T H E S I S

on

PERFORMANCE TEST OF AN INDUCTION MOTOR.

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PERFORMANCE TEST OF AN INDUCTION MOTOR.

The induction motor in its electromagnetic features is essentially a transformer, while in its general behavior it is analogous to the continious-current shunt wound motor. In a transformer the primary and secondary members are both stationary and electrical energy is transformed from one pressure to another by the ratio of the turns of the two members. In a motor the electrical energy is tranformed into mechanical energy by the action of the currents of the two members. The induction motor consists of a stationary member called the stator and the rotating member called the rotor.

The direction of rotation of a direct-current motor, either series or shunt wound, remains unchanged when the direction of the supply current is reversed. Thus any continious motor should operate also with alternating currents. If, however, they are operated on alternating currents the magnetic circuit as well as the armature must be made of laminated iron to avoid excessive heating due to eddy currents. Also the currents in the field and armature circuits must reverse simultaneously, since the shunt motor has the field circuit wound with many turns of fine wire, the current in that circuit lags nearly ninety degrees behind the current in the armature.

The large amount of inductance due to the field circuit winding does not permit the instantaneous reversal of the exciting field and consequently excessive sparking occurs at the brushes. However this can be entirely overcome by utilizing the alternating features of the current;that is,instead of leading the current into the armature by commutator and brushes,producing it thereinby electromagnetic induction,by closing thearmature conductors upon themselves and surrounding the armature by a primary coil at right angles to the field exciting coil. Going a step farther these two structures can be combined into one by having each of the two coils fulfill the double function of magnetizing the field and producing currents in the secondary,which are acted upon by the magnetization produced by the other phase. Also instead of using two phases any number of phases might be used.

Since these conductors were closed upon themselves it is readily seen that the rotor of the motor corresponds to the secondary of a transformer when it is short circuited.

In the first aplication of this principle a copper cylinder was used for the rotor and the next step was the introduction of slits running nearly the full length of the cylinder,or the rotor was simply built up of a number of copper bars joined together at the ends by rings. This method was developed by Dolrowolshy. However no attention was paid to the insulation of these bars from the iron core and consequently not enough current flowed along the bars to give the desired torque. This difficulty was overcome by building the iron core of laminated pieces and insulating the bars from the core.

This is the form of the rotor principally used in small induction motors. However there is a type of motor having a wire wound rotor for the purpose of varying the resistance and thus producing a high starting torque but the discussion in this paper deals only with the former or "squirrel cage"type of rotor.

So far very little has been said concerning the stationary part of the motor called the stator.

The core of the stator is built up of laminated iron punchings clamped together in a suitable frame. The winding of the stator is identically the same as that of the stator of a rotating field polyphase alternator. The winding is embedded in the iron core of the stator in closed slots thus reducing the amount of leakage reactance.

.The transformer feature of the induction motor predominates to such an extent thatin theoritical investigations it is best treated as a transformer.

The system of polyphase electromotive forces applied to the winding of the primary or stator of the motor,produces a rotating magnetic field. This rotating field produces currents in the short-circuited winding of the rotor, and by its action on these currents drags along the secondary conductors,and this speeds up the armature and tends to bring it up to synchronism,that is,to the same speed of the rotating field,at which speed the secondary currents would dissapear by the armature conductors moving together with the rotating field,and thus cutting no lines of force.

If,however,the rotor should revolve with the same speed as the rotating field no lines of force would be cut,no currents would be produced in the short-circuited rotor, no torque would result and the friction of the rotor would cause a decrease in speed. The secondary or rotor therefore slips in speed behind the speed of the rotating field by as much as is required to produce the secondary currents and give the torque neccessary to carry the load. The slip of the induction motor thus increases with increase of load and is approximately thereto. Inversely,if the rotor is driven at a higher speed than that of the rotatingfield, the field drags the conductors back,that is,consumes mechanical torque,and the machine then acts as a brake or induction generator.

A word might here be said regarding the frequency of the currents in the rotor. If the rotor were turned in the opposite direction to that of the rotating field the frequency would be greater than that of the currents supplied to the stator. If the rotor were at a standstill the frequency would be the same and as the rotor accelerates in speed the periodicity becomes less and less until full synchronous speed is reached,when the frequency is zero.

In the polyphase induction motor this magnetic field is produced by a number of electric circuits relatively displaced in space,and excited by currents having the same displacement in phase as the exciting coils have in space

As is readily seen,a heavy starting torque can only be secured by having a great amount of resistance the short-circuited winding of the rotor, and this is not desirable when the motor is operating at full load.. Consequently the usual form of constant speed induction motor has only an average starting torque. It is seen that an induction motor does not run at absolutely at constant speed. If a heavy starting torque were never needed the speed could be made very nearly constant, but the average starting torque required of a motor is above that required at full load..

The induction motor can be used for more purposes than any other motor on the market. It is neat, light, and compact having no moving parts except the rotor which is self contained, and it operates successfully in places where there is so much dirt that other motors would soon be ruined. It has no commutator and conseq-uently the fire risk caused by its use is eliminated. It is simple to operate, requiring no attention except in its starting and stopping. The simplicity of its design makes it very easy to construct and thus reduces the cost..

PERFORMANCE TEST.

The performance test of an induction motor is most easily judged by means of a set of load curves. All the data are plotted to kilowatts out-put as abcissae. The most important of the curves are those of efficiency, power factor, speed, and torqué.

The machine under test was a Weatinghouse three phase induction motor;developing 10 horse power,at 110 volts,frequency 60 cycles,speed at full load 1120 revolutions per minute. The rotor was of the "squirrel cage" type.

The above mentioned curves can be taken fron a brake or load test. However such a test is hard to make on an induction motor besides it involves a great waste of elictrical energy. For this reason a method has been found whereby these curves may be calculated from data taken from the motor withuot loading it. The tests necessary to obtain this data are three,namely,the resistance of the windings,the no-load charachteristic,and the short-circuit charachteristic.

METHOD OF MAKING TESTS.

The resistance of the windings can be obtained by what is known as the drop off potential method using direct current. Two terminals of the windings are connected up to a source of direct current. Have in series with the winding a suitable rheostat,and an ammeter. Attach the leads of a voltmeter across the terminals ofthe coil. Allow a moderate current to flow and at the same time take readings of Volts and Amperes. The resistance is found from the equasion R equals E/I where R is the resistance in olms E is volts and I is Amperes. Make three combinations of tests thus,between leads 1 - 2, 1 - 3, 2 - 3,taking the average of several readings.If the winding of the motor is Y connected the resistance thus obtained will be the combined resistance of the two coils and must be divided by two to obtain the resistance per coil.

Phase	Volts	Amps.	Res.	Average R.
1-3	4	40	.10	
1-3	3.5	36	.097	.099
1-3	2.0	20	.100	
1-2	4.2	44	.095	
1-2	3.8	39	.098	.097
1-2	3.0	30	.100	
2-3	4.0	40	.100	.100
2-3	3.2	32	.100	

Average Resistance per coil, is .05 ohms.

The above data was obtained experimentally for use in the calculation of the resistance of the windings.

NO-LOAD CHARACHTERISTIC.

Before making the test the motor should be allowed to run idle for about thirty minutes in order that the bearings may become well lubricated. The instruments necessary for the polyprhase board are, a voltmeter, ammeter, wattmeter and polyphase board.

The impressed electromotive force should be raised to about 50% above the rated voltage and reduced in steps, taking readings for the different steps. In makingthe test the two wattmeter method was used on the assumption that one wire acts as the common returnwire for the currents flowing in the other two. The follow-ing data were obtained as the result of the experiment.

Volts		Amperes		Watts		Total
Phase		Phase		Phase		Watts
A	B	A	B	A	B	A B
150	151	9.6	9.6	-80	500	420
140	140	8.8	8.8	-65	440	375
131	130	8.0	8.0	-50	390	340
125	125	7.7	7.8	-40	360	320
120	121	7.2	7.0	-38	340	302
110	101	6.7	6.7	0	273	273
95	98	6.4	6.6	0	245	245
81	80	5.8	5.8	29	235	235
70	70	5.3	5.3	43	185	214
65	65	5.1	5.1	50	160	203
55	55	4.8	4.8	60	150	200
38	40	4.4	4.5	72	135	192

The columns headed Volts are the readings of voltage between the two mains and the neutral wire. The readings in the column of Amperes are the values of current flowing in the two mains. The readings in the column headed watts are the readings of the wattmeter of the power delivered over each of themains. As the power factor of the induction motor is usually below 50% when running at no-load the wattmeter reading in one main is reversed with respect to that in the other main and consequently the smaller reading must be subtracted from thelarger to obtain the total power delivered to the motor. At voltages below 50% of the rated supply voltage the wattmeter readings are not reversed and the two readings must be added to obtain the total power delivered.

SHORT-CIRCUIT TEST.

This test is performed in exactly the same way as the no-load test with the exception that the rotor must be blocked to prevent turning. Care must be exercised in making this test that an excessive current is not allowed to flow through the windings as the current which the motor will take at standstill is several times theamount it will take when running at full load.

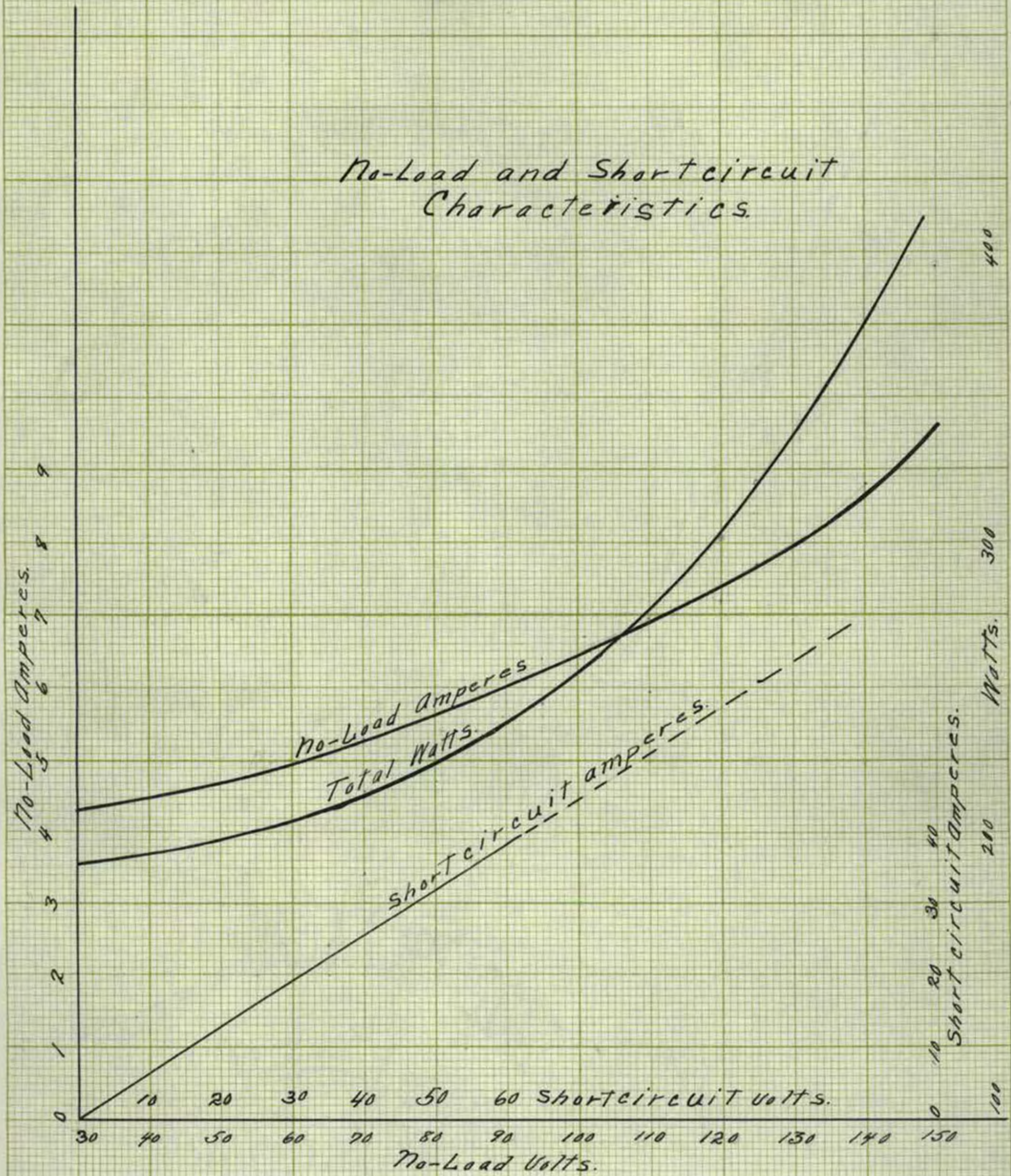
DATA FOR SHORT-CIRCUIT TEST.

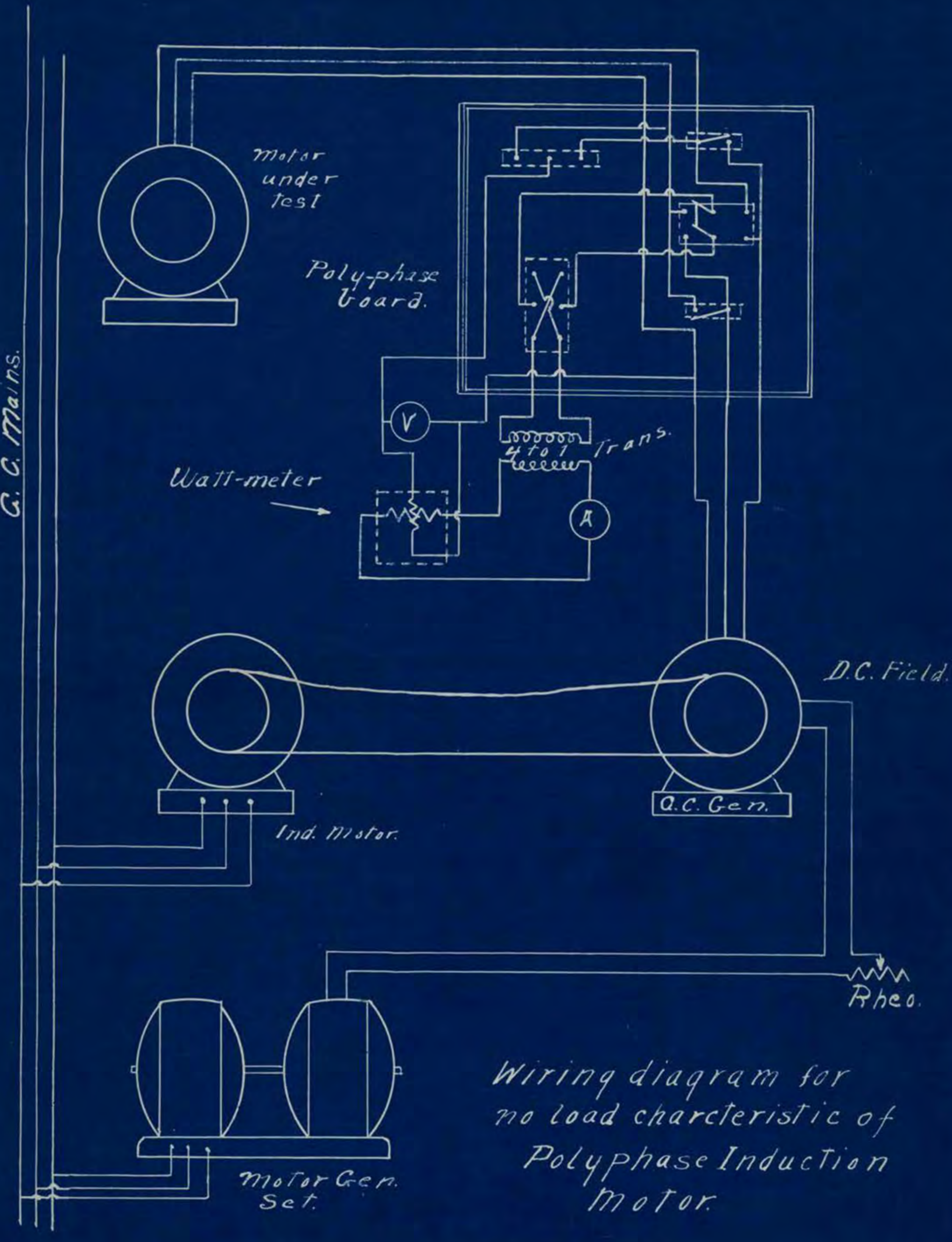
Volts		Amperes		Watts	
Phase		Phase		Phase	
A	B	A	B	A	B
61	57	39	39	880	160
50	47	32	32	560	100
43	42	28	28	400	90
38	38	24	24	320	80

The results of the no-load and short-circuit tests are better shown if represented graphically as shown on thefollowing curve sheet. The blue print following it is a diagram of the connections used in making the tests.

THE CIRCLE DIAGRAM.

The method, mentioned in a previous paragraph, for the calculation of the performance curves is by the use


No-Load and Shortcircuit
Characteristics.
No-Load Amperes
Total Watts.
Shortcircuit amperes.
No-Load Amperes.
0
1
2
3
4
5
6
7
8
9
Watts.
100
200
300
400
Shortcircuit Amperes.
0
10
20
30
40
10
20
30
40
50
60
Shortcircuit volts.
30
40
50
60
70
80
90
100
110
120
130
140
150
No-Load Volts.



Wiring diagram for no load charcteristic of Polyphase Induction Motor.

of the circle diagram.

CONSTRUCTION OF THE DIAGRAM.

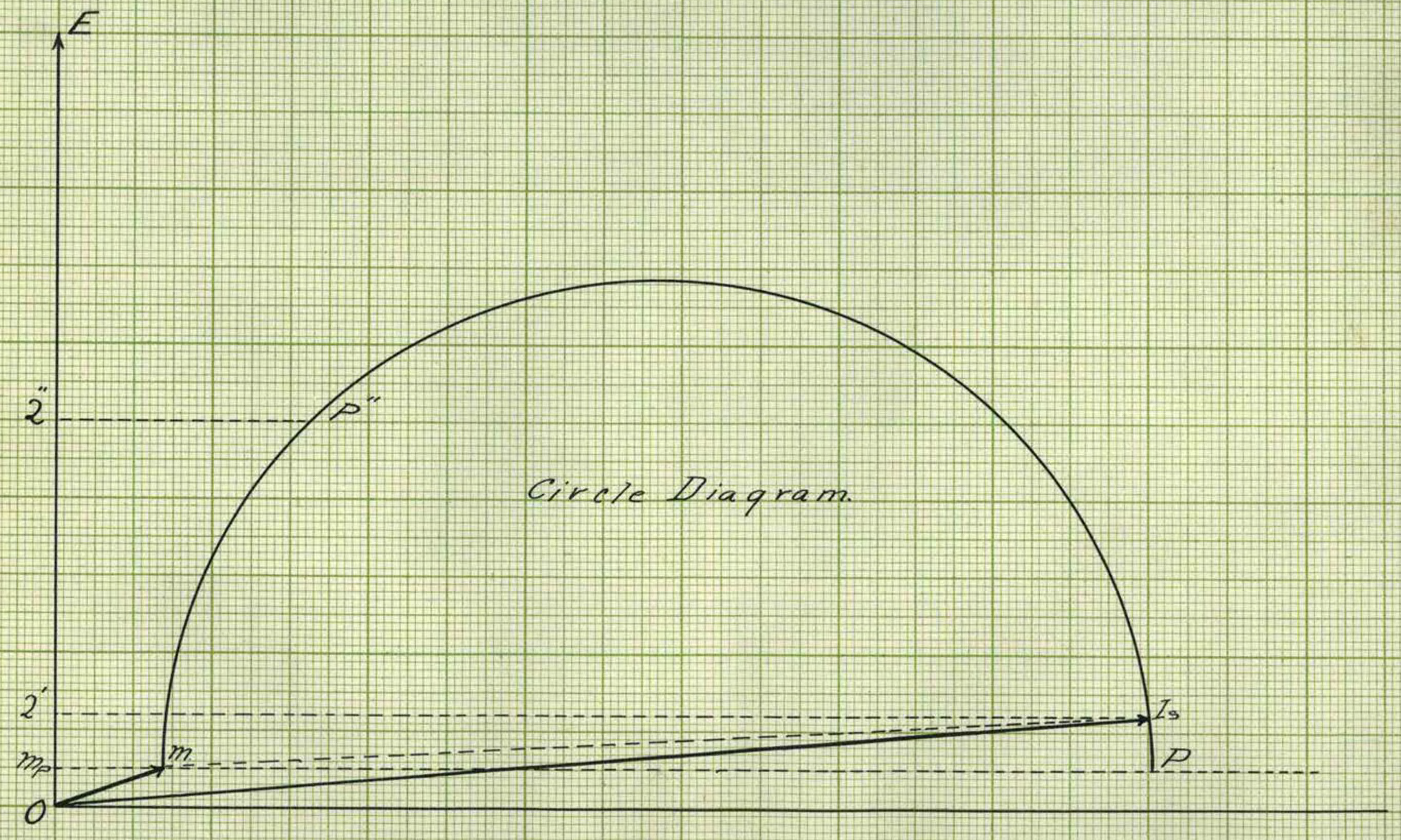
As indicated in the no-load test data the current per phase taken by the motor at no load and at the rated voltage is 7 amperes and the total power is 280 watts. All this power is used to supply losses in the motor. The component of the magnetizing current parallel to the impressed electromotive force is $\frac{280}{E}$ or 2.5 amperes. Thus the position of M on the diagram of plate four is found.

OI_s the short circuit current cannot be found from the actual data, as the amount would be injurious to the insulation of the windings. Since the ampere curve is a straight line, by proportion the short-circuit current is 70.4 amperes. The curve of watts is a parobola and can be found by the eqiation $\frac{Watts}{E^2} = C$ or the power at rated voltage on short-circuit is 616 watts. The component of the current parallel to E at standstill is $\frac{Ws}{E} = 5.6$ amperes.

This determines the position of OI_s. Now draw the straight line MI_s. From I_s perpendicular to MI_s draw I_sP. Now on MP as a diameter draw a circle through the point I_s. The following plate is a graphical representation of the circle diagram.

USE OF THE CIRCLE DIAGRAM.

Lay off on OE a suitable scale as the power factor and with O as a radius strike an arc. Now take a series


E
2''
P''
Circle Diagram.
2'
I_s
m
m_p
P
O

of positions of I on the circular locus,draw OP,producing it until it cuts the arc. Produce this intersection to the power factor scale and read the power factor. Measure OP and MP. From these values the table on plate three was calculated thus;

(1). Power delivered to stator equals OP x MP x P.F.

(2). Stator I^2R loss equals $\overline{OP}^2$ x R.

(3). Power delivered to rotor equals equation 1 minus equation 2.

(4). Electrical power developed in rotor equals $R'' \times \overline{MP}^2$.

(5). Mechanical power developed in rotor equals equation 3 minus equation 4.

(6). Total loss equals equation 4 minus equation 5.

(7). Slip equals $\frac{\text{equation 3}}{\text{equation 4}}$.

(8). Speed equals synchronous speed minus slip speed

(9). Torque equals 2 N.

(10). Efficiency equals ratio of equation 1 to equation 5.

The following table shows the calculations made by the use of the diagram.

AMPERES OP	AMPERES MP	POWER DELIVERED TO STATOR WATTS	STATOR I^2R LOSS WATTS	POWER DELIVERED TO ROTOR WATTS
8.5	3.0	539	3.6	280
12.0	7.0	1043	7.2	781
19.0	14.5	1828	19.0	1554
27.0	21.0	2449	33.0	2161
34.5	29.0	2849	59.5	2534
45.0	39.0	3572	107.4	3210
54.0	49,0	3802	146.0	3401

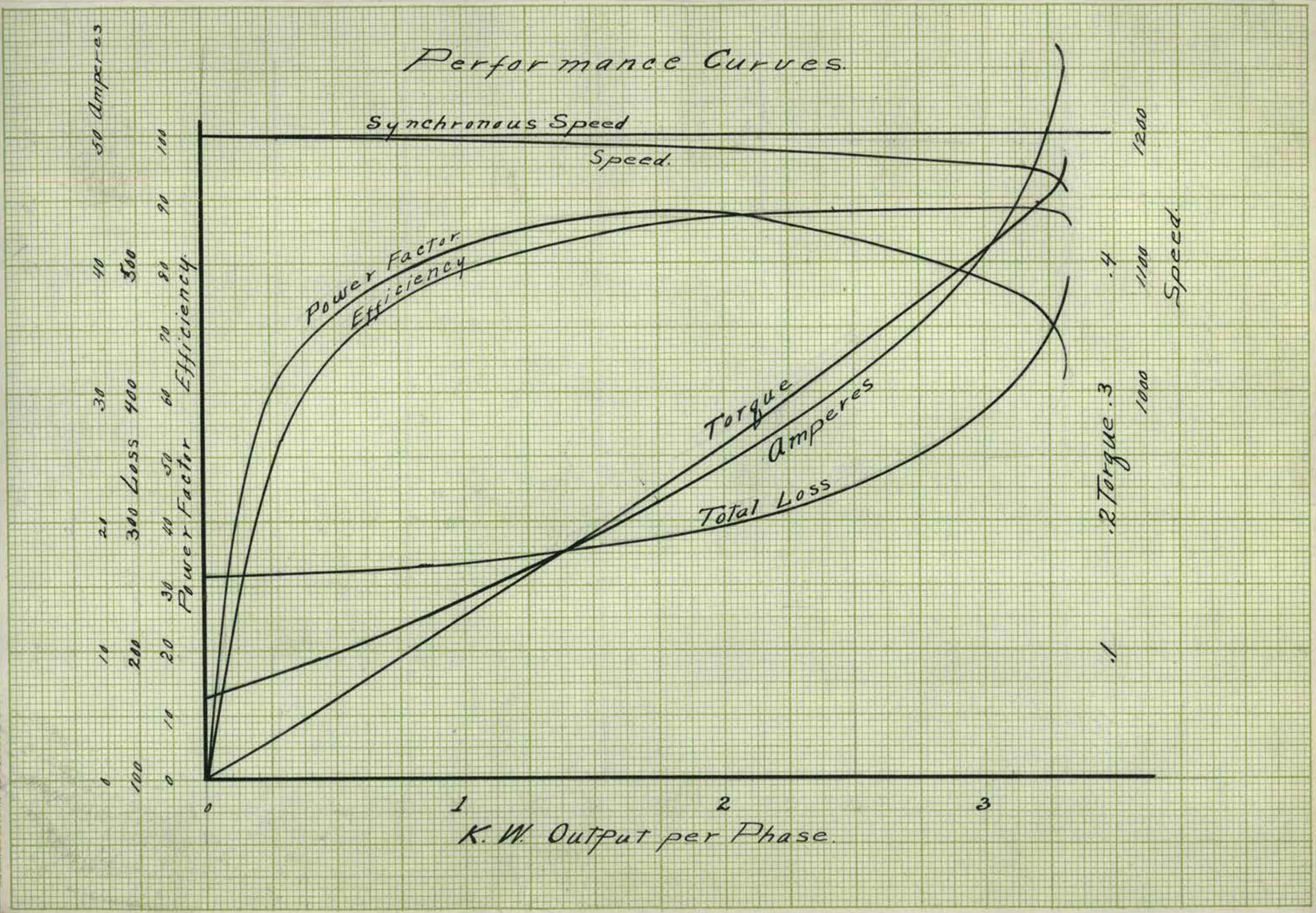
(continued).

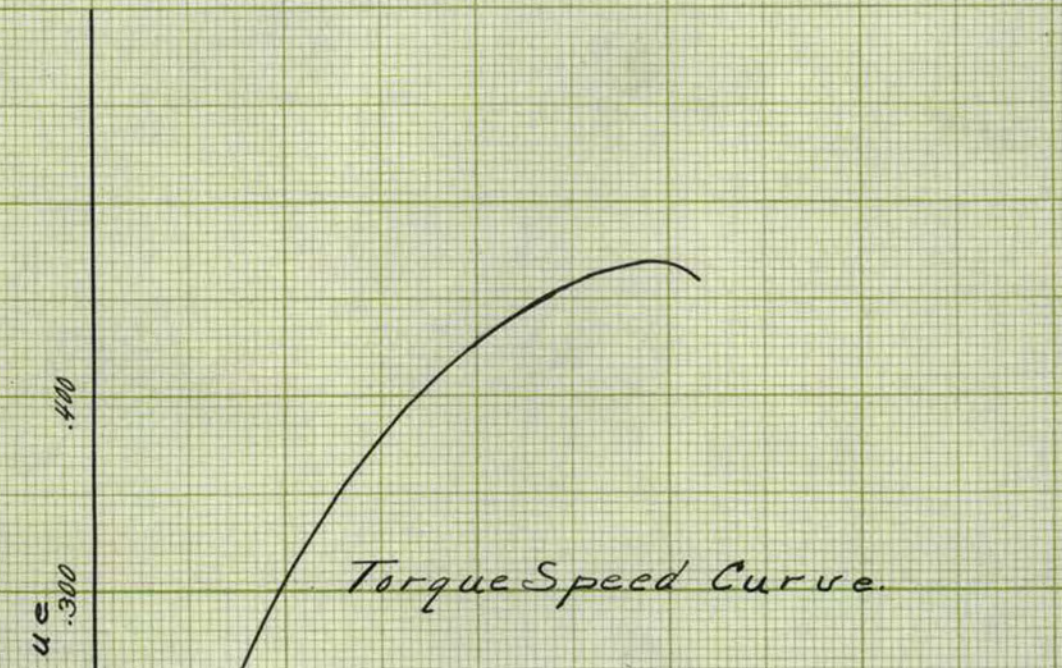
POWER FACTOR %	ELEC. POWER DEVELOPED IN ROTOR WATTS	MECHANICAL POWER DEVELOPED	TOTAL LOSS IN WATTS	SLIP %
.63	.3	279.7	259.3	.00107
.79	1.6	779.0	264.0	.0021
.87	6.9	1547.0	281.0	.004
.86	14.7	2146.0	303.0	.006
.83	28.0	2506.0	343.0	.011
.75	50.8	3159.0	413.0	.015
.64	76.9	3324.0	478.0	.022

(continued).

EFFICIENCY %	SPEED R.P.M.	TORQUE SYNCHRONOUS WATTS.
.519	1198	.037
.747	1197	.103
.845	1195	.194
.876	1192	.288
.879	1187	.339
.884	1181	.432
.874	1173	.461

The following curve sheet is a graphical representation of the above table.


Performance Curves.
Synchronous Speed
Speed.
Power Factor
Efficiency
Torque
Amperes
Total Loss
K. W. Output per Phase.
0
1
2
3
50 Amperes
40
30
20
10
0
500
400
300 Loss
200
100
100
90
80
70
60
50
40
30
20
10
0
Power Factor Efficiency
1200
1100
1000
Speed
.4
.3
.2 Torque
.1



Torque Speed Curve.
Torque
0
.100
.200
.300
.400
1200
1190
1180
1170
1160
Speed R.P.M.

CONCLUSION.

The graphical representation of the performance curves show that the power factor is at its maximumat about 50% load and the efficiency at maximum at full load. For this reason the motor operates very satisfactory at an average load or about 7 tenths full load. At that point the load on the motor may vary to quite a large extent without any perseptible variation in speed,the greatest variation being in values of torque and amperes.

The speed torque curve gives a good idea of how the torque varies with only a slight variation in the speed of the rotor.

The tests show that the motor to be a very efficient one throughout a great variation in load thus making a good one for general use.

Respectfully submitted

H.P.C.

H.D.B.

14"
5"
3 3/4"
coil
Scale 1/2"
13 1/2"
2 3/8"
1/2" bolt
Core
Scale 1/2
26"