	1.675	81.6	.855	.02	1.75	60.0	.80	.030	1.55	75.5	.84	.04	1.45	59	0.82	.0725
0.4	1.675	58.0	.55	.013	1.325	76.25	.83	.010	1.3	47.5	.77	.023	1.075	70.?	.812	.0225	0.9	67.5	0.75	.04
0.2	1.475	42.5	.45	.0075	1.1	62.5	.725	.005	1.05	30.0	.68	.0125	0.675	50.0	.755	.01	0.475	40.	0.53	.015

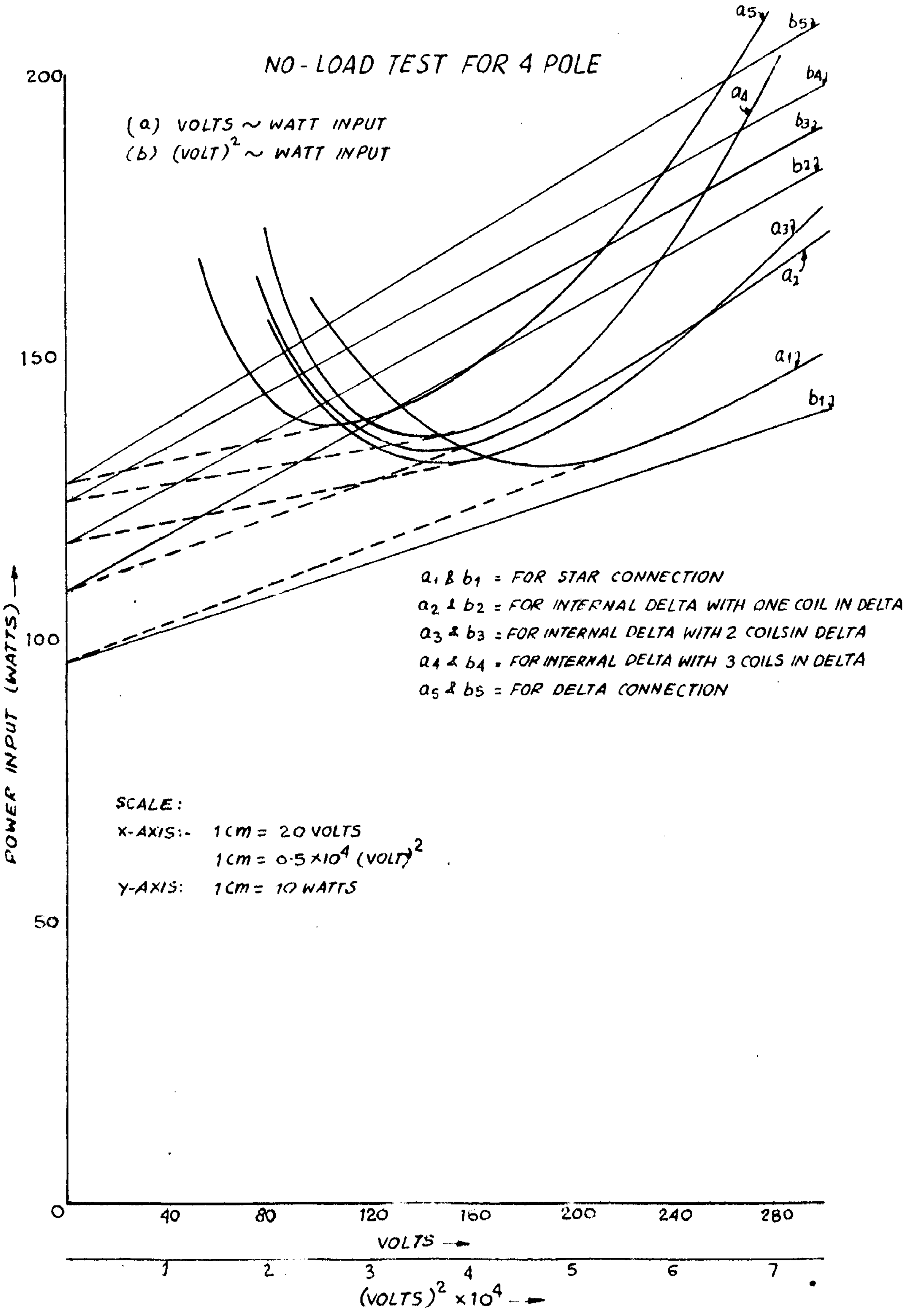
TABLE NO. 7.13

SIX POLE WINDING

H.P.	y = 1				y =.833				y = .667				y = .5				y = .333				y =.167				y = 0			
Hp.	I Amps	η %	P.F.	Slip	I Amps	η %	P.F.	Slip	I Amps	η %	P.F.	Slip	I Amps	η %	P.F.	Slip	I Amps	η %	P.F.	Slip	I Amps.	η %	P.F.	Slip	I Amps	η %	P.F.	Slip
2.0	5.25	80	.78	.06	5.45	73	.84	.12	5.63	72	.88	[illegible]	>6.0	66	.79		>6	33.5	.91		>6	14.0	.95		>6	28.5	.92	
1.8	4.8	82	.76	.05	4.8	75.5	.83	.087	4.9	70	.84		5.25	78	.77		5.6	40.5	.905		>6	26.5	.95		>6	45	.925	
1.6	4.4	83.5	.75	.045	4.25	78.	.8	.067	4.3	74	.83	.117	4.55	83.5	.74		4.77	52.0	.89		5.13	38.5	.95		>6	56.5	.91	
1.4	4.0	84.7	.73	.04	3.77	80.5	.77	.05	3.77	77.5	.81	.087	3.91	88.	.71		4.0	63.0	.9		4.25	50	.94		4.6	66.5	.90	
1.2	3.65	85	.7	.03	3.35	82.1	.75	.04	3.27	80.7	.78	.07	3.31	92.5	.67	.09	3.32	72	.85	.13	3.37	61	.91		3.41	76.0	.87	
1.0	3.32	85	.67	.025	2.95	84.0	.707	.027	2.81	83.0	.75	.055	2.8	95.0	.63	.061	2.7	79.1	.84	.08	2.7	71.5	.88	.1	2.2	84.0	.84	.435
0.8	3.02	82.5	.635	.02	2.55	85	.66	.017	2.4	85.0	.71	.041	2.27	96.0	.58	.045	2.15	83.5	.77	.05	2.05	81.25	.83	.06	1.5	89.0	.81	.2
0.6	2.75	78.5	.585	.015	2.15	85	.61	.01	1.95	86.25	.64	.030	1.77	94.5	.51	.025	1.72	86.2	.71	.03	1.57	89.5	.75	.037	1.085	91.0	.76	.123
0.4	2.5	71.0	.51	.007	1.75	86	.53	.005	1.5	85.0	.55	.02	1.27	90.5	.48	.01	1.32	86.0	.615	.01	1.2	94.5	.65	.02	0.7	89.2	.68	.075
0.2	2.27	55.0	.41	.005	1.4	69	.42	.025	1.15	72.5	.435	.007	0.95	80.5	.34	0	1.0	76.5	.475	0	0.925	85.0	.50	.007	0.525	77.0	.56	.025

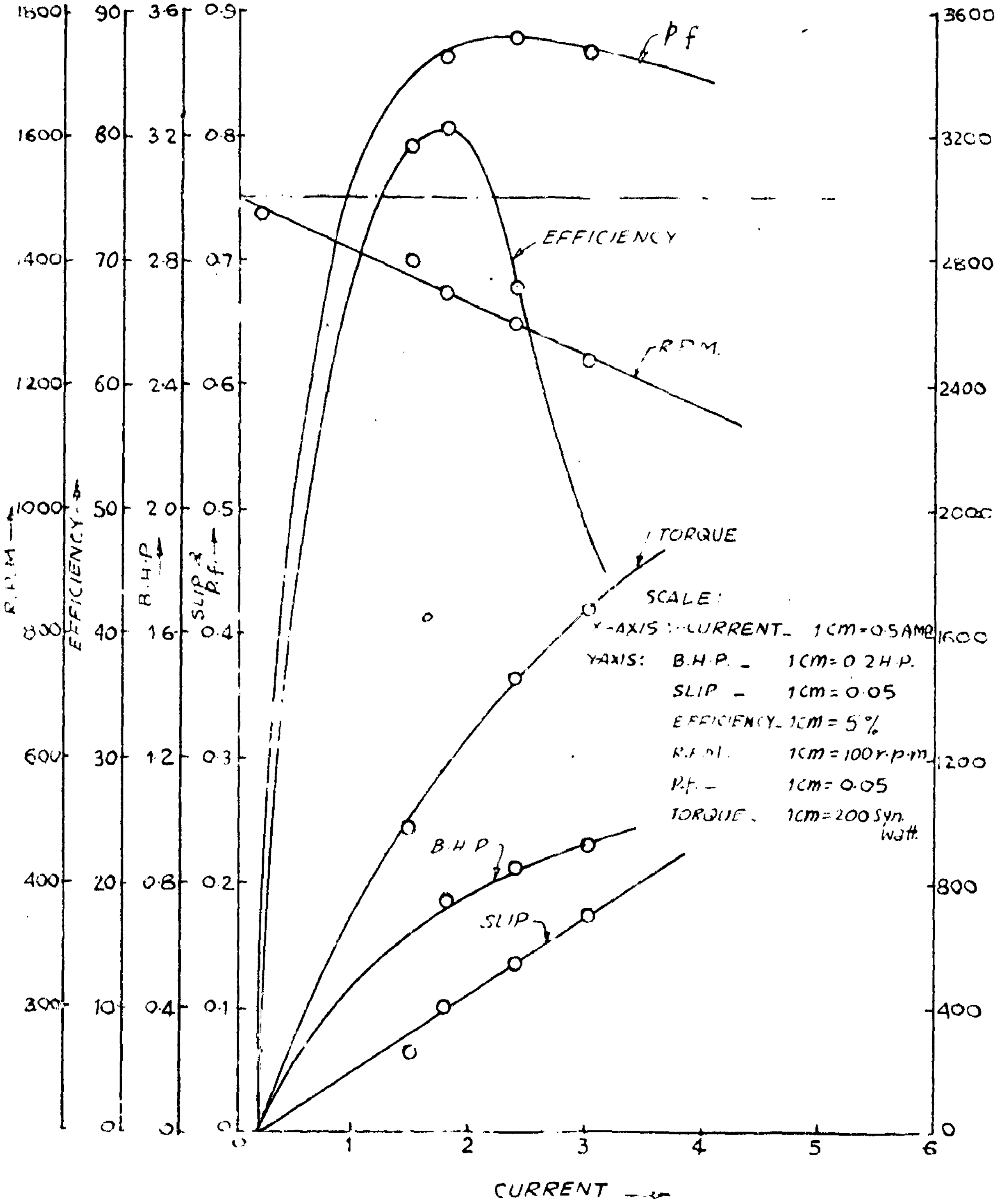
TABLE No. 7.14

y =	I_λ / I_λ int.		T_λ / T_λ int.	
	without con. sat.&har.	con. sat. & har.	without con. sat.& har.	con. sat. & har.
0	2.932	3.066	2.87	2.972
0.25	2.31	2.47	2.532	2.706
0.50	1.835	2.012	2.09	2.332
0.75	1.215	1.282	1.154	1.19
0	3.23	3.57	2.648	3.214
0.166	2.8	3.00	2.548	2.868
0.333	2.172	2.332	1.95	2.166
0.50	1.786	1.91	1.486	1.724
0.667	1.446	1.526	1.034	1.323
0.833	1.2	1.254	1.134	1.253

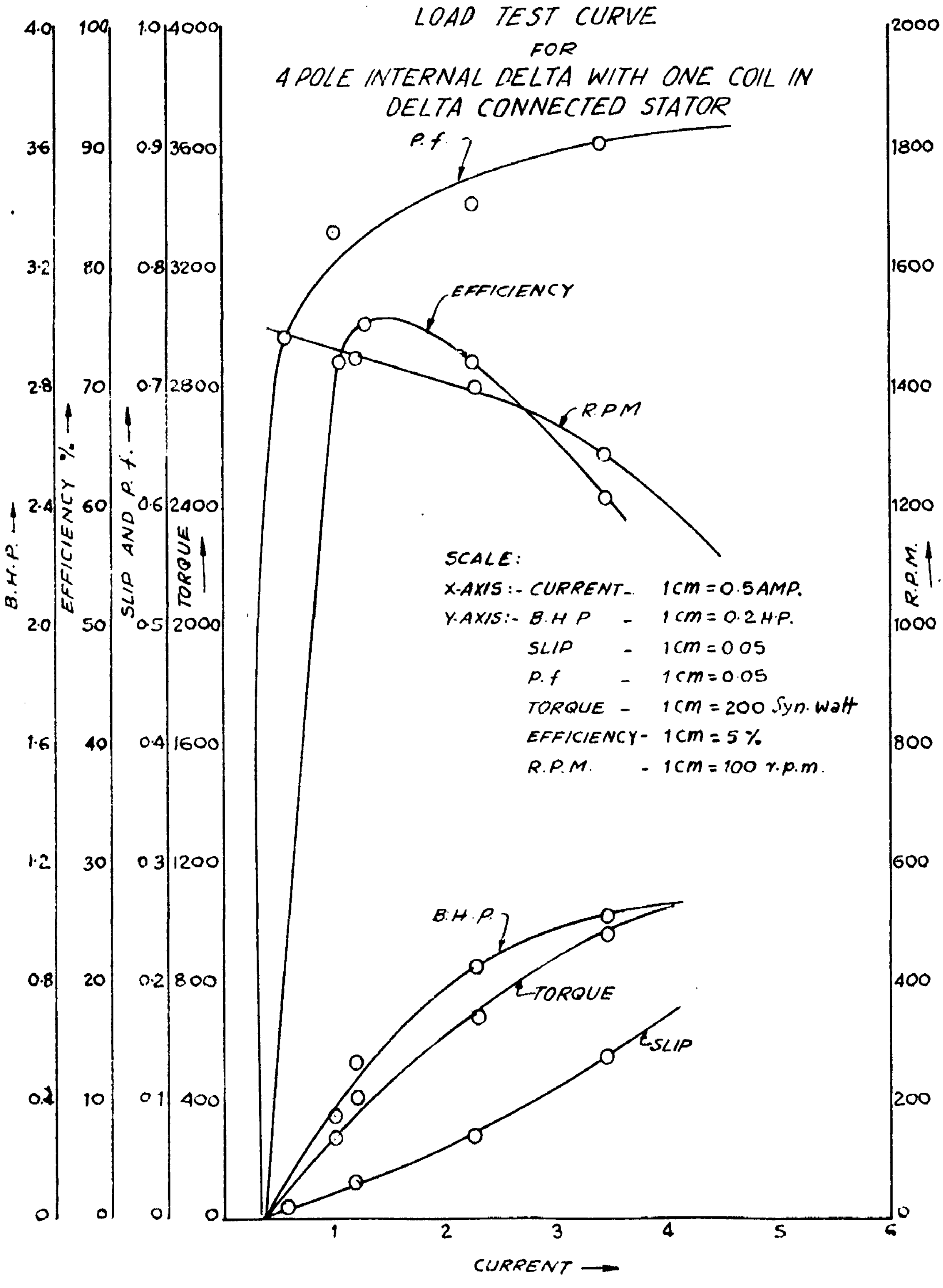

NO-LOAD TEST FOR 4 POLE
(a) VOLTS ~ WATT INPUT
(b) $(VOLT)^2$ ~ WATT INPUT
a_5
b_5
b_4
a_4
b_3
b_2
a_3
a_2
a_1
b_1
a_1 & b_1 = FOR STAR CONNECTION
a_2 & b_2 = FOR INTERNAL DELTA WITH ONE COIL IN DELTA
a_3 & b_3 : FOR INTERNAL DELTA WITH 2 COILS IN DELTA
a_4 & b_4 = FOR INTERNAL DELTA WITH 3 COILS IN DELTA
a_5 & b_5 = FOR DELTA CONNECTION
SCALE:
X-AXIS:- 1 cm = 20 VOLTS
1 cm = 0.5×10^4 $(VOLT)^2$
Y-AXIS: 1 cm = 10 WATTS
POWER INPUT (WATTS) →
200
150
100
50
0
40
80
120
160
200
240
280
VOLTS →
1
2
3
4
5
6
7
$(VOLTS)^2 \times 10^4$ →

GRAPH No 1

LOAD TEST CURVE
FOR
4 POLE STAR CONNECTED STATOR



GRAPH No 2



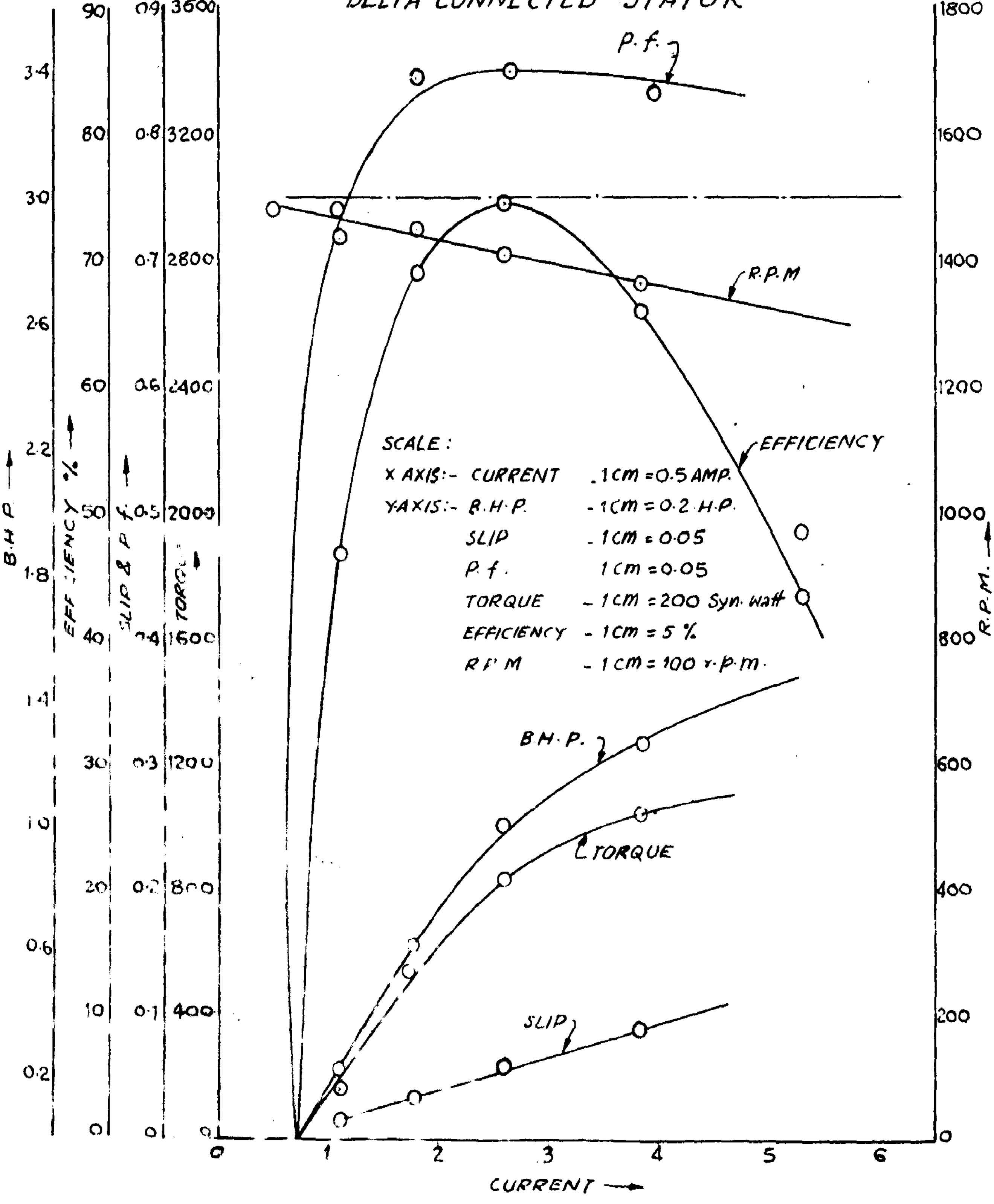
LOAD TEST CURVE
FOR
4 POLE INTERNAL DELTA WITH ONE COIL IN
DELTA CONNECTED STATOR

SCALE:
X-AXIS :- CURRENT - 1cm = 0·5 AMP.
Y-AXIS :- B.H.P - 1cm = 0·2 H.P.
SLIP - 1cm = 0·05
P.f - 1cm = 0·05
TORQUE - 1cm = 200 Syn. watt
EFFICIENCY - 1cm = 5 %
R.P.M. - 1cm = 100 r.p.m.

4 POLE INTERNAL DELTA ONE COIL

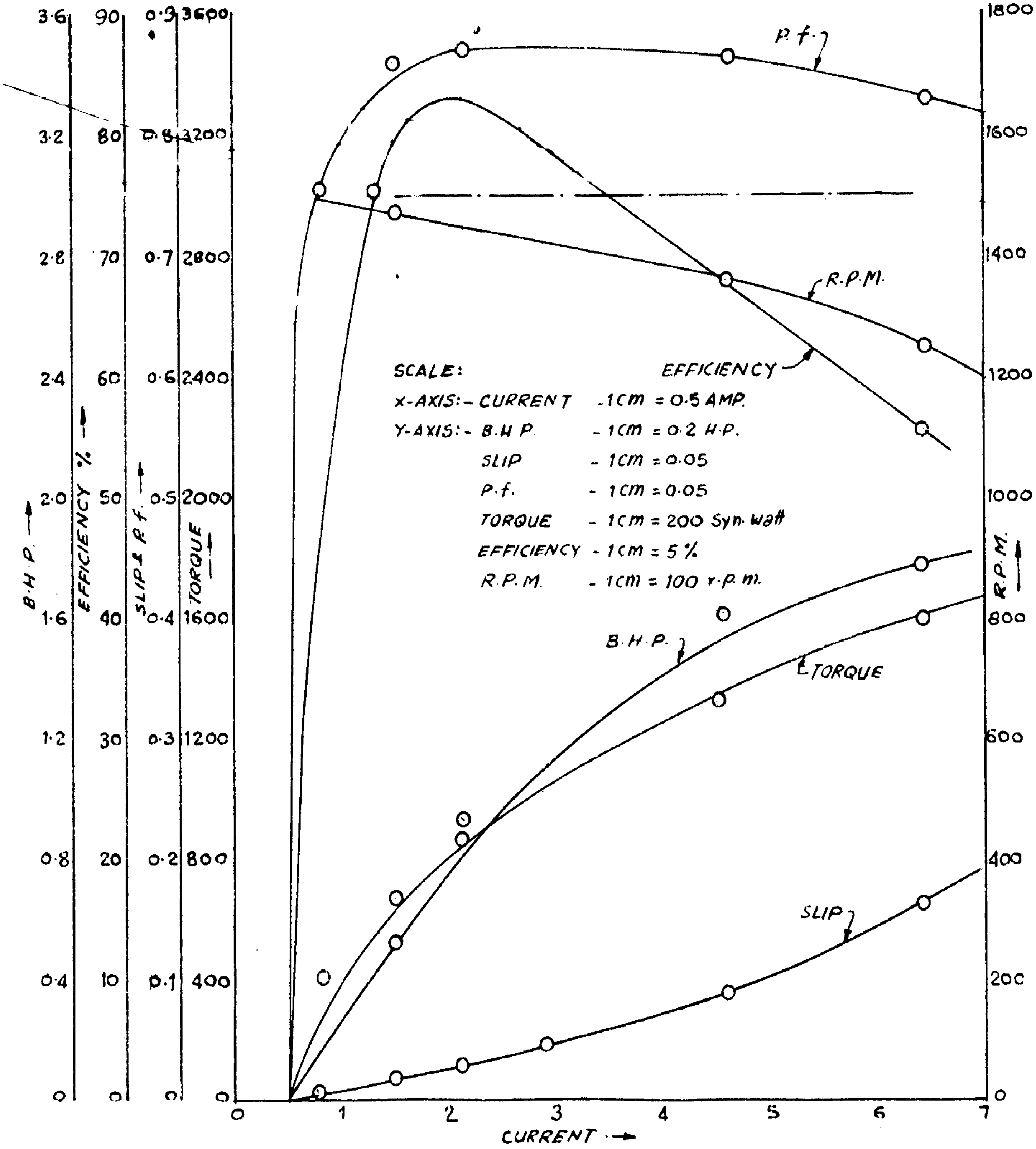
GRAPH No 3

LOAD TEST CURVE
FOR
4 POLE INTERNAL DELTA WITH 2 COIL IN DELTA CONNECTED STATOR



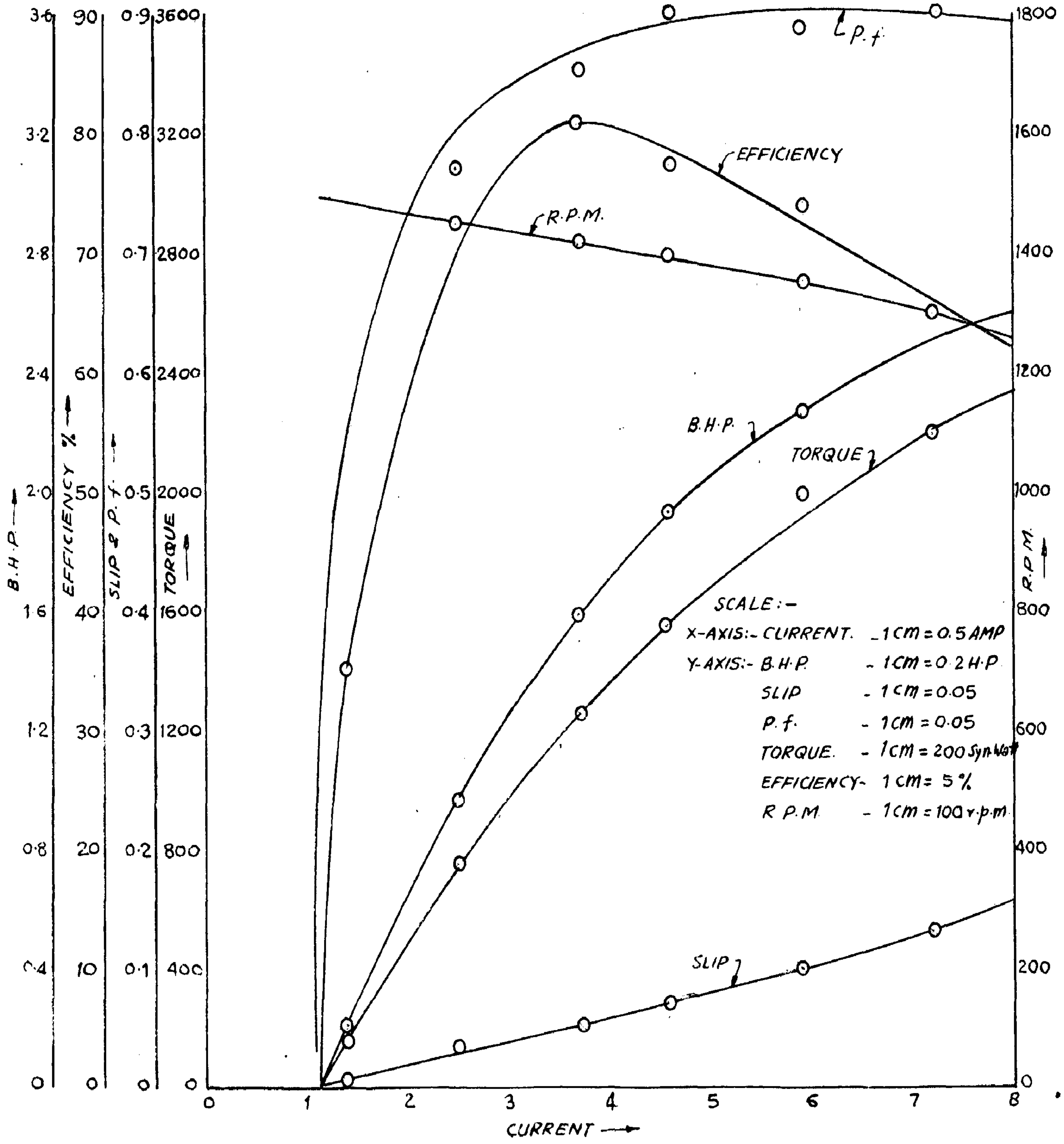
GRAPH No. 4

LOAD TEST CURVE
FOR
4 POLE INTERNAL DELTA WITH 3 COIL IN
DELTA CONNECTED STATOR

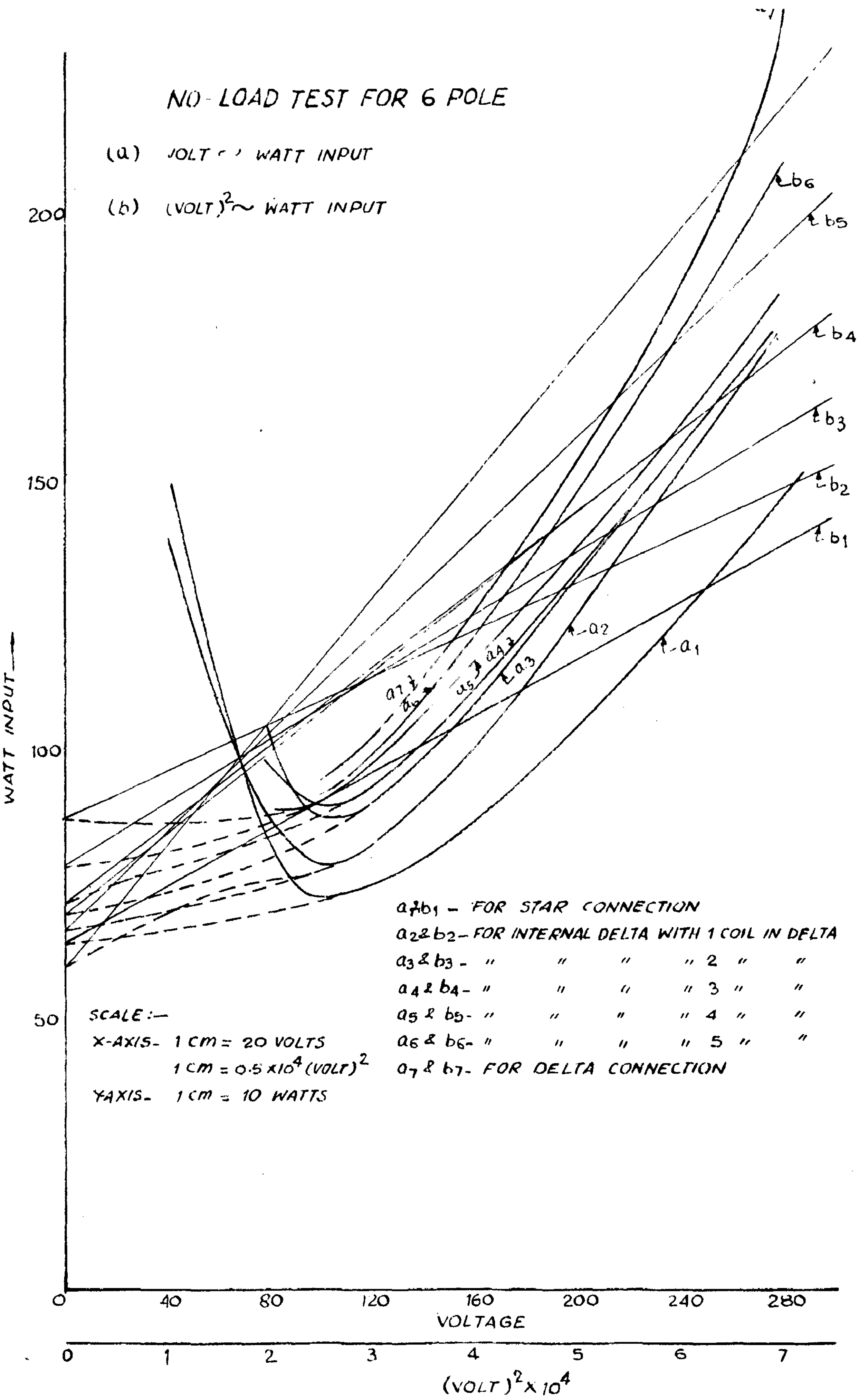


GRAPH No 5

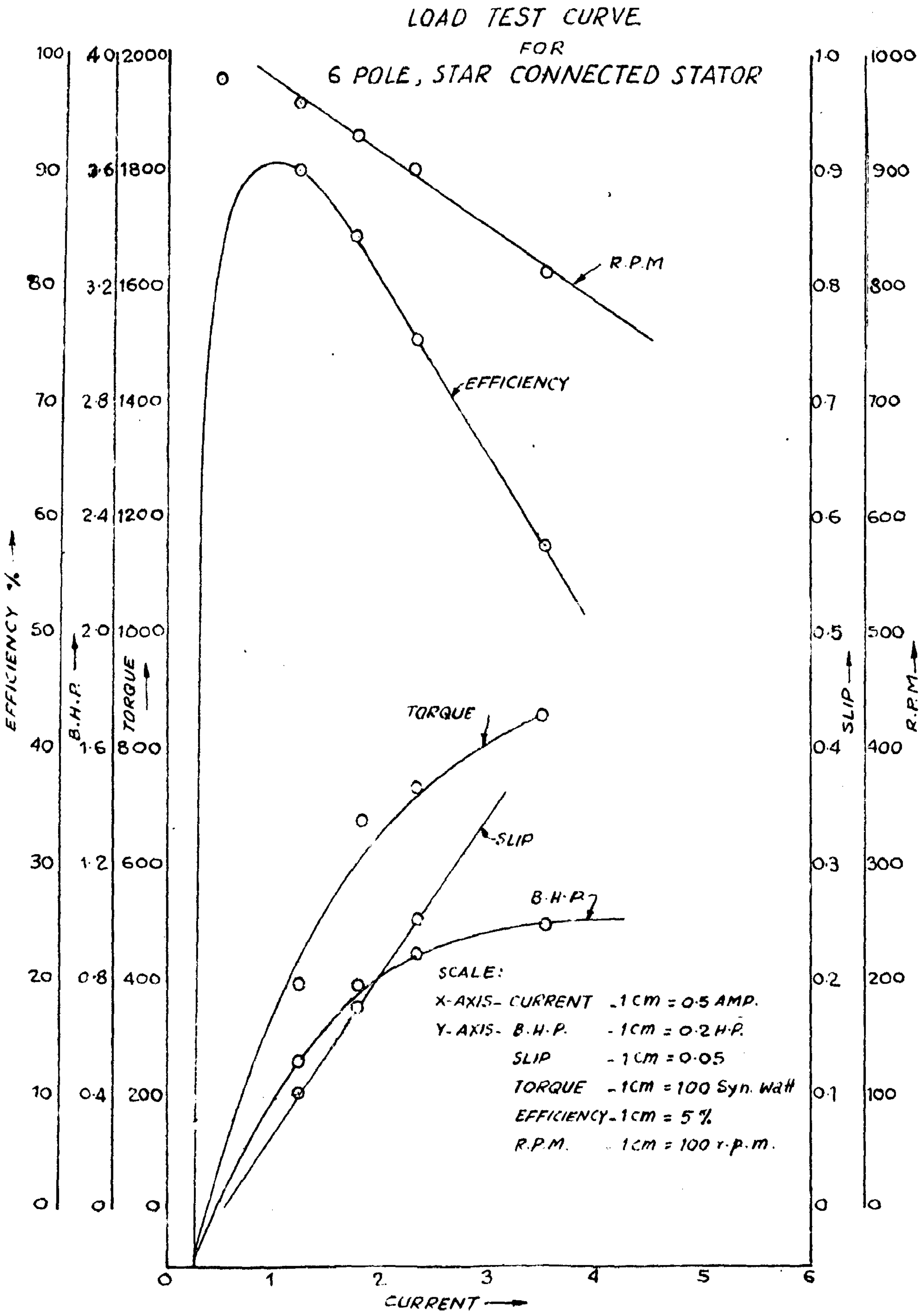
LOAD TEST CURVE
FOR
4 POLE DELTA CONNECTED STATOR



GRAPH No 6

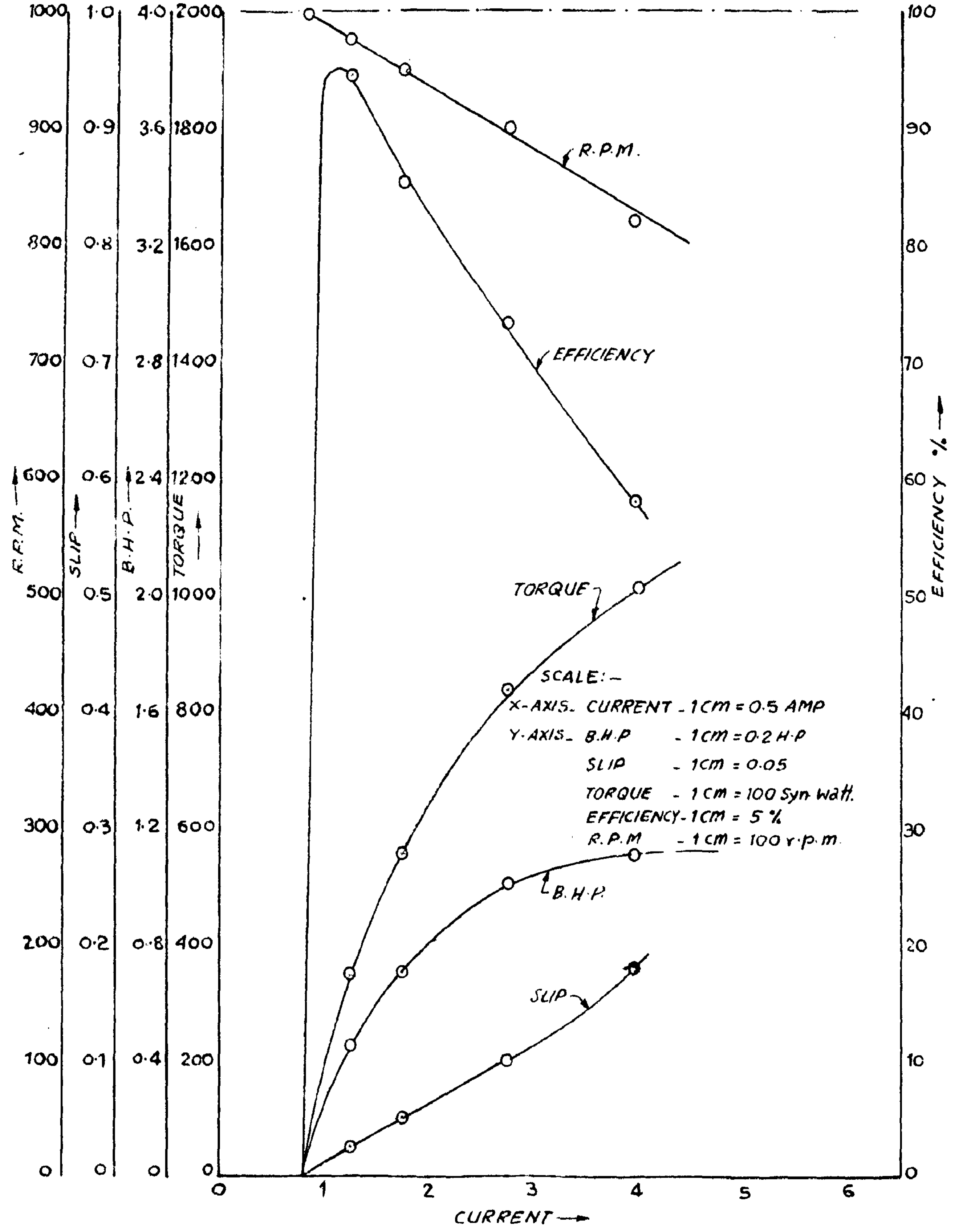

NO-LOAD TEST FOR 6 POLE
(a) VOLT ~ WATT INPUT
(b) (VOLT)^2 ~ WATT INPUT
WATT INPUT
200
150
100
50
0
40
80
120
160
200
240
280
VOLTAGE
0
1
2
3
4
5
6
7
(VOLT)^2 x 10^4
b6
b5
b4
b3
b2
b1
a2
a1
a3
a4
a5
a7
b6
a1 & b1 - FOR STAR CONNECTION
a2 & b2 - FOR INTERNAL DELTA WITH 1 COIL IN DELTA
a3 & b3 - " " " " 2 " "
a4 & b4 - " " " " 3 " "
a5 & b5 - " " " " 4 " "
a6 & b6 - " " " " 5 " "
a7 & b7 - FOR DELTA CONNECTION
SCALE :-
X-AXIS - 1 cm = 20 VOLTS
1 cm = 0.5 x 10^4 (VOLT)^2
Y-AXIS - 1 cm = 10 WATTS

GRAPH No 7


LOAD TEST CURVE
FOR
6 POLE, STAR CONNECTED STATOR
EFFICIENCY %
B.H.P.
TORQUE
SLIP
R.P.M.
100 90 80 70 60 50 40 30 20 10 0
4.0 3.6 3.2 2.8 2.4 2.0 1.6 1.2 0.8 0.4 0
2000 1800 1600 1400 1200 1000 800 600 400 200 0
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
1000 900 800 700 600 500 400 300 200 100 0
R.P.M
EFFICIENCY
TORQUE
SLIP
B.H.P
SCALE:
X-AXIS- CURRENT - 1 cm = 0.5 AMP.
Y-AXIS- B.H.P. - 1 cm = 0.2 H.P.
SLIP - 1 cm = 0.05
TORQUE - 1 cm = 100 Syn. watt
EFFICIENCY - 1 cm = 5 %
R.P.M. - 1 cm = 100 r.p.m.
0 1 2 3 4 5 6
CURRENT

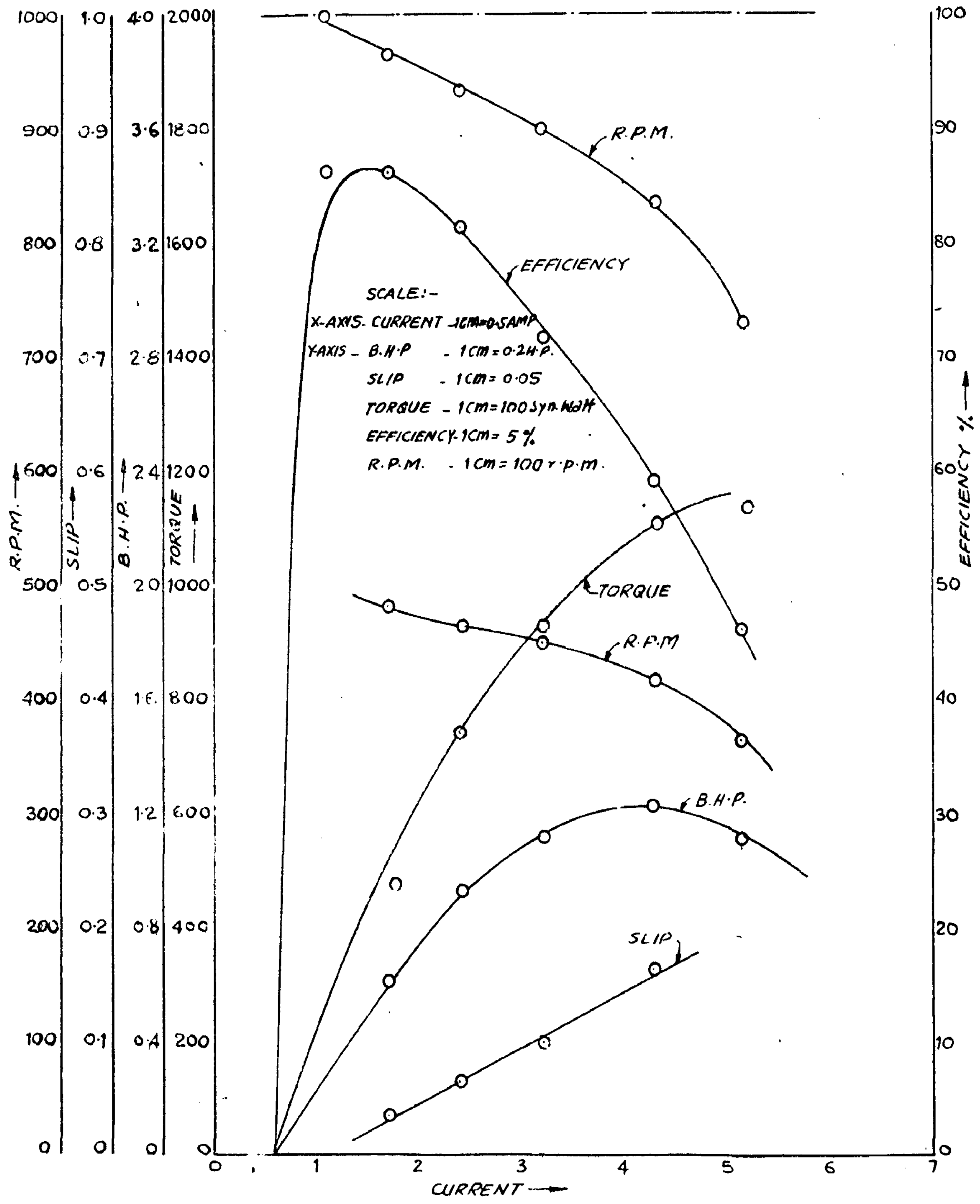
GRAPH No. 8

LOAD TEST CURVE
FOR
6 POLE INTERNAL DELTA WITH ONE COIL
IN DELTA CONNECTED STATOR



GRAPH No 9

LOAD TEST CURVE
FOR
6 POLE INTERNAL DELTA WITH 2 COILS IN DELTA CONNECTED STATOR



SCALE:-

X-AXIS- CURRENT - 1CM=0.5AMP

Y-AXIS - B.H.P - 1CM = 0.2H.P.

SLIP - 1CM = 0.05

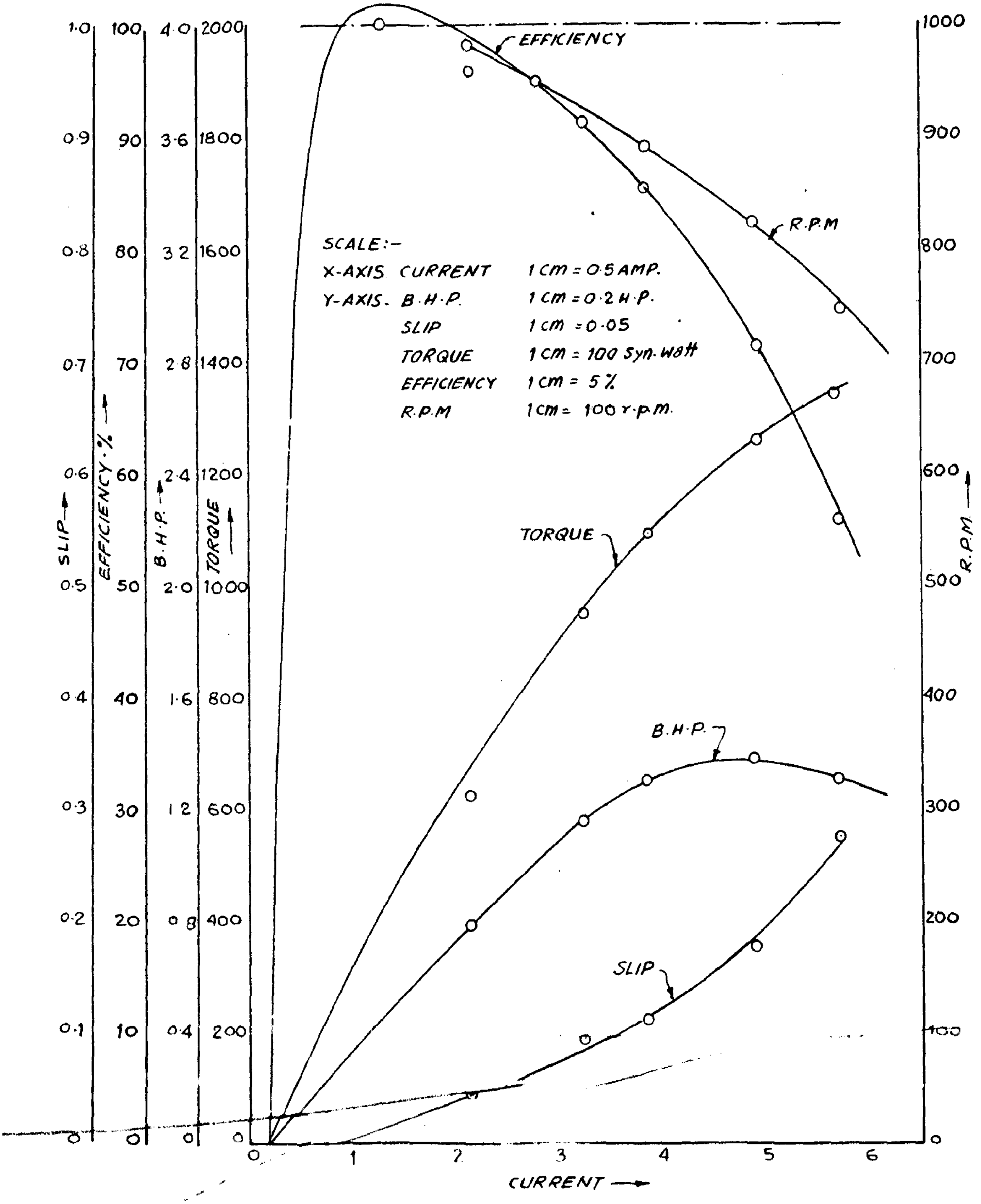
TORQUE - 1CM = 100 Syn. Watt

EFFICIENCY - 1CM = 5%

R.P.M. - 1CM = 100 r.p.m.

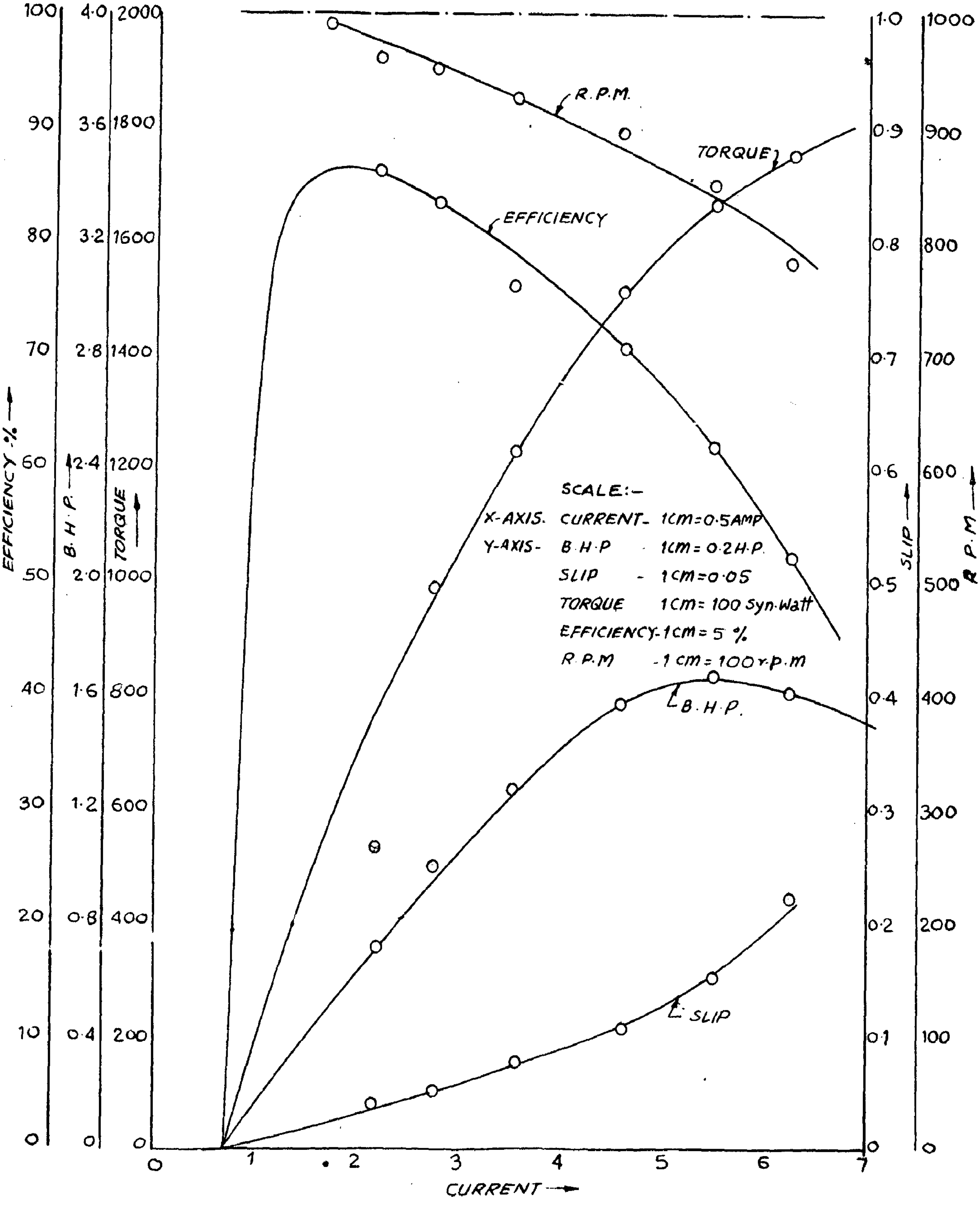
GRAPH No 10

LOAD TEST CURVE
FOR
6 POLE INTERNAL DELTA WITH 3 COILS IN DELTA CONNECTED STATOR



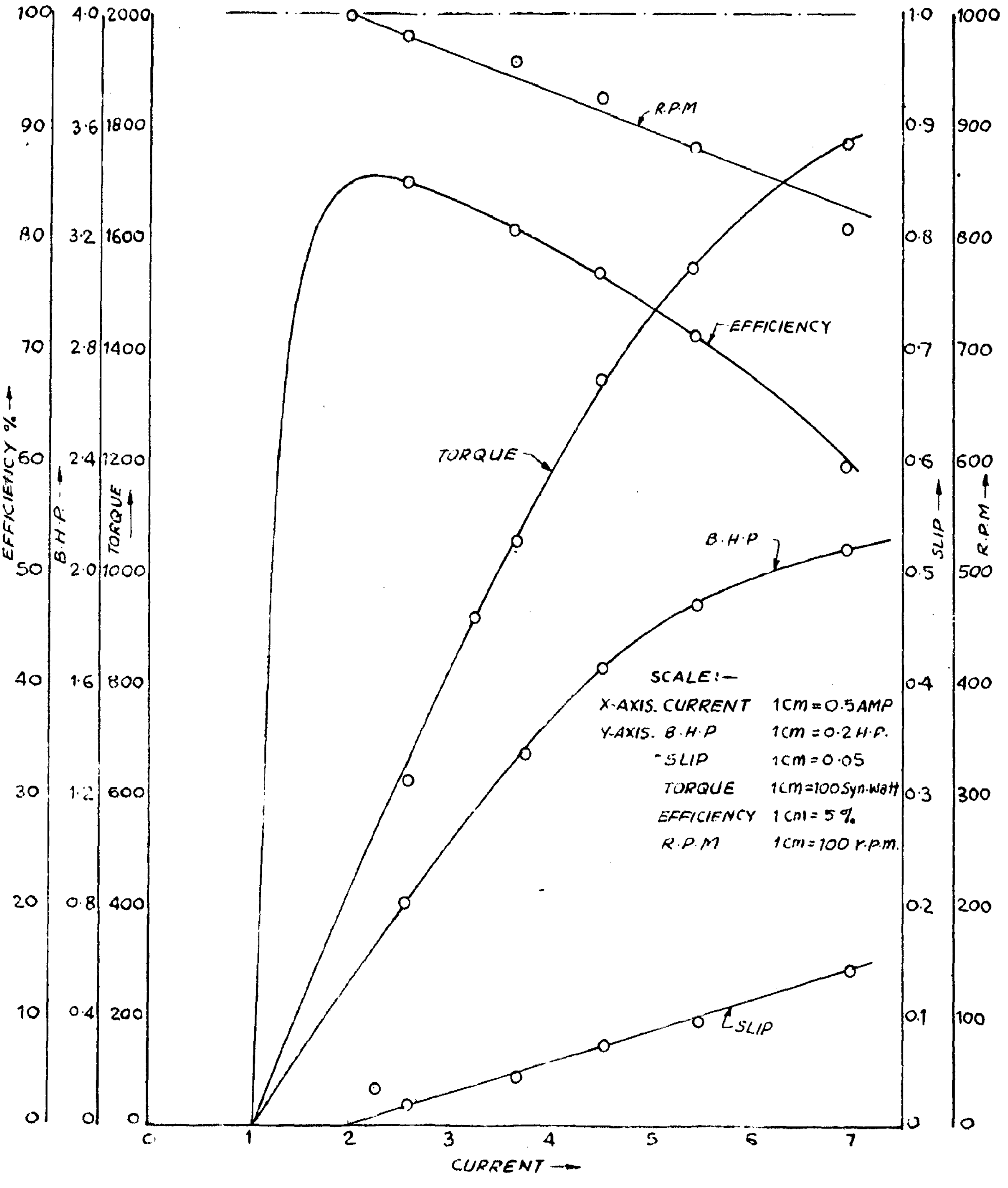
GRAPH No 11

LOAD TEST CURVE
FOR
6POLE INTERNAL DELTA WITH 4 COILS
IN DELTA CONNECTED STATOR



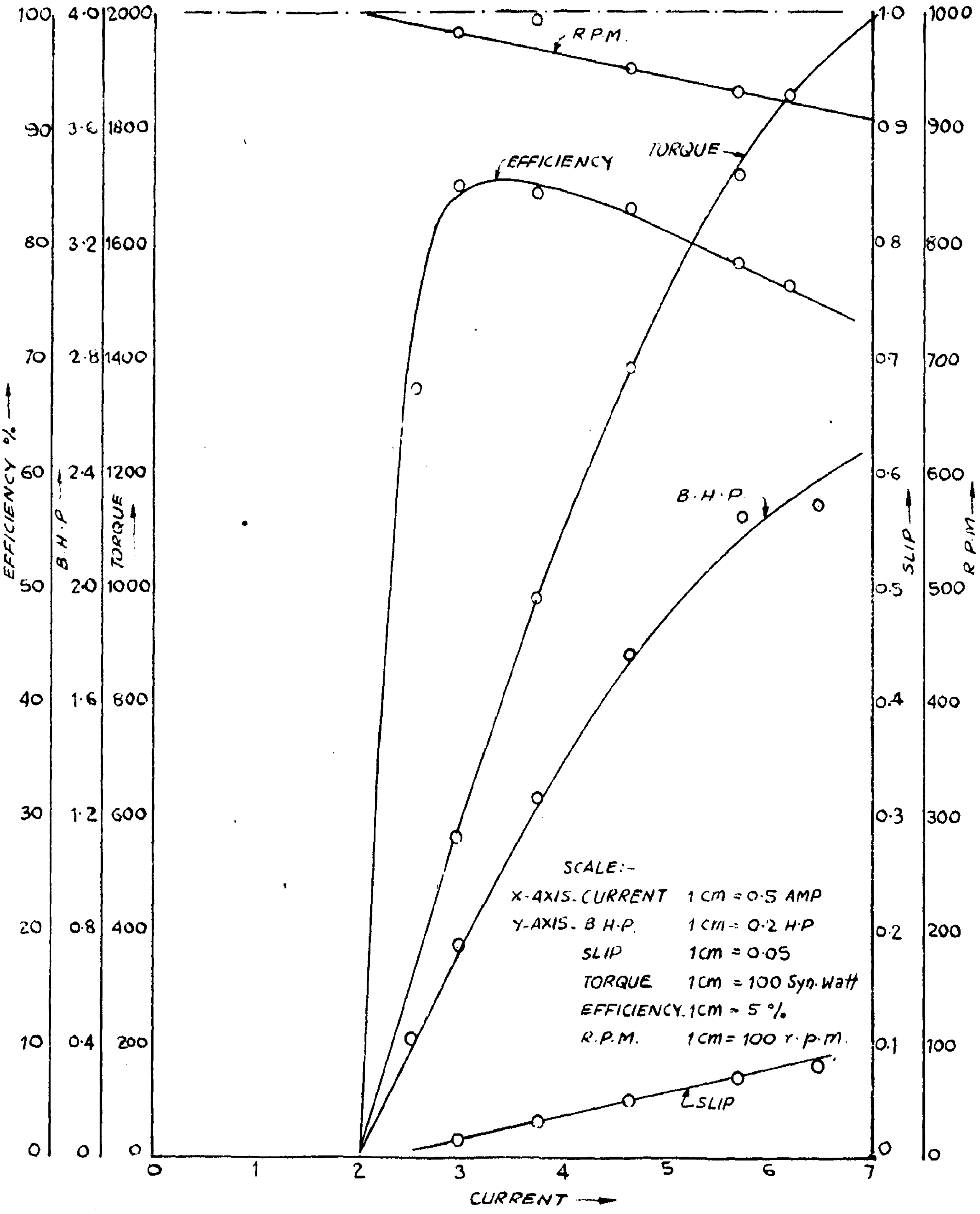
GRAPH No. 12

LOAD TEST CURVE
FOR
6 POLE, INTERNAL DELTA WITH 5 COILS
IN DELTA CONNECTED STATOR



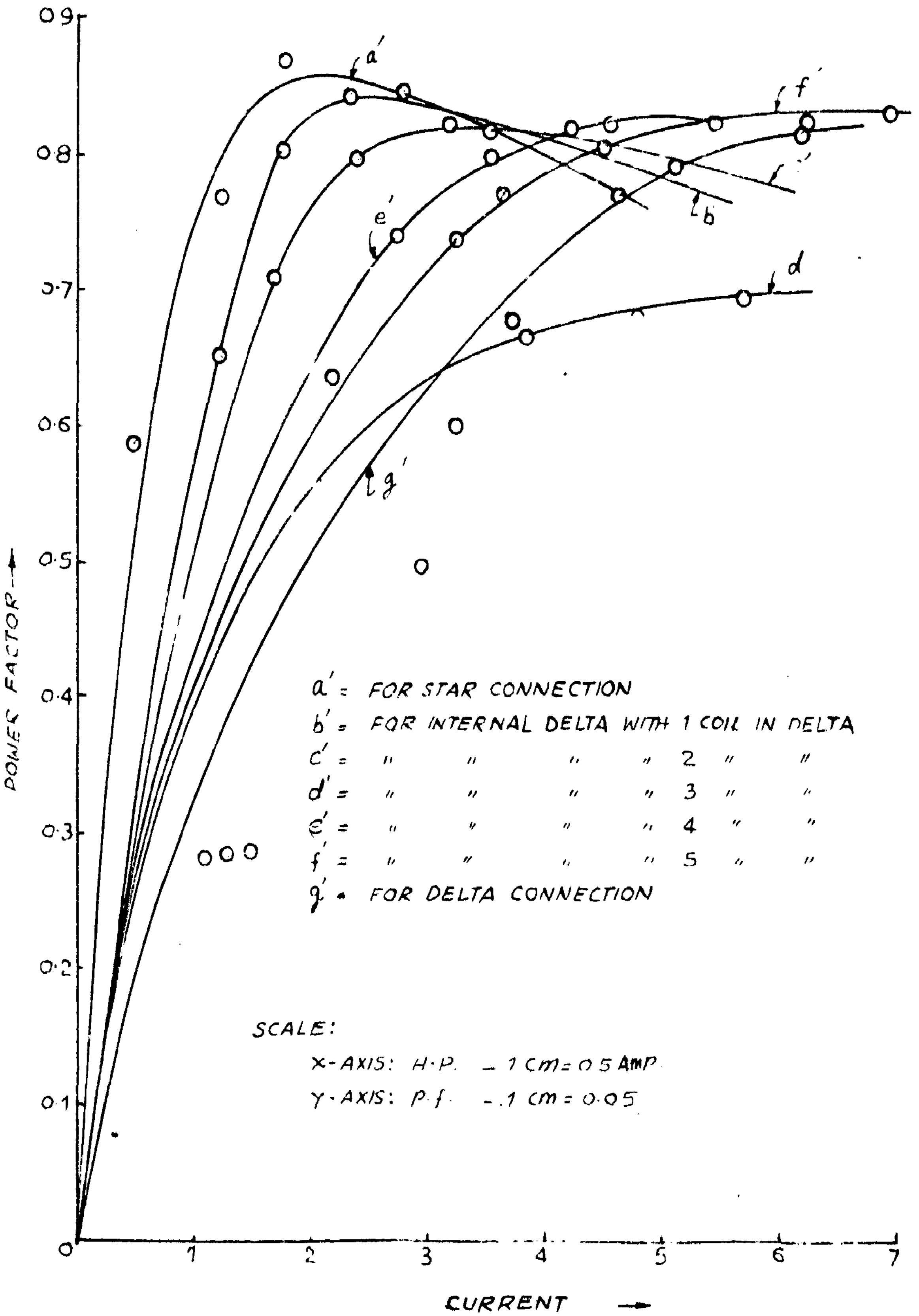
GRAPH NO. 13

LOAD TEST CURVE
FOR
6 POLE DELTA CONNECTED STATOR

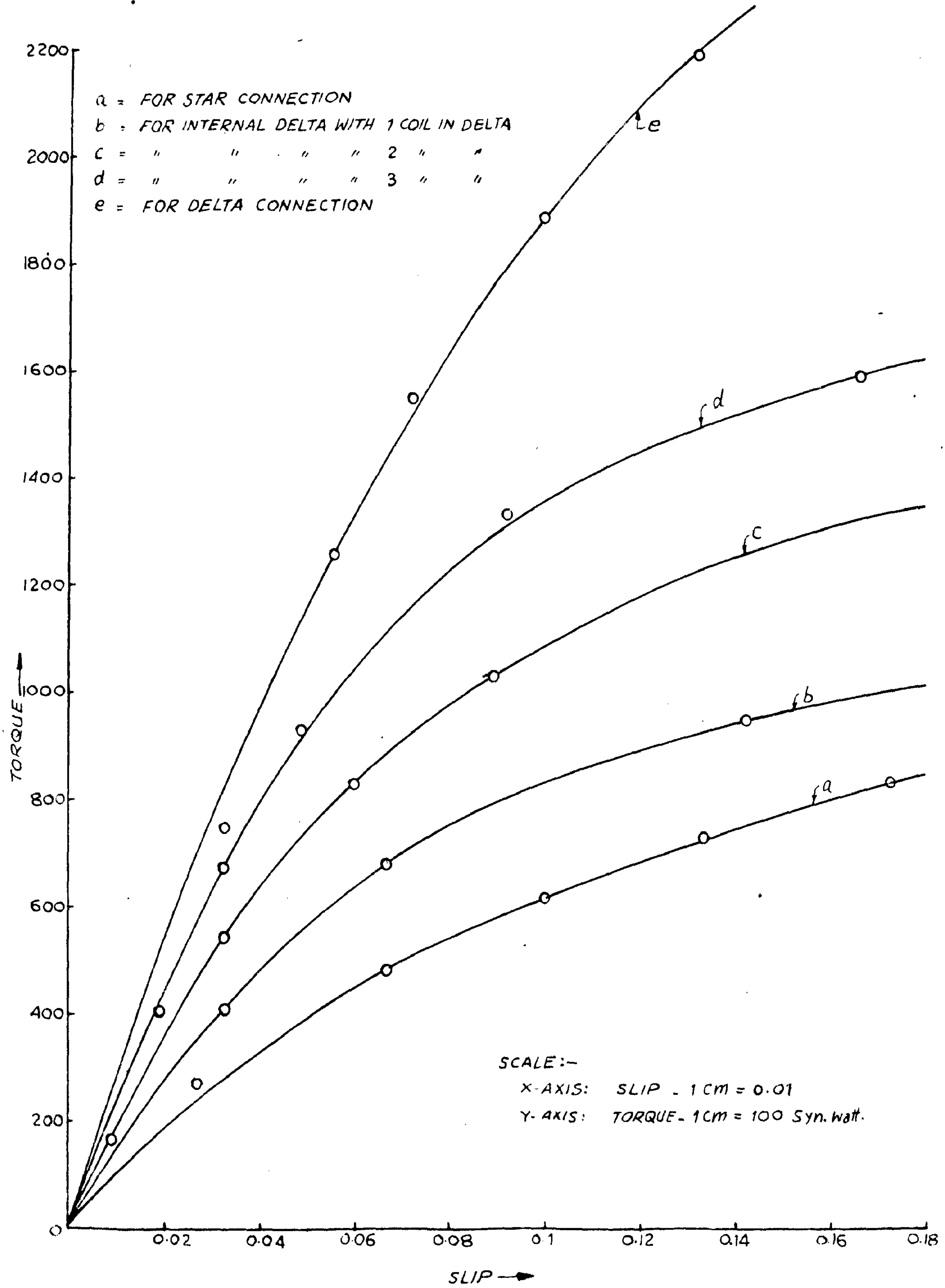


GRAPH NO. 14

CURRENT VS POWER FACTOR CURVES FOR 6-POLE WINDING

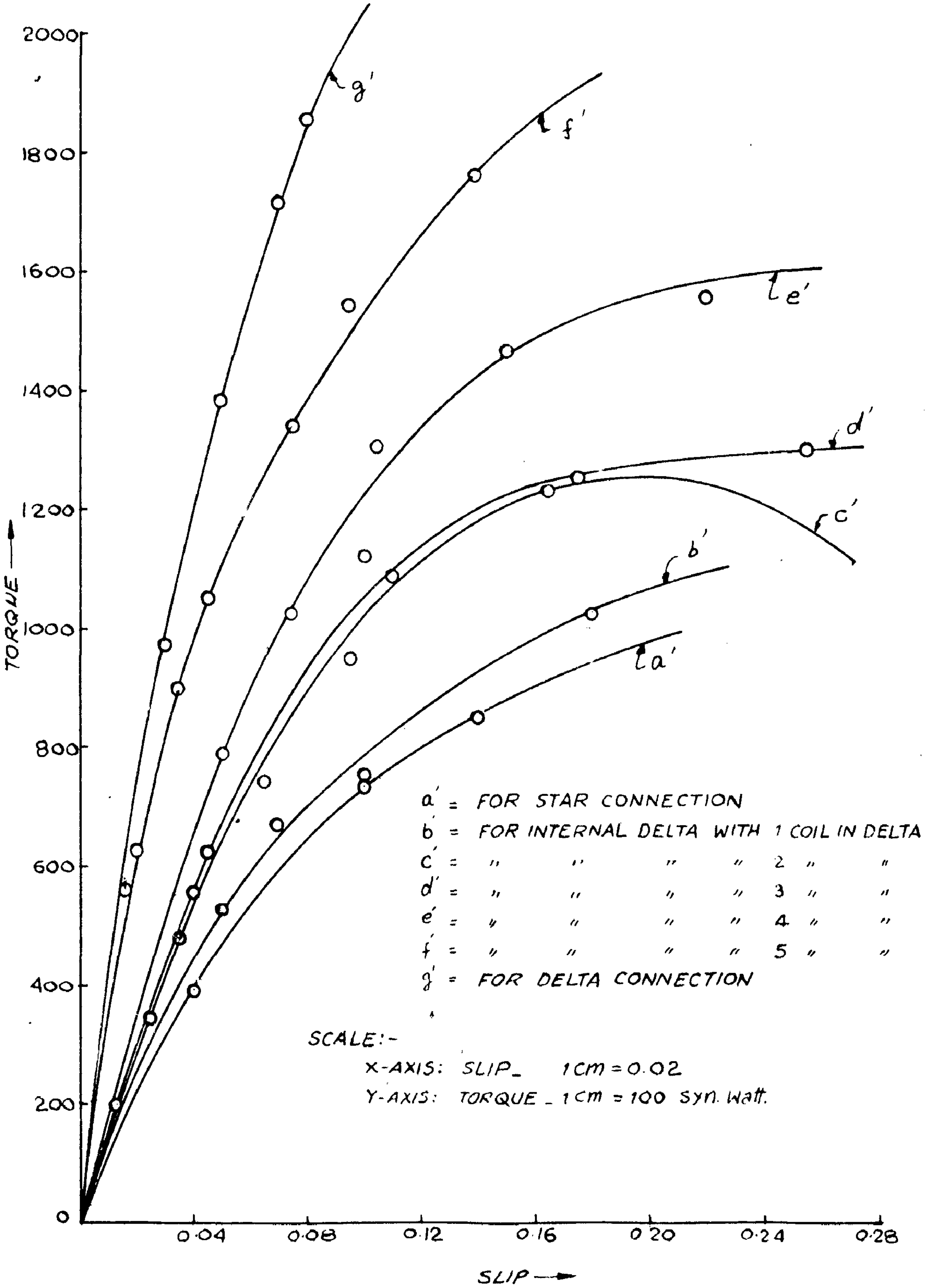


SLIP VS TORQUE CURVES FOR 4 POLE WINDING



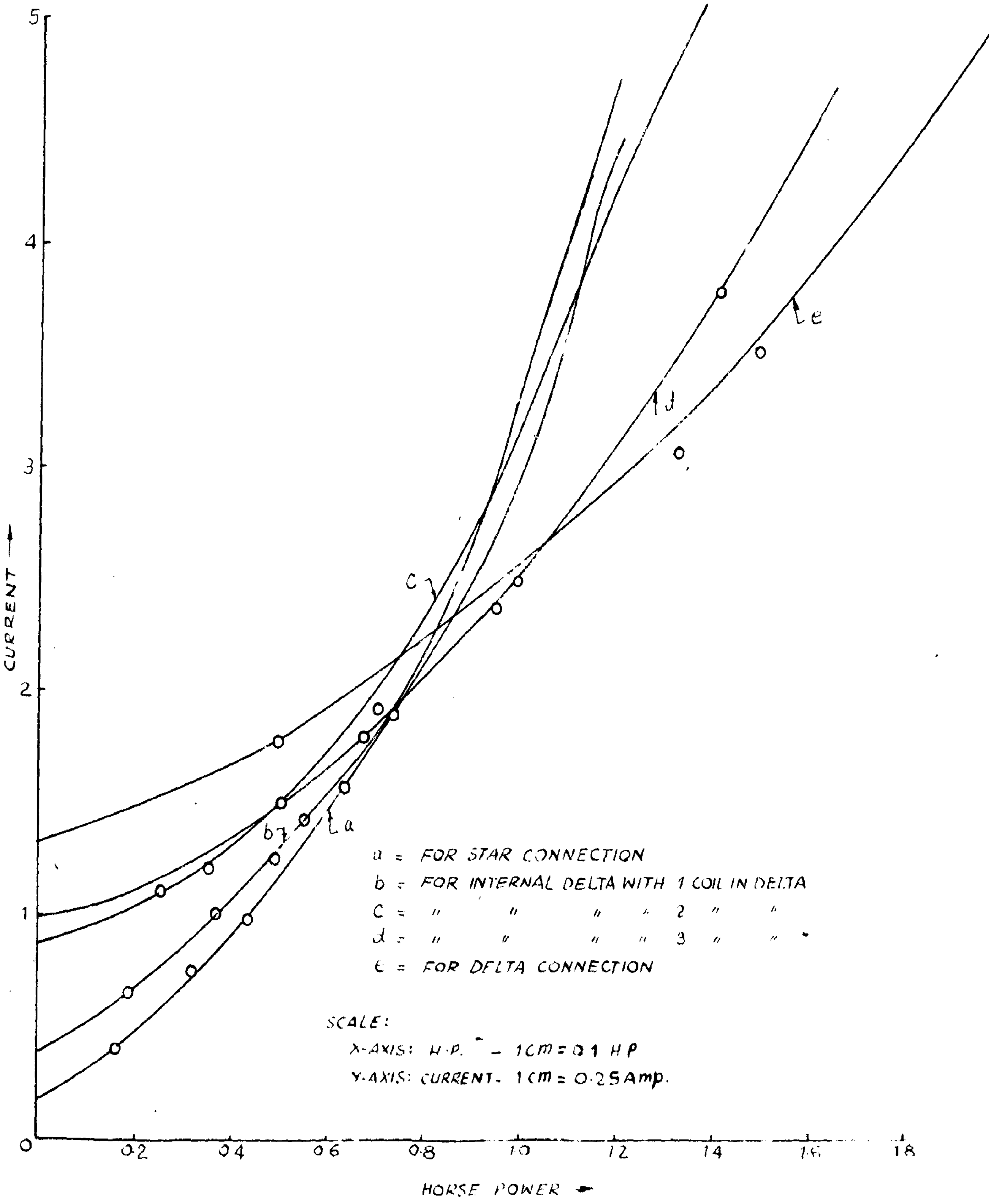
GRAPH No. 16

SLIP VS TORQUE CURVES FOR 6 POLE WINDING

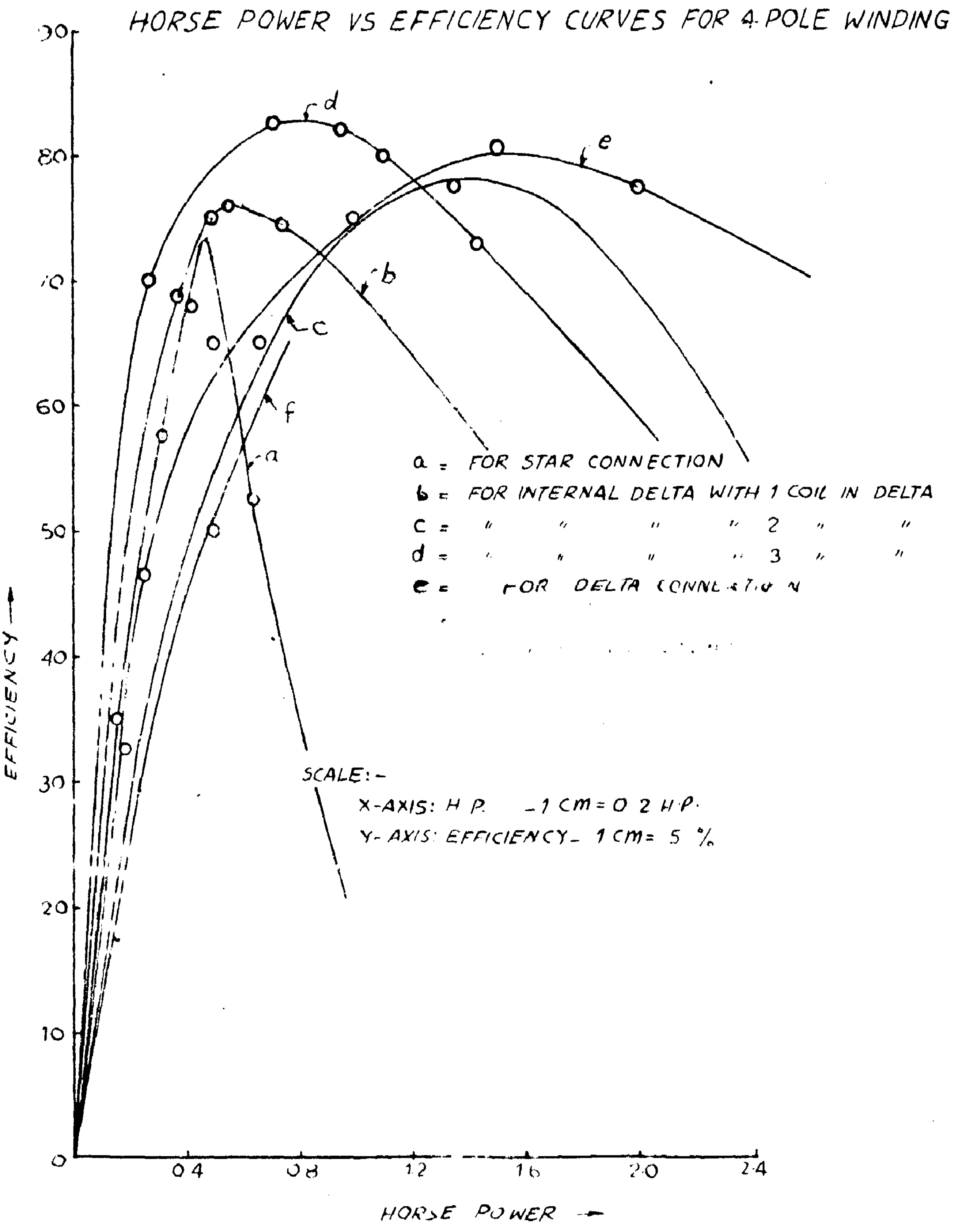


GRAPH NO. 17

HORSE POWER VS CURRENT CURVES FOR 4-POLE WINDING



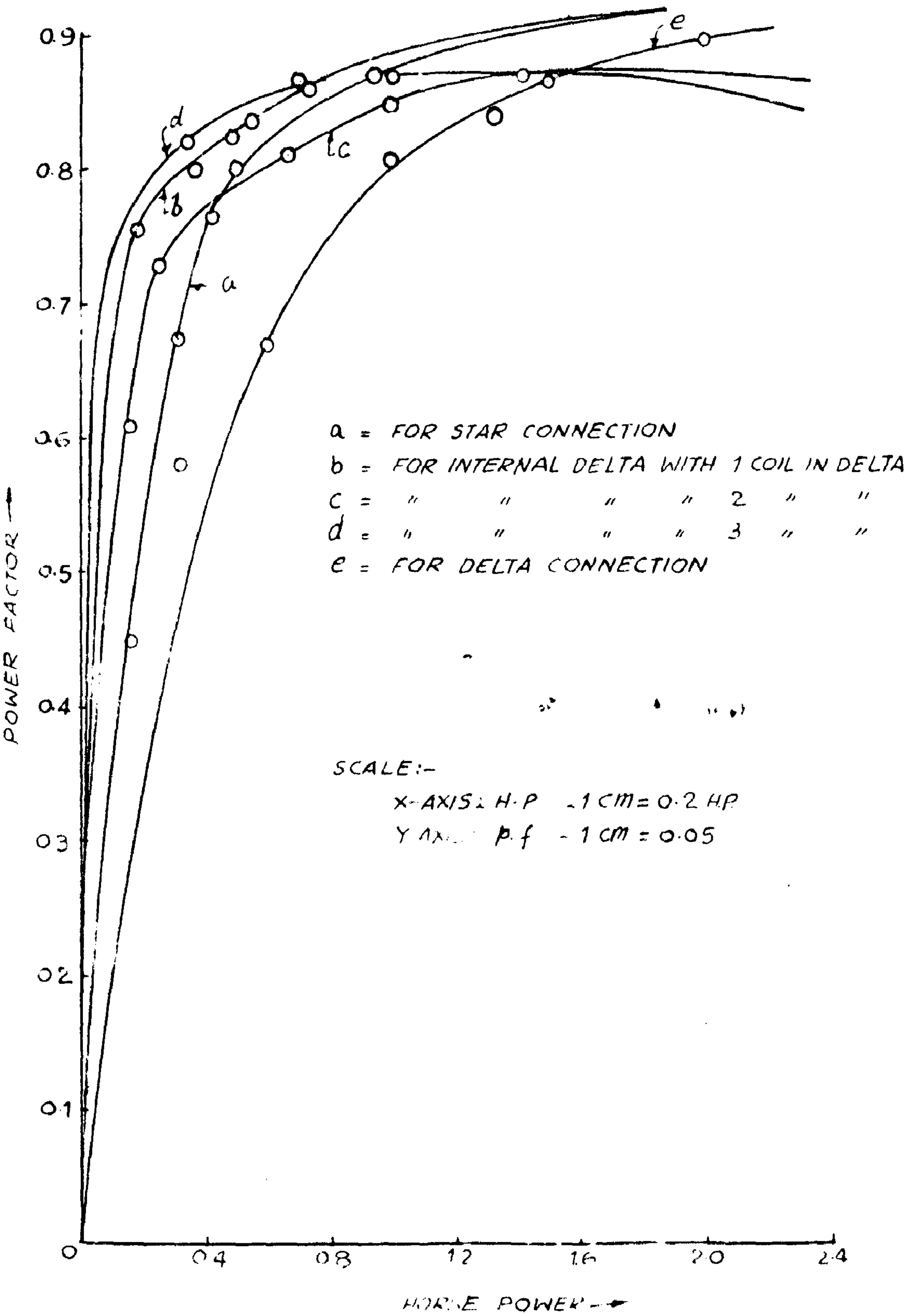
GRAPH No. 18



HORSE POWER VS EFFICIENCY CURVES FOR 4-POLE WINDING

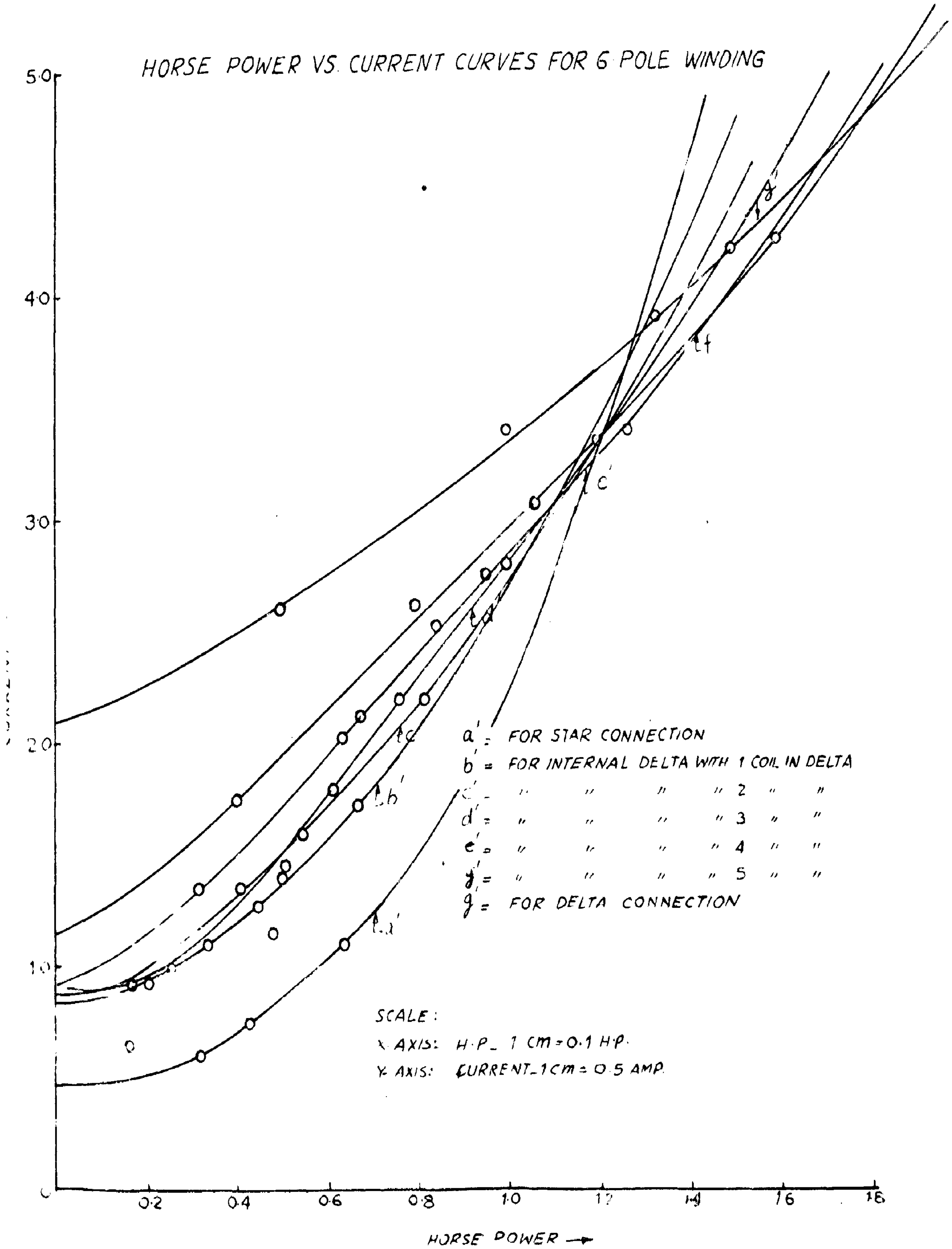
GRAPH No 19

HORSE POWER VS POWER FACTOR CURVES FOR 4-POLE WINDING



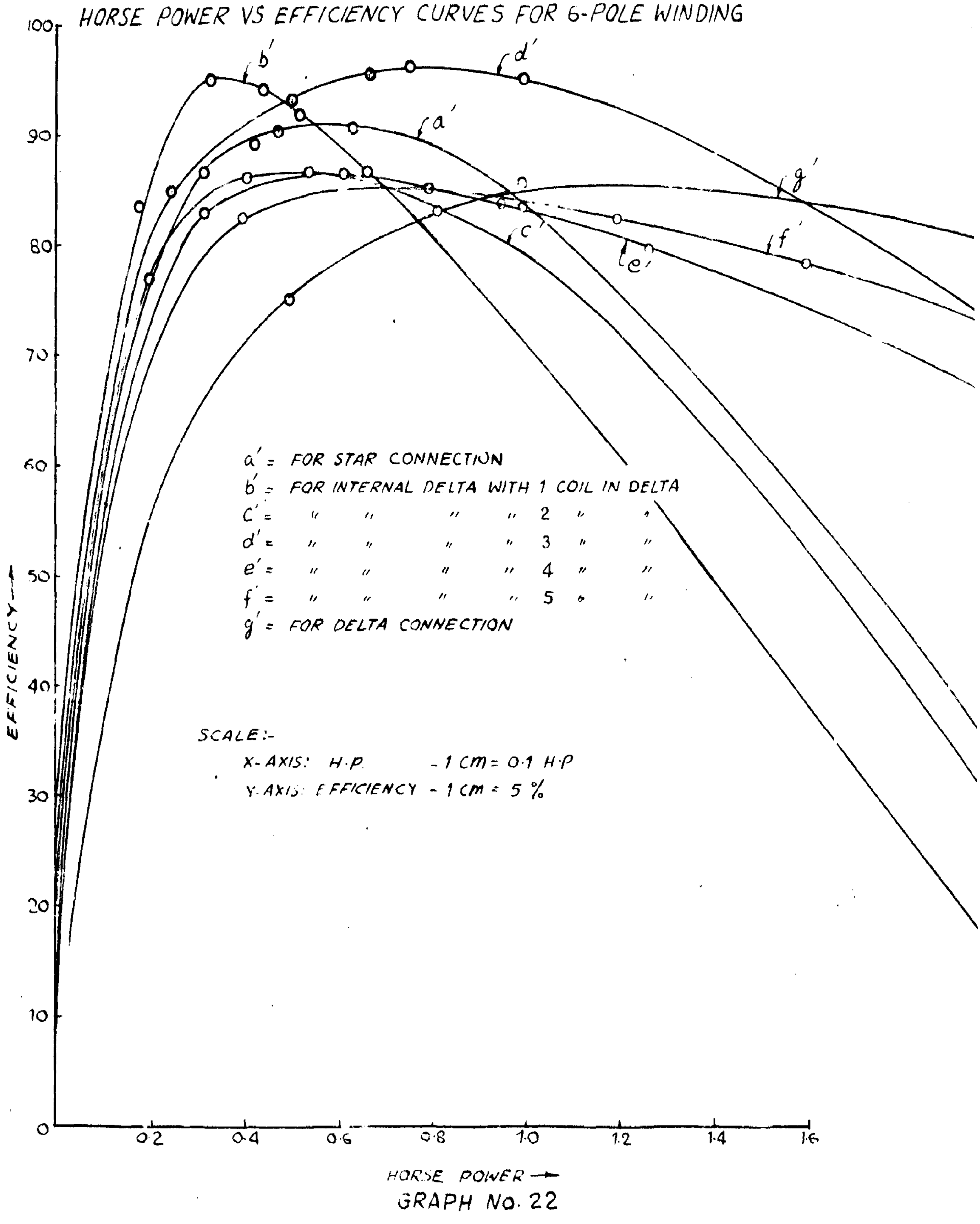
GRAPH No. 20

HORSE POWER VS. CURRENT CURVES FOR 6 POLE WINDING



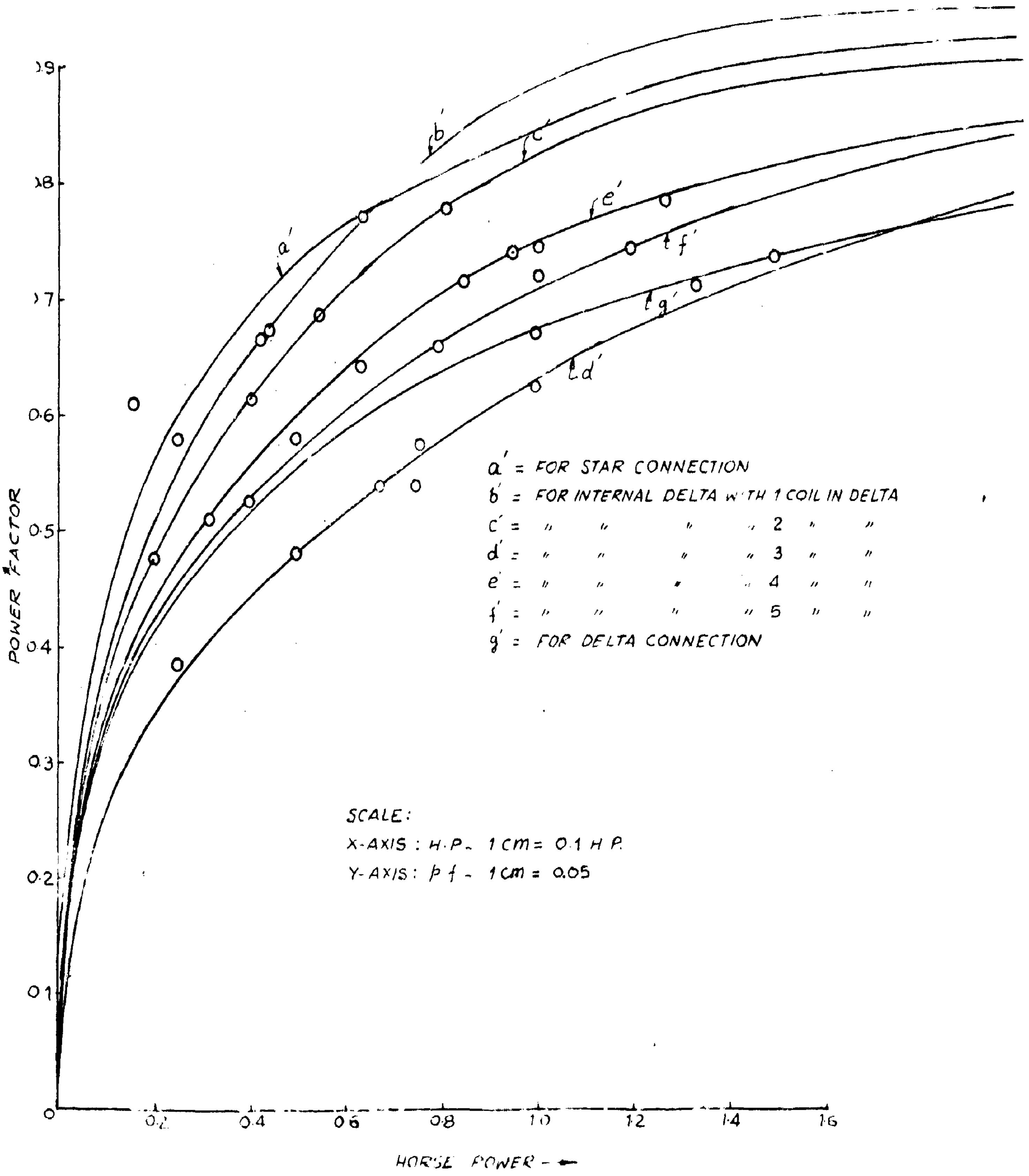
GRAPH No 21

HORSE POWER VS EFFICIENCY CURVES FOR 6-POLE WINDING



GRAPH No. 22

HORSE POWER VS POWER FACTOR CURVES FOR 6-POLE WINDING

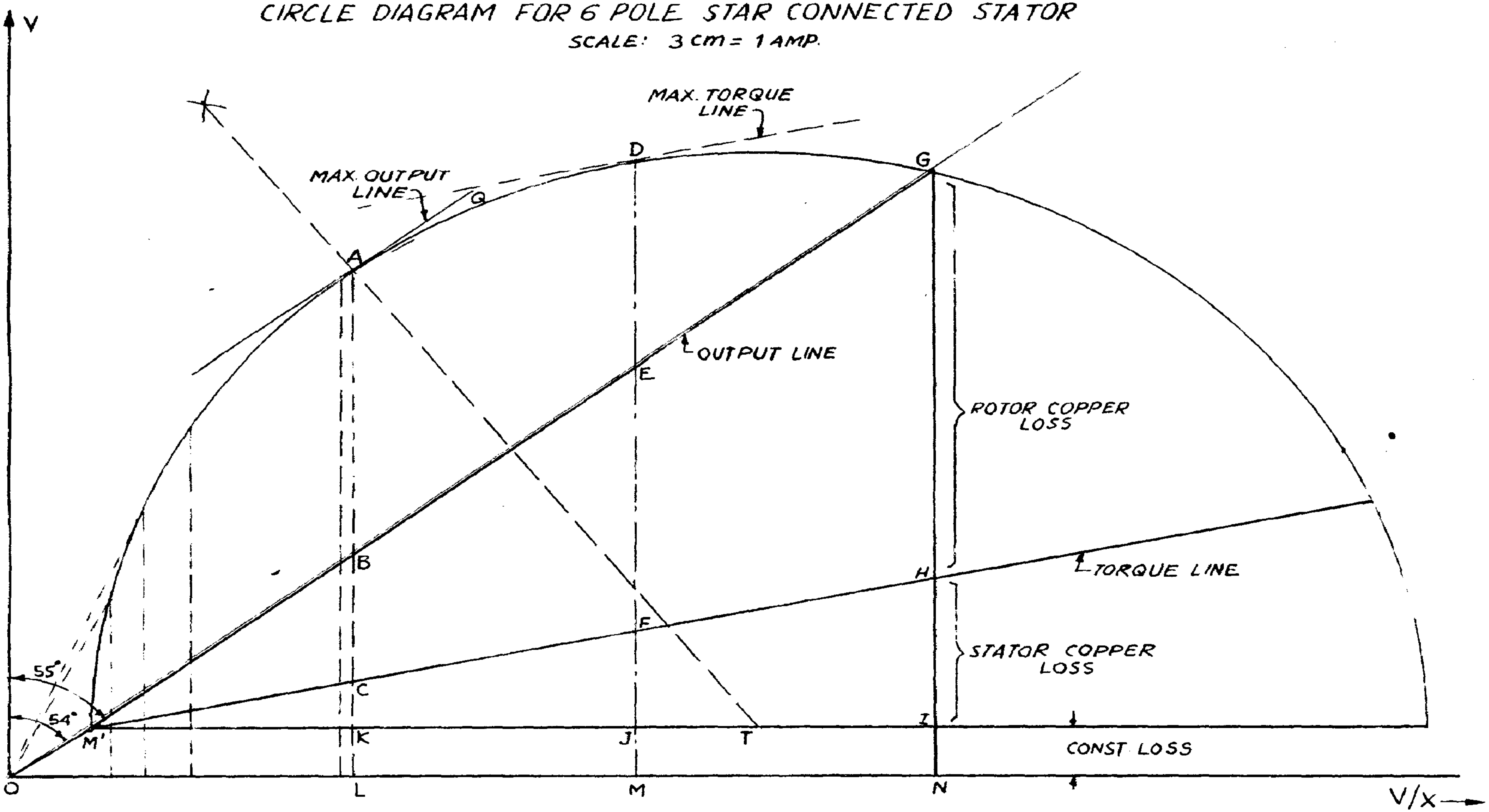


GRAPH No. 23

CIRCLE DIAGRAM No. 1

CIRCLE DIAGRAM FOR 6 POLE STAR CONNECTED STATOR

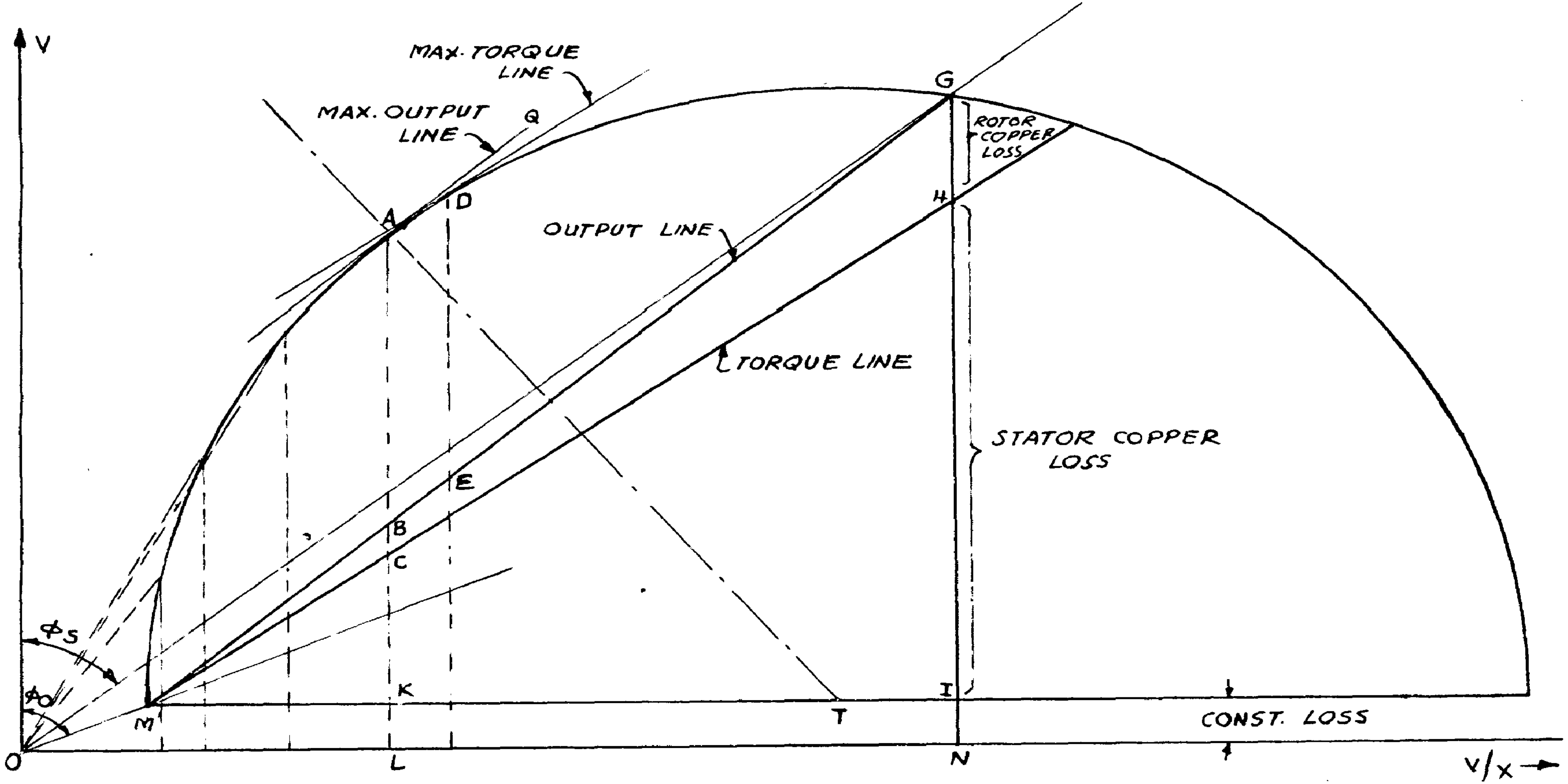
SCALE: 3 cm = 1 AMP.



CIRCLE DIAGRAM No. 2

CIRCLE DIAGRAM FOR 6 POLE INTERNAL DELTA WITH 1 COIL IN DELTA

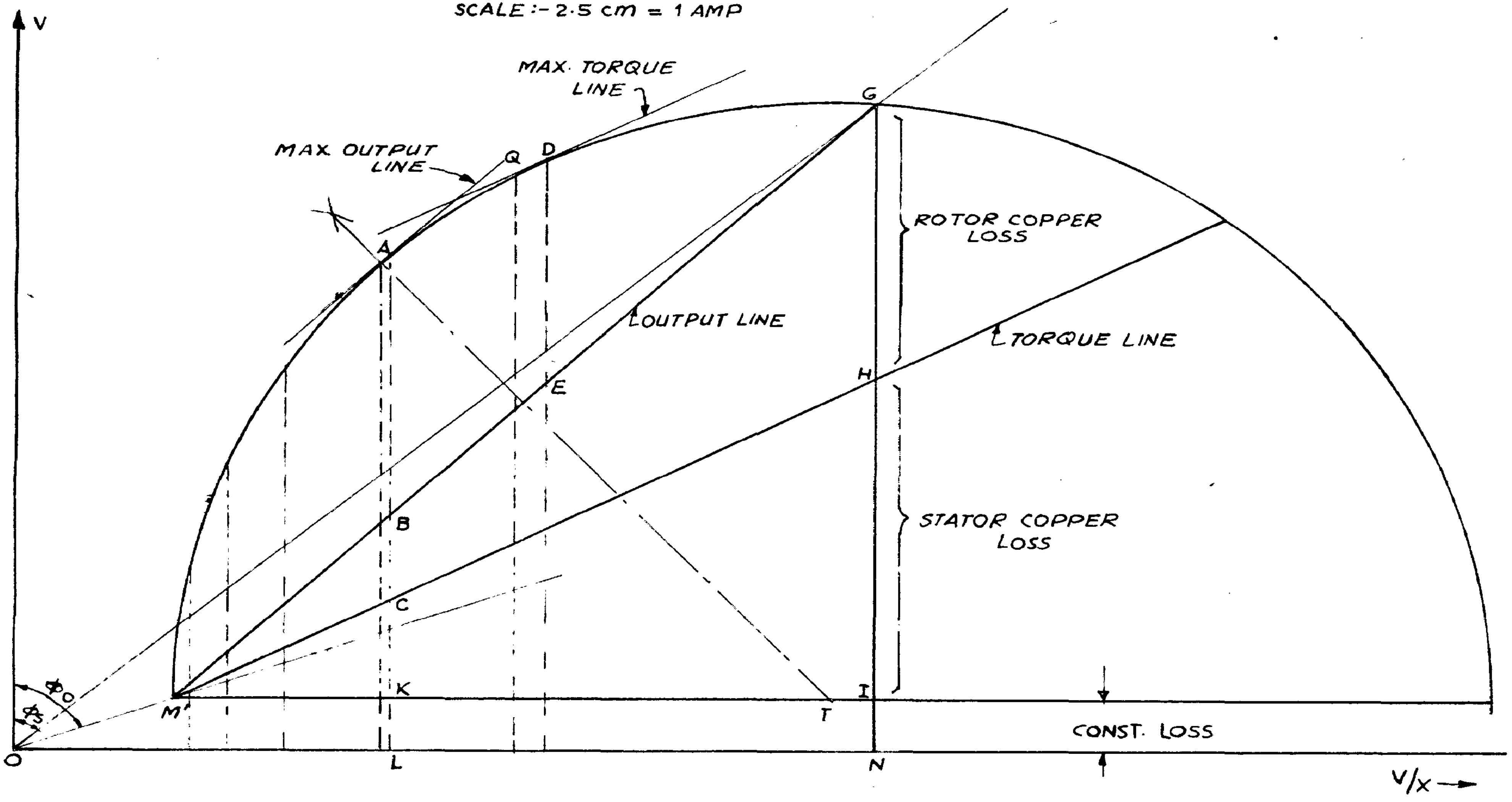
SCALE:- CURRENT- 2.5 CM = 1 AMP.



CIRCLE DIAGRAM No. 3

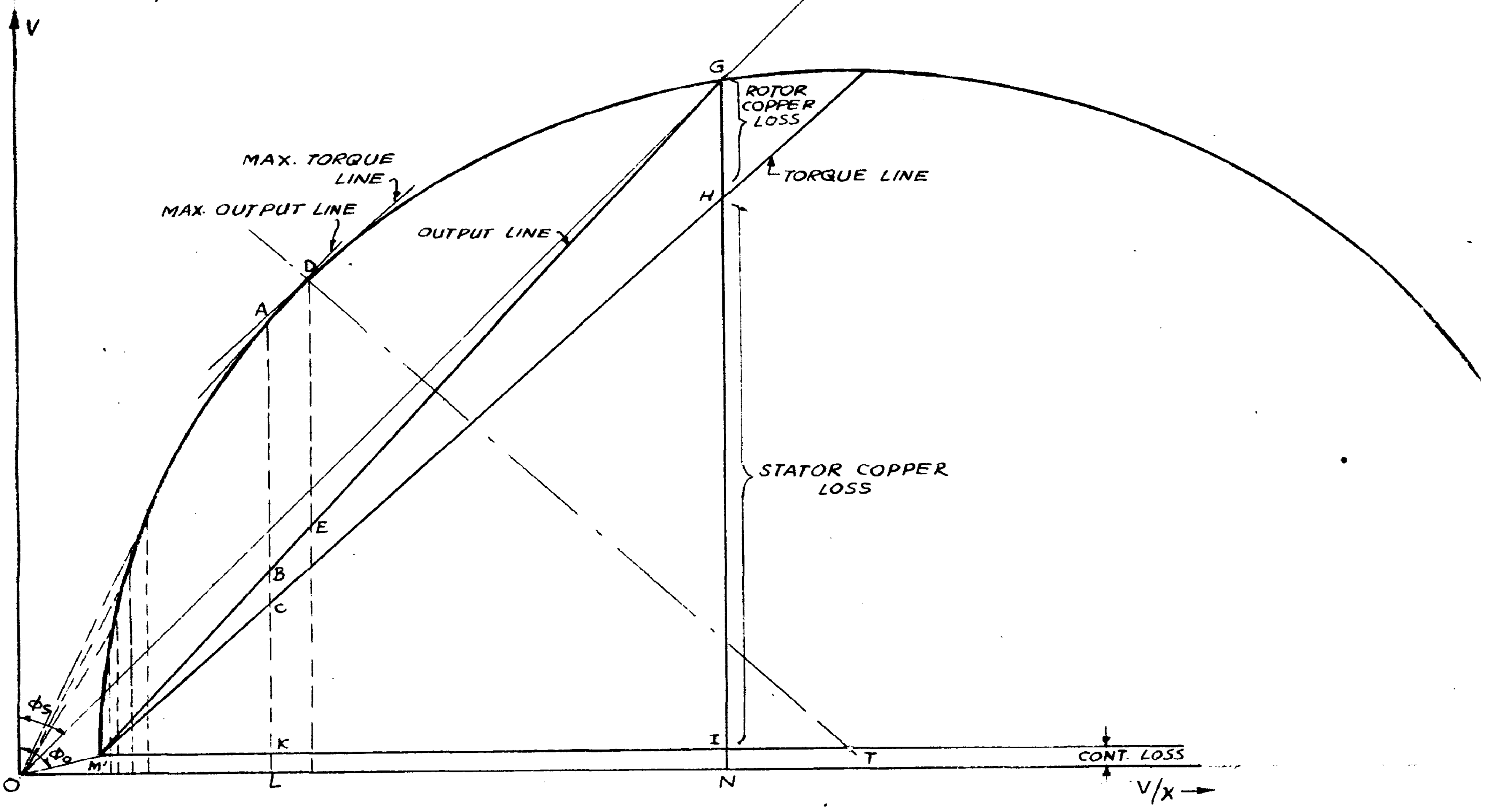
CIRCLE DIAGRAM FOR 6 POLE INTERNAL DELTA WITH 2 COIL IN DELTA

SCALE :- 2.5 cm = 1 AMP



CIRCLE DIAGRAM No. 4

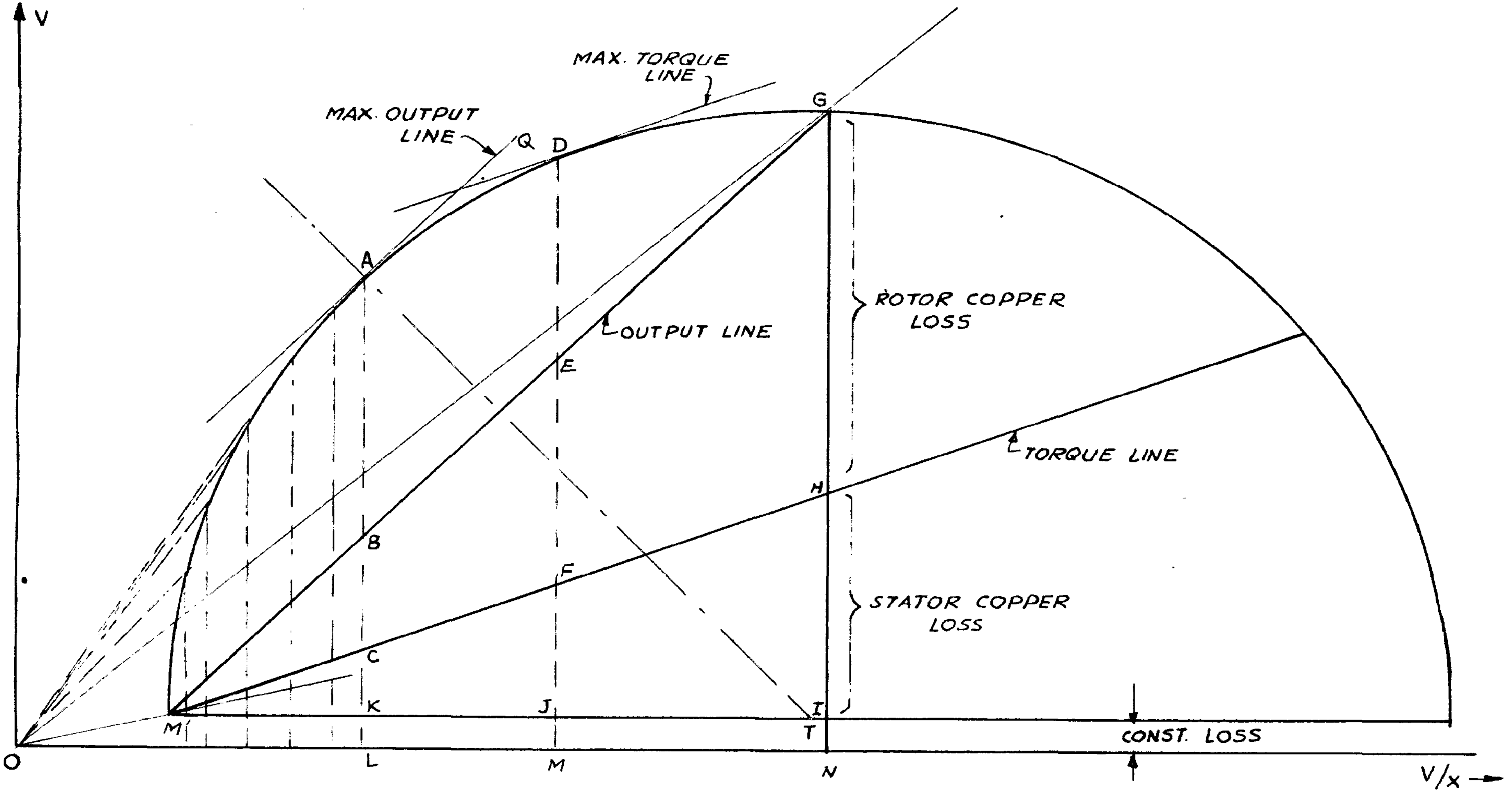
CIRCLE DIAGRAM FOR 4 POLE INTERNAL DELTA WITH 3 COIL IN DELTA



CIRCLE DIAGRAM No. 5

CIRCLE DIAGRAM FOR 6 POLE INTERNAL DELTA WITH 4 COIL IN DELTA

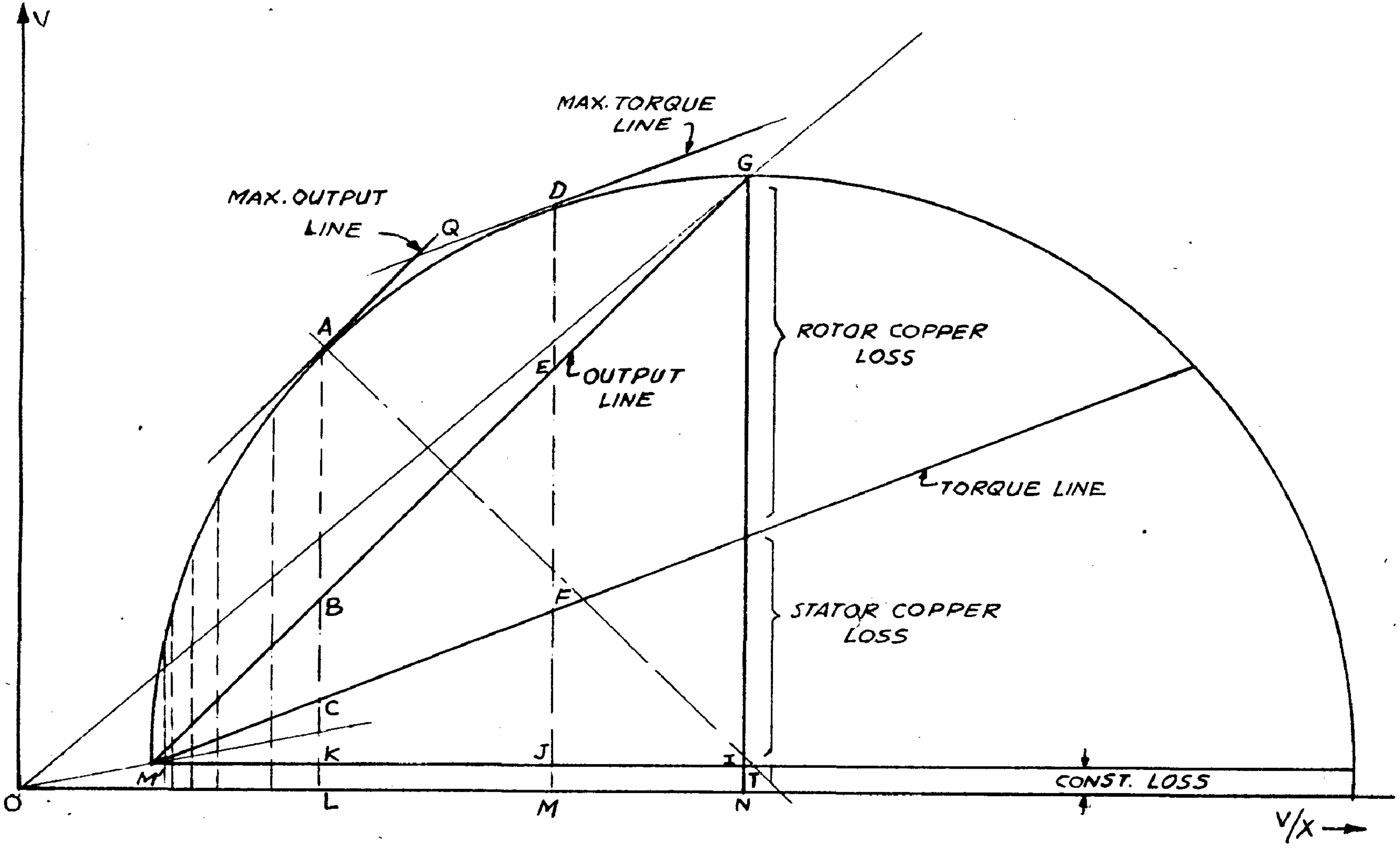
SCALE:-CURRENT 1·5cm = 1 AMP.



CIRCLE DIAGRAM NO. 6

CIRCLE DIAGRAM FOR 6 POLE INTERNAL DELTA WITH 5 COIL IN DELTA

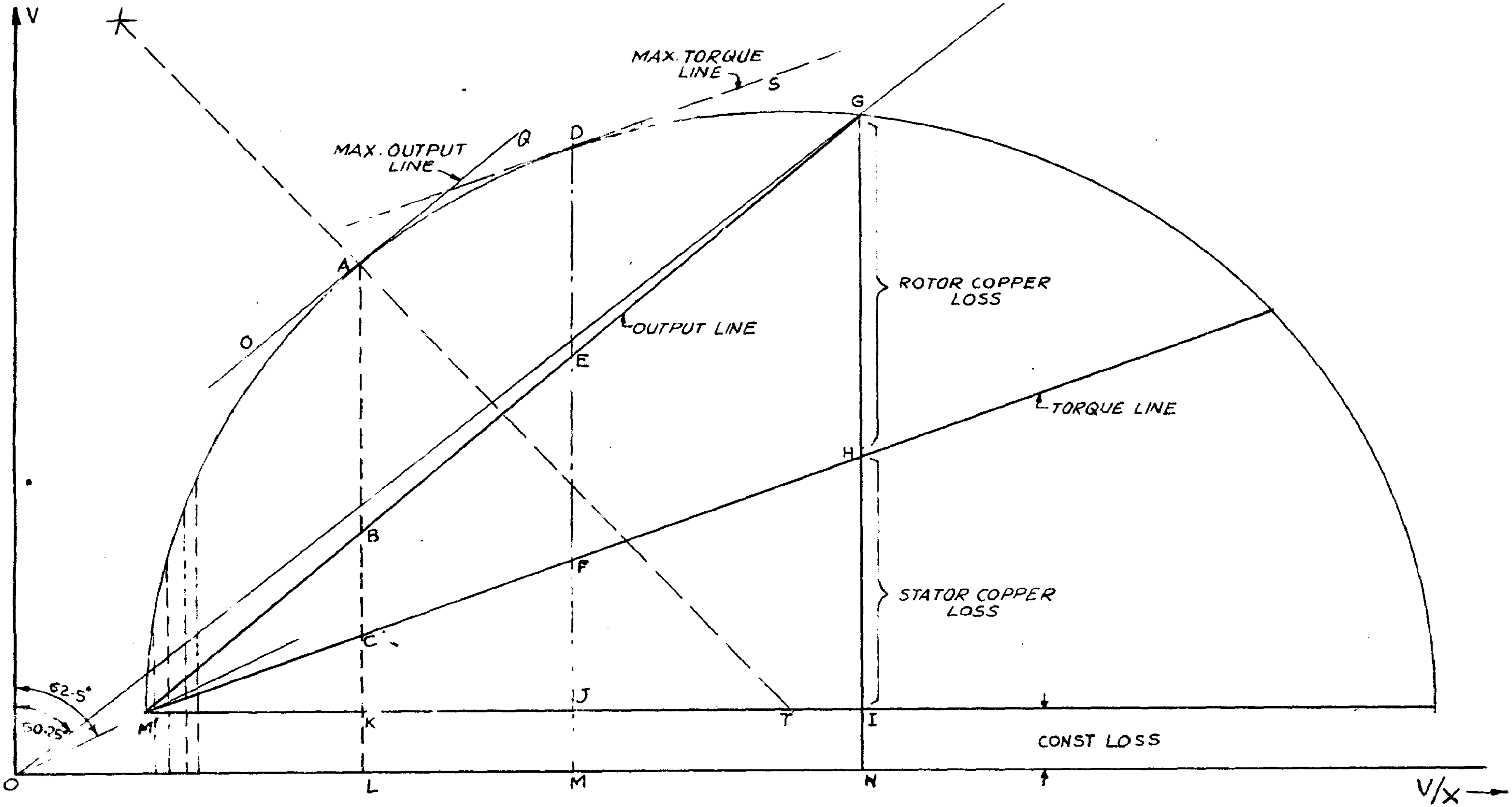
SCALE:- CURRENT - 1 CM = 1 AMP.



CIRCLE DIAGRAM No.7

CIRCLE DIAGRAM FOR 6 POLE DELTA CONNECTED STATOR

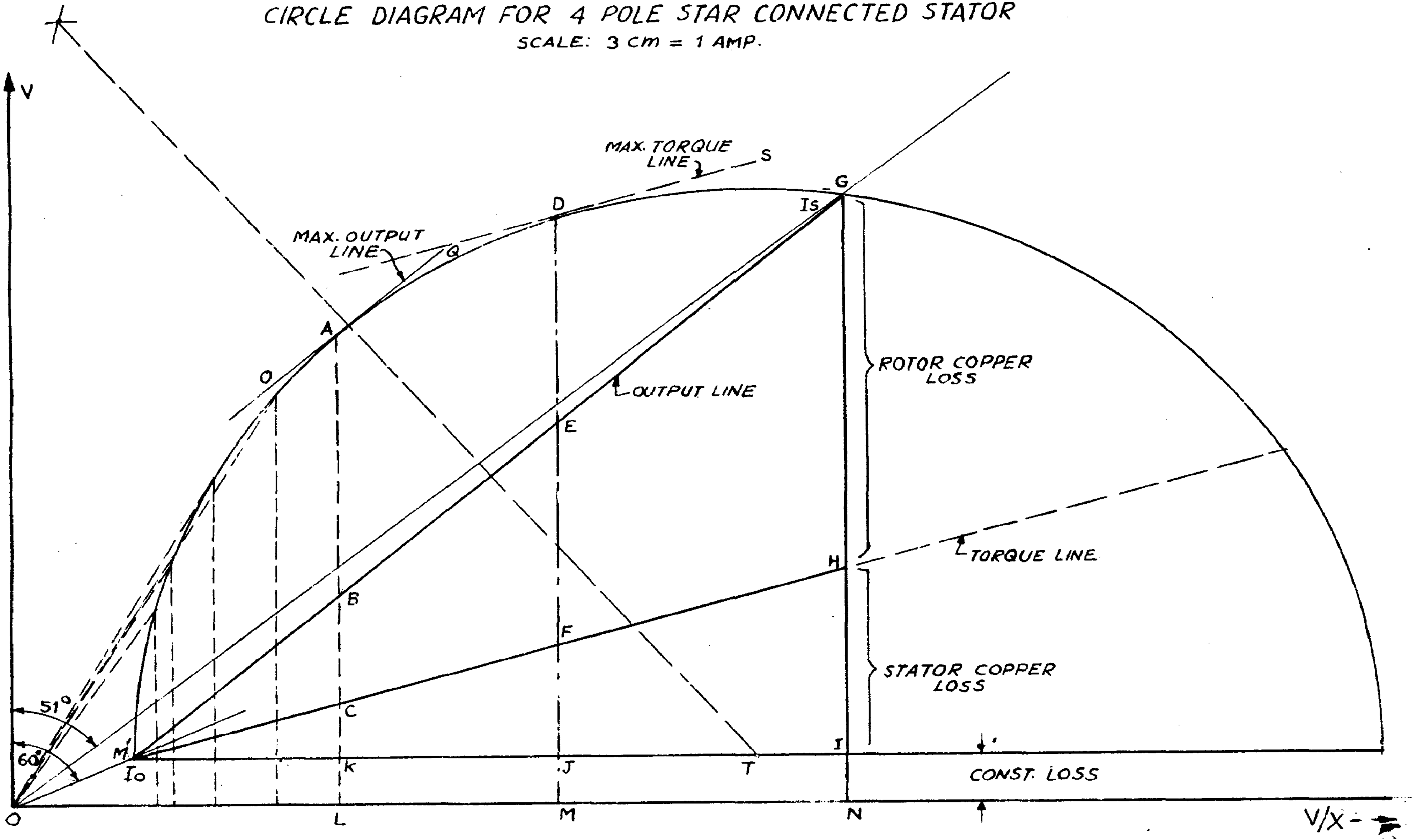
SCALE: 1 cm = 1 AMP



CIRCLE DIAGRAM No. 8

CIRCLE DIAGRAM FOR 4 POLE STAR CONNECTED STATOR

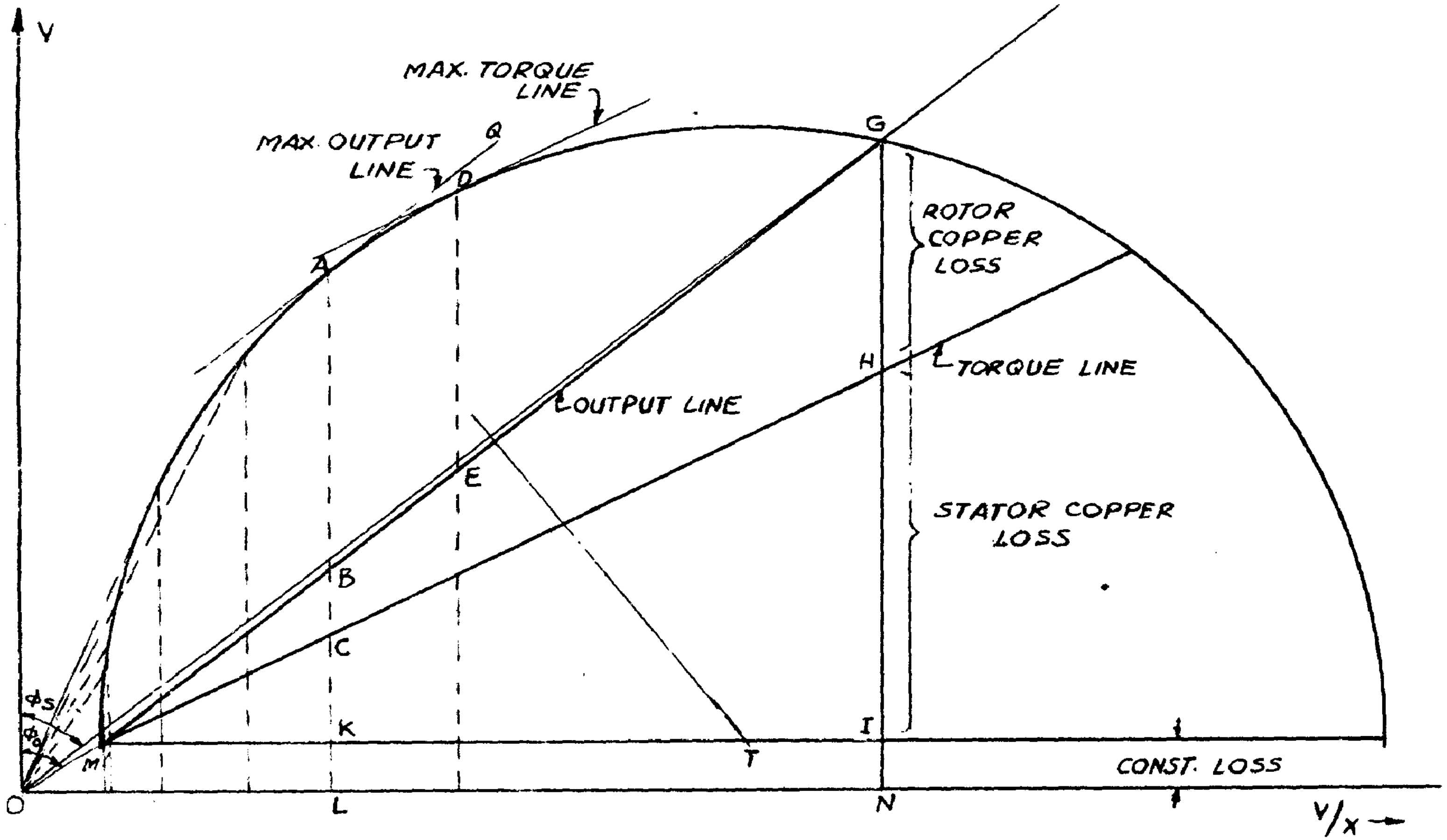
SCALE: 3 cm = 1 AMP.



CIRCLE DIAGRAM NO. 9

CIRCLE DIAGRAM FOR 4 POLE INTERNAL DELTA WITH 1 COIL IN DELTA

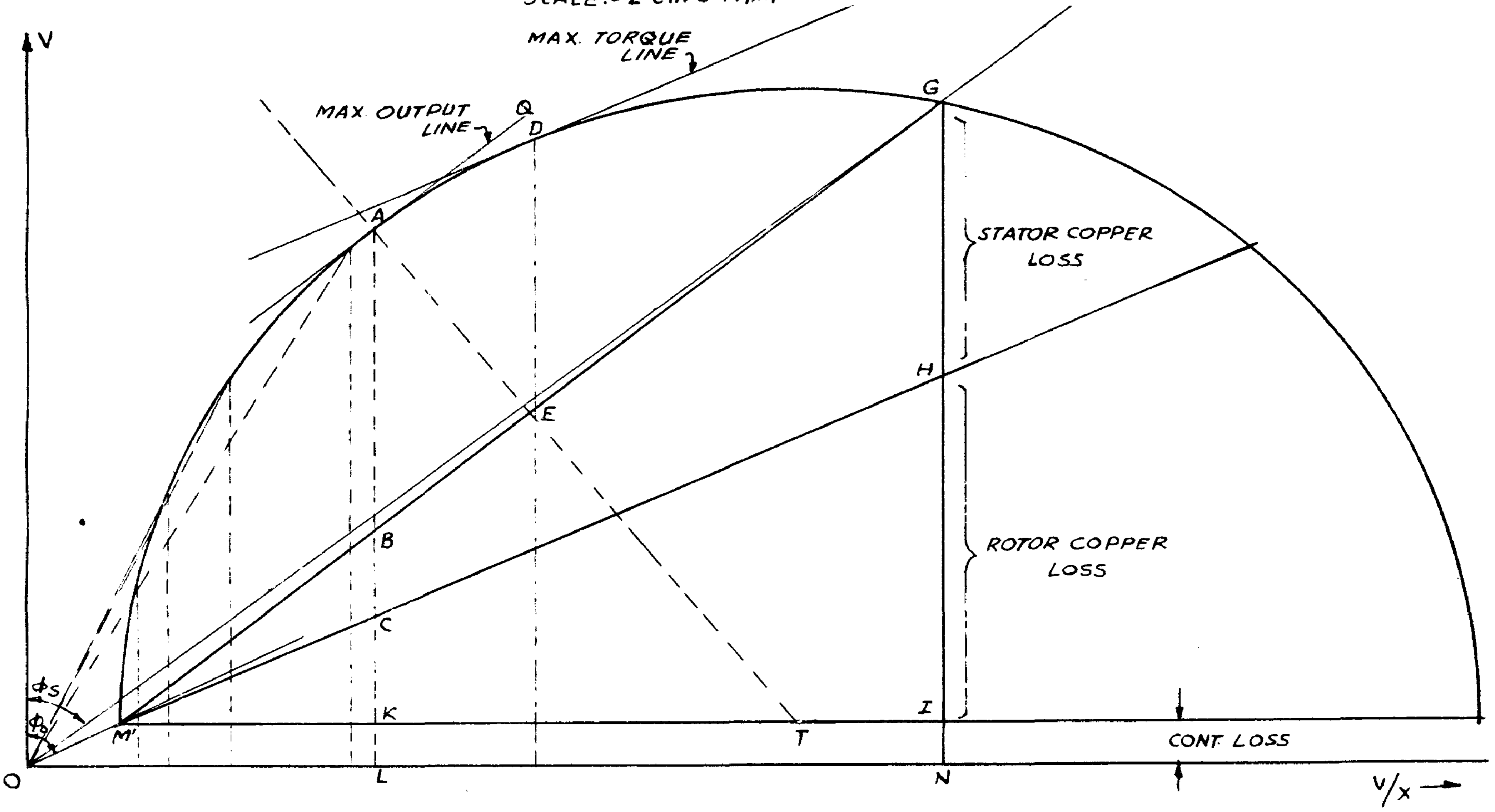
SCALE:- CURRENT- 2 cm = 1 AMP.



CIRCLE DIAGRAM No. 10

CIRCLE DIAGRAM FOR 4 POLE INTERNAL DELTA WITH 2 COIL IN DELTA

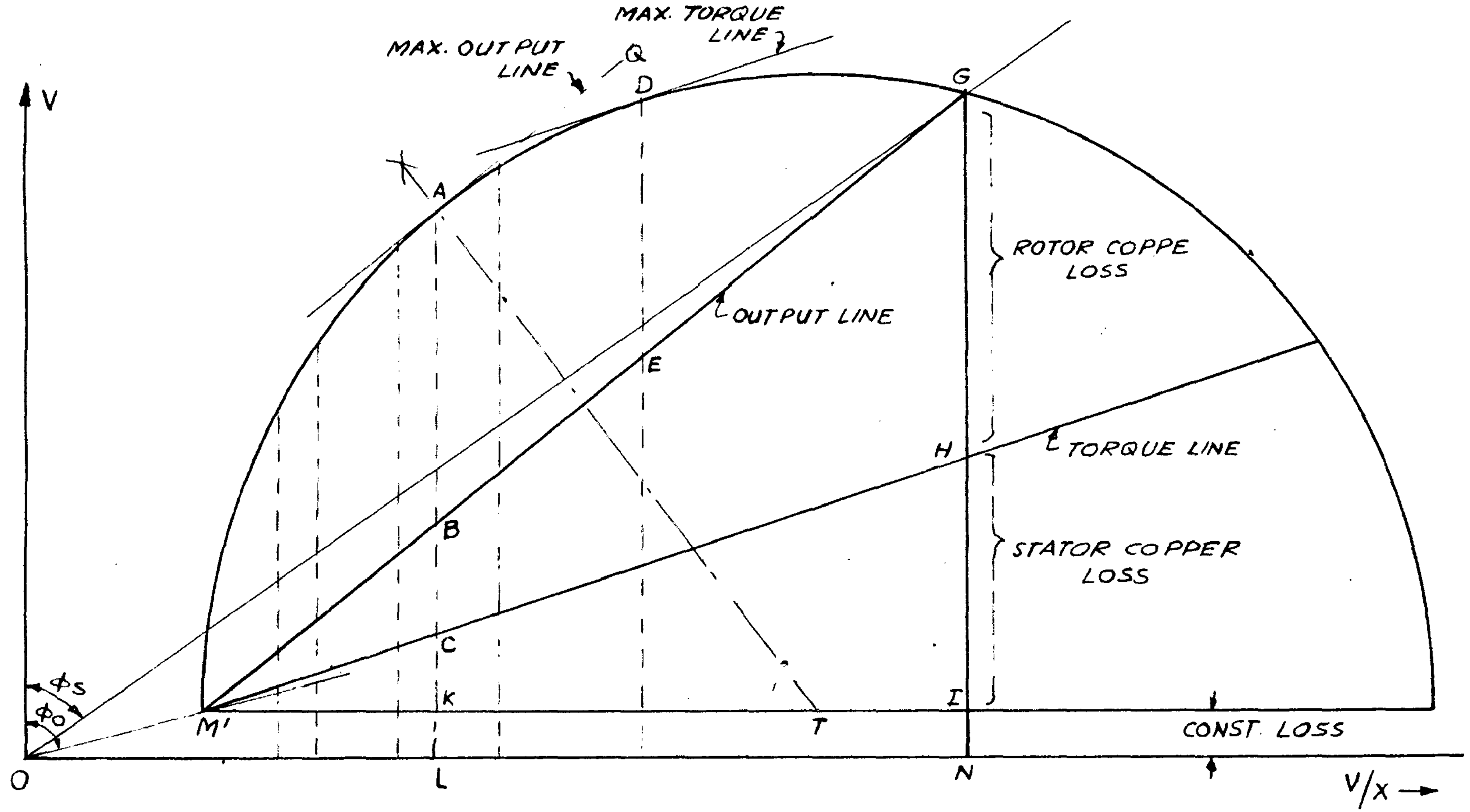
SCALE:- 2 Cm = 1 AMP



CIRCLE DIAGRAM No 11

CIRCLE DIAGRAM FOR 6 POLE INTERNAL DELTA WITH 3 COIL IN DELTA

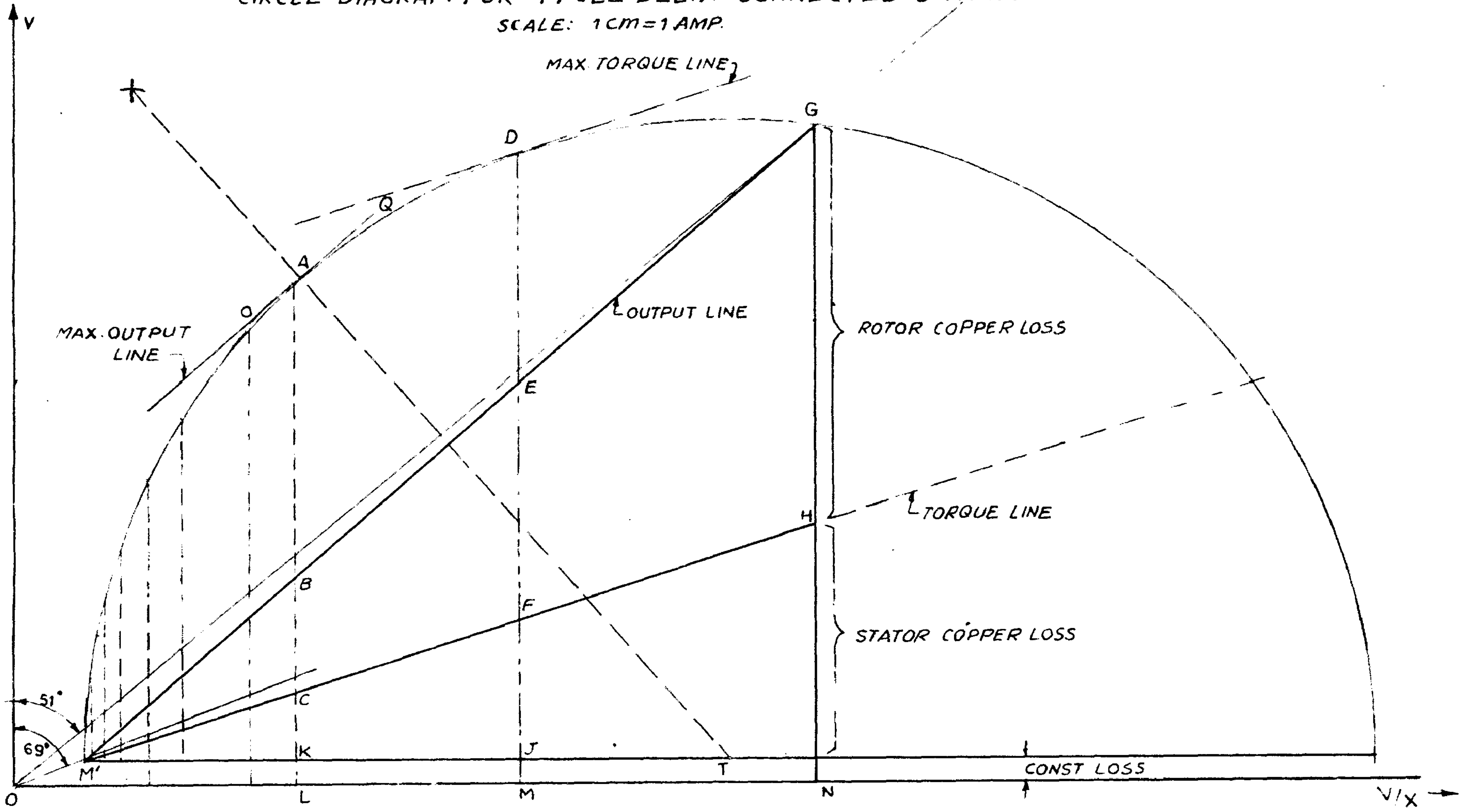
SCALE:- 2cm = 1 AMP



CIRCLE DIAGRAM NO. 12

CIRCLE DIAGRAM FOR 4 POLE DELTA CONNECTED STATOR

SCALE: 1 CM = 1 AMP.



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