THESIS

on

THE TEST OF AN INDUCTION MOTOR GENERATOR SET.

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FOREWORD.

The line of investigation that appealed more to the writers than many which were under consideration was the testing of a motor generator set, because of the fact that a large field of experimentation was opened up, as the dynamo was a compound direct current machine while the induction motor was driven by electrical energy supplied from the long distance transmission line.

Knowing therefore that much of our knowledge of electricity obtained in the class room and laboratory would be brought into use, the aforesaid subject was chosen.

Oregon Agricultural College,
May 31, 1910.

J.C.Plankinton.
V.P.Gianella.

THE TEST OF AN INDUCTION MOTOR GENERATOR SET.

This thesis comprises a series of tests run on a compound direct current gererator and an induction motor; separately and combined as a set, with sheets of data; characteristic and efficiency curves and deductions drawn therefrom relative to the two machines.

The induction motor generator set is coming more into use owing to its simplicity and reliability.

In many places where the rotary converter was used to transform the alternating current into direct current for street railway power, for lighting and for the charging of storage batteries etc. the induction motor or the synchronous motor driving suitable dynamos has displaced it.

Of the alternating current machines just mentioned the asynchronous type is much the more dependable, because of its sturdy construction, its short circuited secondary of massive copper, no rotating contacts, no separate field connections and therefore a safer machine owing to its having no sparking points.

The induction motor has the advantages over the synchronous type of machine in that it has a large starting torque and can be brought up to speed by aid of the auto transformer or compensator whereas the synchronous motor must first be synchronized which requires much time.

These sets are used extensively in alternating current power plants for the obtaining of direct current for the excitation of the generators. They are also used in connection with hydro-electric stations where they are direct connected to the water wheel. The induction motor here has a steadying effect upon the wheel whenever small fluctuations occur in the water supply.

These tests were run on a direct connected induction motor generator set with the following rating:

Motor.

Westinghouse, 3.6 H.P., 3 phase, 4 pole, 60 cycle, 110 volt, 19.5 amperes.

Generator.

Westinghouse, 2 K.W., 125 volt, 16 amperes, 1700 R.p.m., 4 pole.

The test includes the following curves;

Generator.

1. No Load Characteristic. (Plate 1)

2. Load Characteristic. (Plates 2,4)

3. Efficiency. (Plate 3)

4. Performance. (Plate 4)

Motor.

5. No Load Characteristic. (Plates 5,8)

6. Locked Saturation. (Plates 6, 8)

7. Performance. (Plates 3,7,8)

8. Circle Diagram. (Plate 8)

The significance of these curves is given below.

1. The no load characteristic shows the variation of terminal voltage with a change of field current. For good operation the curve should rise sharply to about 80% of the rated voltage and then bend over running flat up to nearly one and one fourth load where it falls off.

The flat of the curve is due to the saturation of the iron being reached. On this portion of the curve a considerable variation of the field current produces but little change in the terminal voltage.

2. The load characteristic gives the drop of voltage with the increase in load. The ideal load curve gives gives nearly no load voltage up to about one and a fourth load where it gradually falls due to armature reactions being excessive. In order to give the ideal curve the machine must be compounded to take care of the I^2R loss, armature reactions and hysteresis and eddy current losses.

3. The efficiency of a generator is the input divi divided by the input plus the losses. In the test the efficiency of the generator could not be found directly owing to the fact that the two machines were rigidly connected. However it was computed from the efficiencies of the motor and of the unit. The efficiency of the set is the output of the generator divided by the power delivered to the motor, it is also the product of the efficiencies of the two machines. That of the motor being found from the circle diagram that of the generator is computed.

4. The performance curves reveal the operating features of the machine.and comprise the following: efficiency, load, kilo-watts output and field current curves.

5. The no-load characteristic represents the power required to run the motor at no load.and shows the variation between the volts amperes and watts, This

power consists of the iron losses due to hysteresis and eddycurrents, magnetizing current and a small I^2R loss of the windings.

6. The locked saturation curves taken with the rotor blocked are practically the same as those obtained from the transformer and give the relation between watts and amperes taken by the atator. The current curve is nearly a straight line while the watt curve is a parabola. Much care must be exercised in this test as thecurrent i is much larger at the rated voltage that the amperage of the machine at full load. I t is usually impossible to get this current value as the windings heat up rapidly due to the excessive current. In such cases readings are taken at much lower voltages and extrapolated to its rated voltage by means of the equation,

$$\text{Watts} = C \times E^2$$

where C is a constant.

$$\text{Power component}, = \frac{\text{Watts}}{E} = CE.$$

Plotting this power component to volts as abcissae will give approximately a straight line. Produce this line to the rated voltage. The ordinates of the curve multiplied by the corresponding voltages give the ordinates of the watt curve.

7. The performance curves represent the operation of the motor and consist of rotor speed, synchronous speed, power factor, efficiency, apparent and true kilo-watt, torque and slip curves. These are obtained from data from the circle diagram.

8. The circle diagram is the means by which the performance curves of the induction motor are obtained. The nescessary data for the circle diagram is procured from the no-load characteristic and locked saturation curve.

From the magnetizing and no-load watts and the impressed voltave the phase position of the magnetiging vector is found. That is,

$$EI \cos \theta = \text{Watts.}$$

The value of the magnetizing current is layed off to scale and phase angle from co-ordinate axes of which the x axis represents the input line and the y axis the impressed voltage. The stator locked current is made up of two components, one in phase with the electromotive force and the other in quadrature. The current in phase is found by dividing the watts at the locked point by the impressed voltage. This value of the current is layed off on the y axis and through this point a line is drawn paralled to the x axis. Where the locked current measured from the origin intersects this line a point is determined on the current locus. Another point is at the extremity of the magnetizing current vector. The diameter is a line drawn through the latter point paralled to the x axis. A line connecting these points gives a chord whose perpendicular bisector intersects the diameter at its center. The power factor quadrant is circumscribed about the origin with a radius of convenient scale, divided into one hundred parts, each representing one per cent power-factor. The power-factor of any current is determined by projecting upon the y axis the intersection of its vector with the power-factor quadrant.

Let the following notation represent the points and vectors of the circle diagram:

O is the origen.

OM the magnetizing current.

OP' the locked current in the stator.

OP the current in the stator at any time.

MP' the intake current in the rotor at standstill.

MP the current in the rotor at any time.

Synchronous speed is one.

Power input is OP X E X cosΘ (Eq.1)

Stator I^2R is $(OP)^2$ X R of stator. (Eq.2)

Power delivered to rotor is Eq.1 - (Eq.2 + 480) (Eq.3)

Rotor I^2R is $(MP)^2$ x R of Rotor. (Eq.4)

Total loss is Eq.2 + Eq.4 + 480. (Eq.5)

Output is Eq.1 - Eq.5. (Eq.6)

Efficiency in per cent is $\frac{Eq.6}{Eq.1}$ (Eq.7)

Per cent slip is $\frac{Eq.4}{Eq.3}$ (Eq.8)

Torque is $\frac{Eq.3}{2 \times 3.1416 \times (1-Eq.8)}$ (Eq.9)

DATA FOR CURVES.

****

NO LOAD CHARACTERISTIC.
Dirrect Current Generator.
(See plate 1)

Volts	Field Amperes
13	.1
15	.15
20	.25
25	.3
30	.35
35	.45
40	.5
50	.6
55	.7
60	.725
65	.8
70	.85
75	.95
80	1
90	1.15
95	1.2
100	1.3
105	1.4
110	1.45
120	1.6
130	1.7
140	2
150	2.3

DIRRECT CURRENT LOAD CHARACTERISTIC.
(Plate 2 &4)

Volts.	Amperes.
127	0.5
120	2.5
112	4
118	5
110	6.5
109	7
100	7.5
97	9
96	10
75	12.5
83	10
87	9.75
77	12.5
70	12.8
63	13
48	11
52	12
47	12.5

146	0
142	2
142	1.5
141	1.75
138	3
131	5.5
130	7
126	7.5
124	8.5
121	9.5
117	10.75
114	11.5
109	12.25
104	12
96	12.5
92	15
90	16
88	15
80	16.5
77	17.25
75	18
72	16.75
65	16.25
60	15

EFFICIENCY OF UNIT.
(Plate 3)

Direct Current.			Alternating Current Watts		
K.W.	Volts.	Amperes	Phase 1	Phase 2	Eff %
.1775	143	1.25	-60	1000	19.9
.34	137	2.5	-40	1060	33
.64	135	4.75	60	1140	42
.65	130	5	120	1200	48.5
.77	124	6.25	200	1260	55
.9	121	7.5	240	1320	53
.83	110	8.75	260	1340	60
.9	105	9	250	1200	61
1.2	100	12	300	1620	62.5
1.3	97	13.9	390	1760	64
1.5	96	15.5	480	1820	65
1.65	95	17.4	540	1960	66
2	93	21.5	750	2250	66
2.2	90	24.2	1000	2500	63
2.4	85	28.2	1200	2800	60

INDUCTION MOTOR.
Locked Saturation.
(Plates 6 & 8)

Volts	Amperes	Kilowatts.
20	11	.115
25	14	.2
31	17.5	.25
40	23	.43
60	35	.615
80	47	1.243
110	73	3.000

No Load.
(Plates 5 & 8)

Volts	Amperes	Watts
27	.5.	25
30	.5.	26
39	.51	28
50	.74	30
70	1.25	75
80	1.7	118
100	3	250
110	4.2	480

INDUCTION MOTOR PERFORMANCE CURVES.
(Plates 3,7,8)

Rotor Amps.*	0	5	10	20	30	40	50	55
Stator Amps*	4.2.	8.75	13.55	23.8	34	44.2	54.3	59.7
Power Factor*	.54	.91	.94	.93	.89	.83	.73	.66
Rotor I^2R Loss	0	6	24	96	216	384	600	725
Stator I^2R "	4	18	44	137	278	470	702	858
Total Loss	484	504	548	713	975	1334	1782	2063
Input Watts	484	876	1409	2460	3330	4020	4360	4370
Output Watts	0	372	861	1747	2356	2686	2578	2307
Efficirncy %	0	42	61	67	71	67	59	53
Torque in Watts	0	91	295	320	418	512	690	815
Slip %	0	.6	.9	1.9	2	3	4.9	5.4
Volts	110	110	110	110	110	110	110	110
Power to Rotor	0	377	885	1843	2562	3070	3178	3032

* Taken from circle diagram.

Constant loss 480 watts. 4.2 amperes magnetizing current. Locked point amperes 73, Watts 3000. Resistance per stator phase .25 ohms. Calculated equivalent rotor resistance .24 ohms. Current of stator at locked point in phase with the electromotive force 54.5

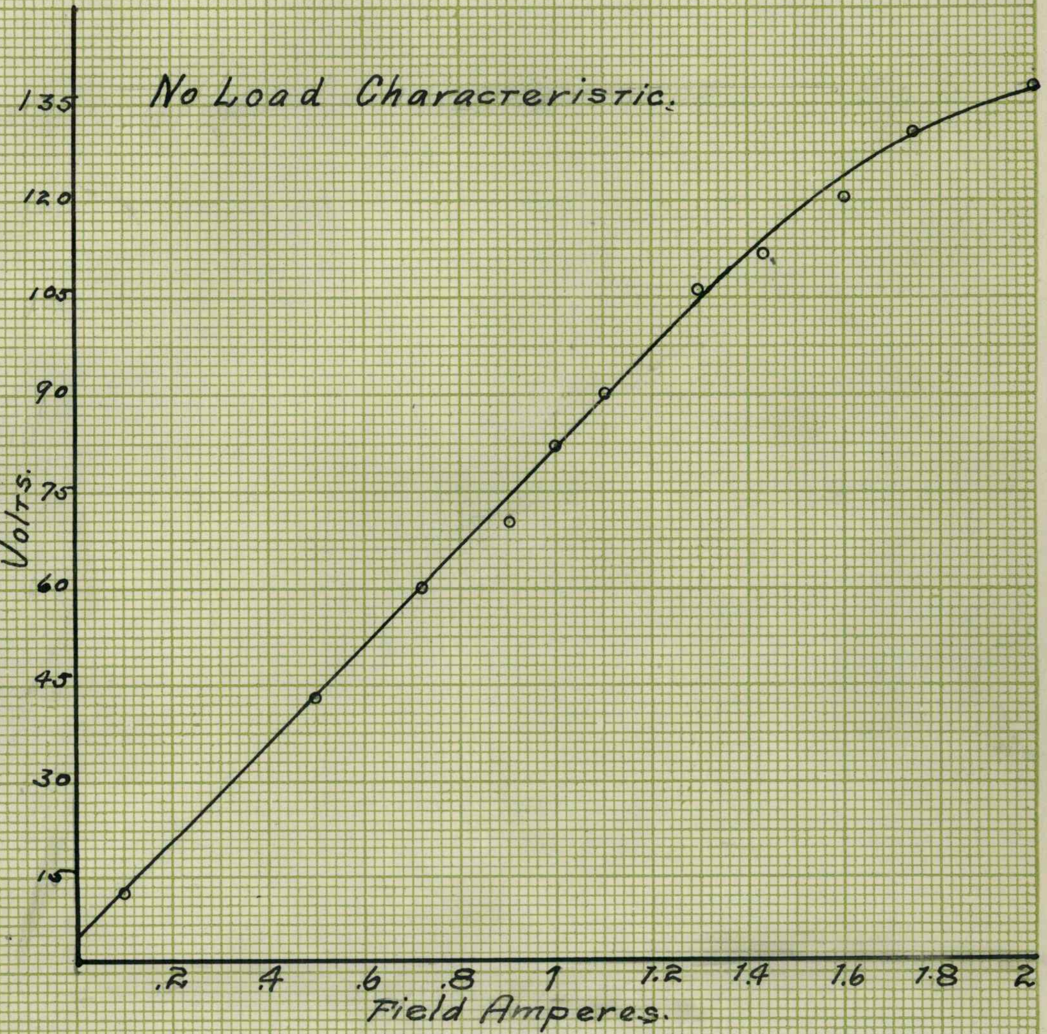

No Load Characteristic.
135
120
105
90
75
60
45
30
15
Volts.
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
Field Amperes.

Plate I

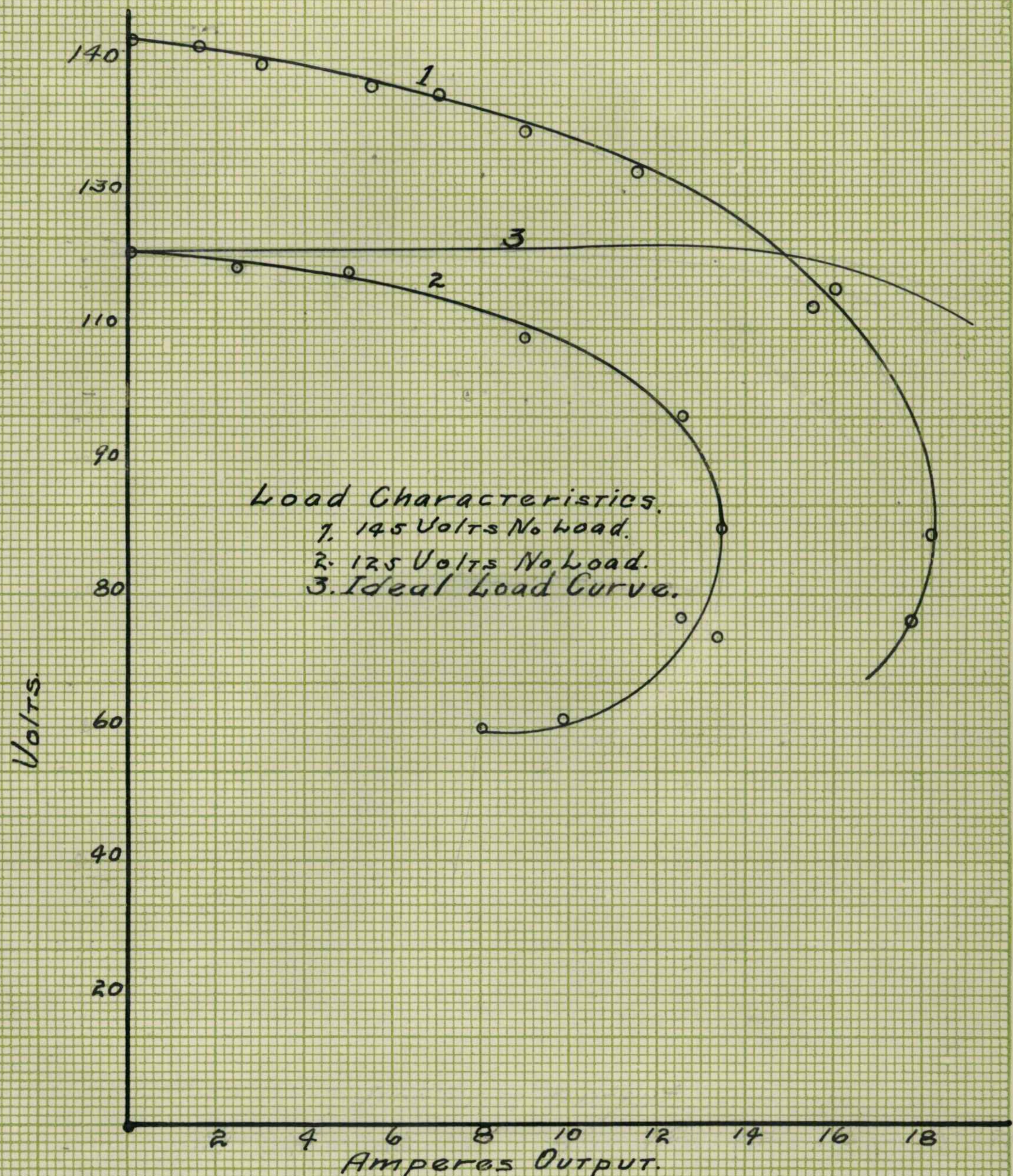

140
130
110
90
80
60
40
20
Volts.
2
4
6
8
10
12
14
16
18
Amperes Output.
1
2
3
Load Characteristics.
1. 145 Volts No Load.
2. 125 Volts No Load.
3. Ideal Load Curve.

Plate II

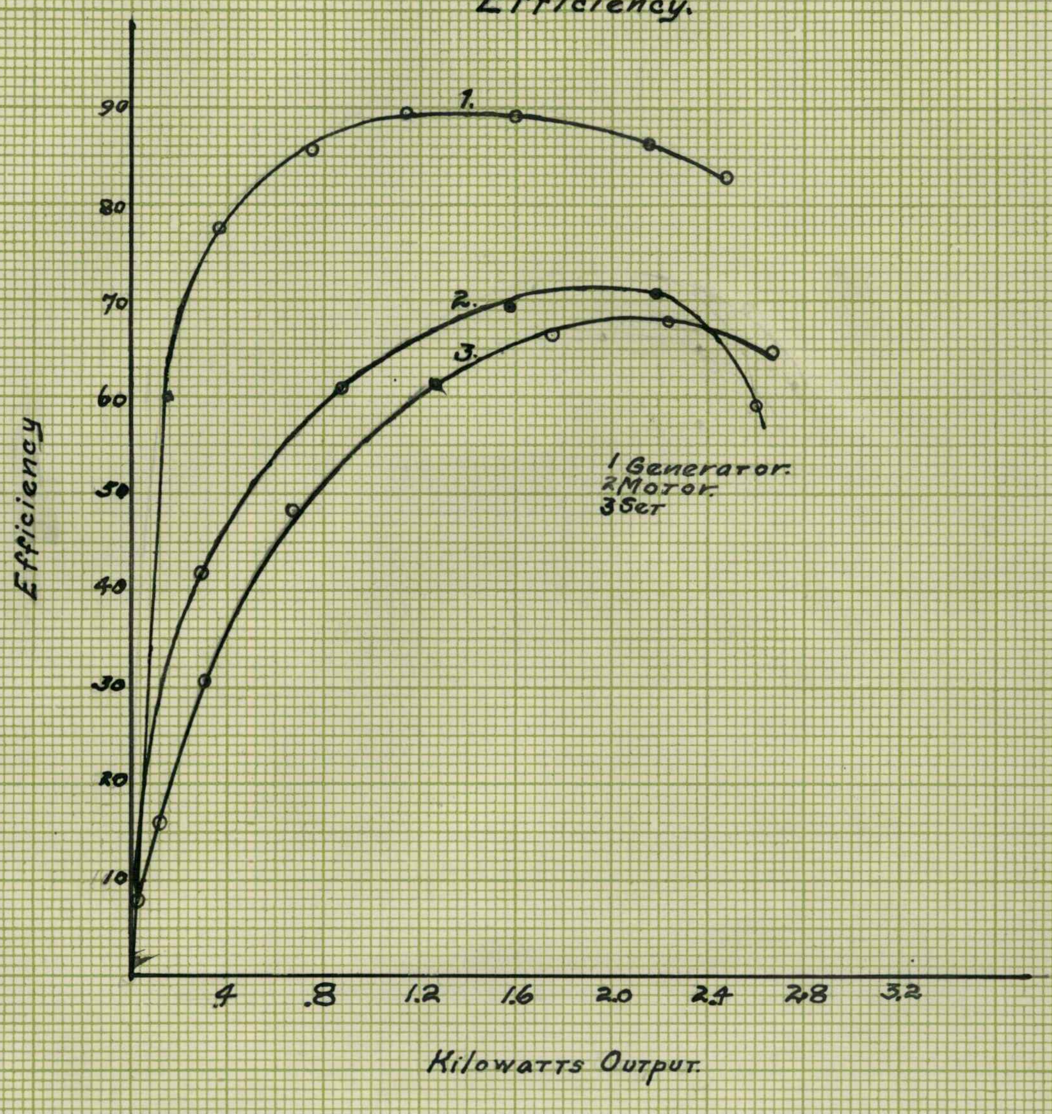
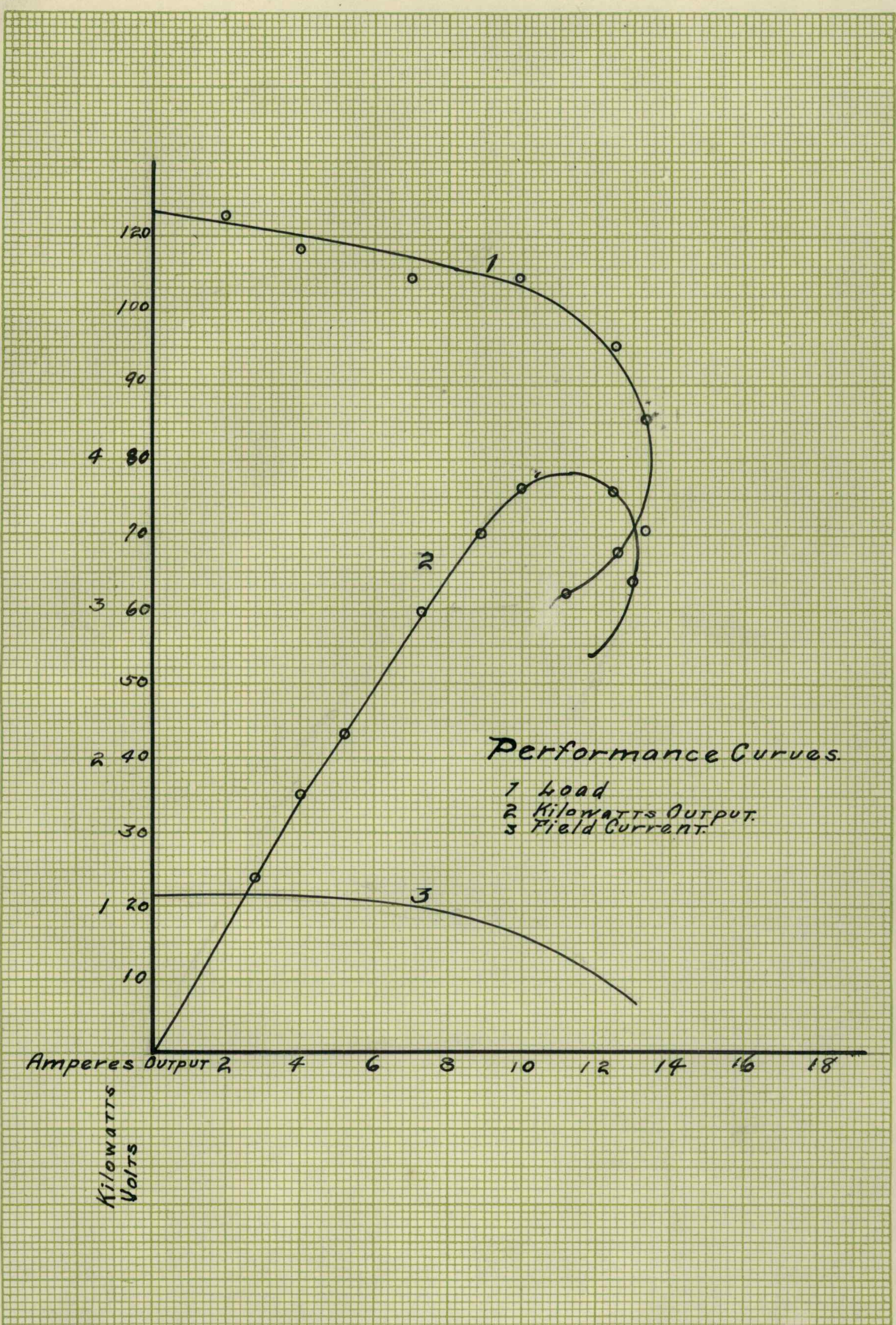

Efficiency.
1.
2.
3.
90
80
70
60
50
40
30
20
10
Efficiency
1 Generator.
2 Motor.
3 Set
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
Kilowatts Output.

Plate III.



Performance Curves.
1 Load
2 Kilowatts Output.
3 Field Current.
1
2
3
120
100
90
4 80
70
3 60
50
2 40
30
1 20
10
Amperes Output 2 4 6 8 10 12 14 16 18
Kilowatts
Volts

Plate IV.

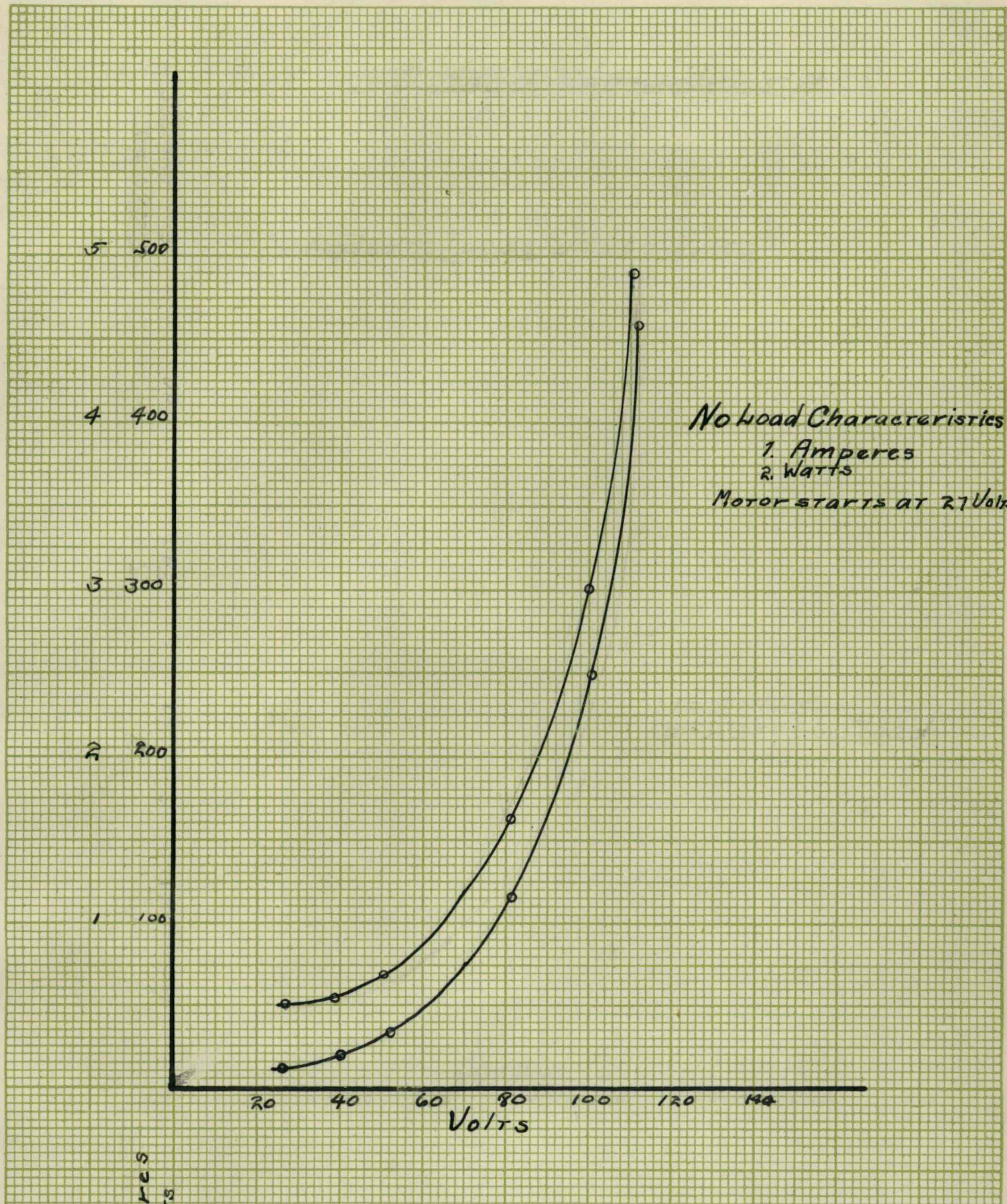

No Load Characteristics
1. Amperes
2. Watts
Motor starts at 27 Volts
5 500
4 400
3 300
2 200
1 100
20 40 60 80 100 120 140
Volts
Amperes
Watts

Plate V

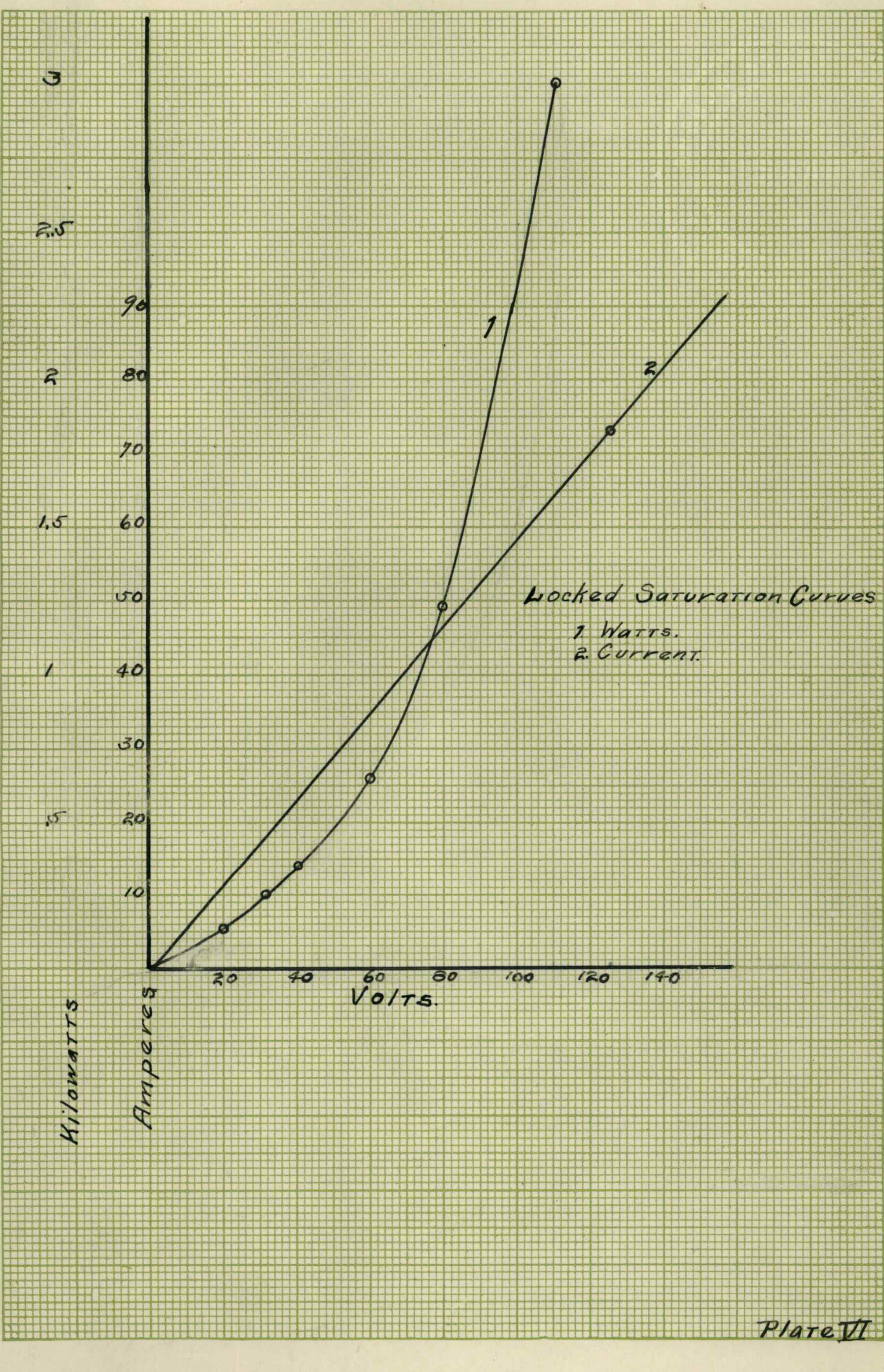

Locked Saturation Curves
1. Watts.
2. Current.
Kilowatts
Amperes
Volts.
3
2.5
2
1.5
1
.5
90
80
70
60
50
40
30
20
10
20
40
60
80
100
120
140
1
2

Plate VI

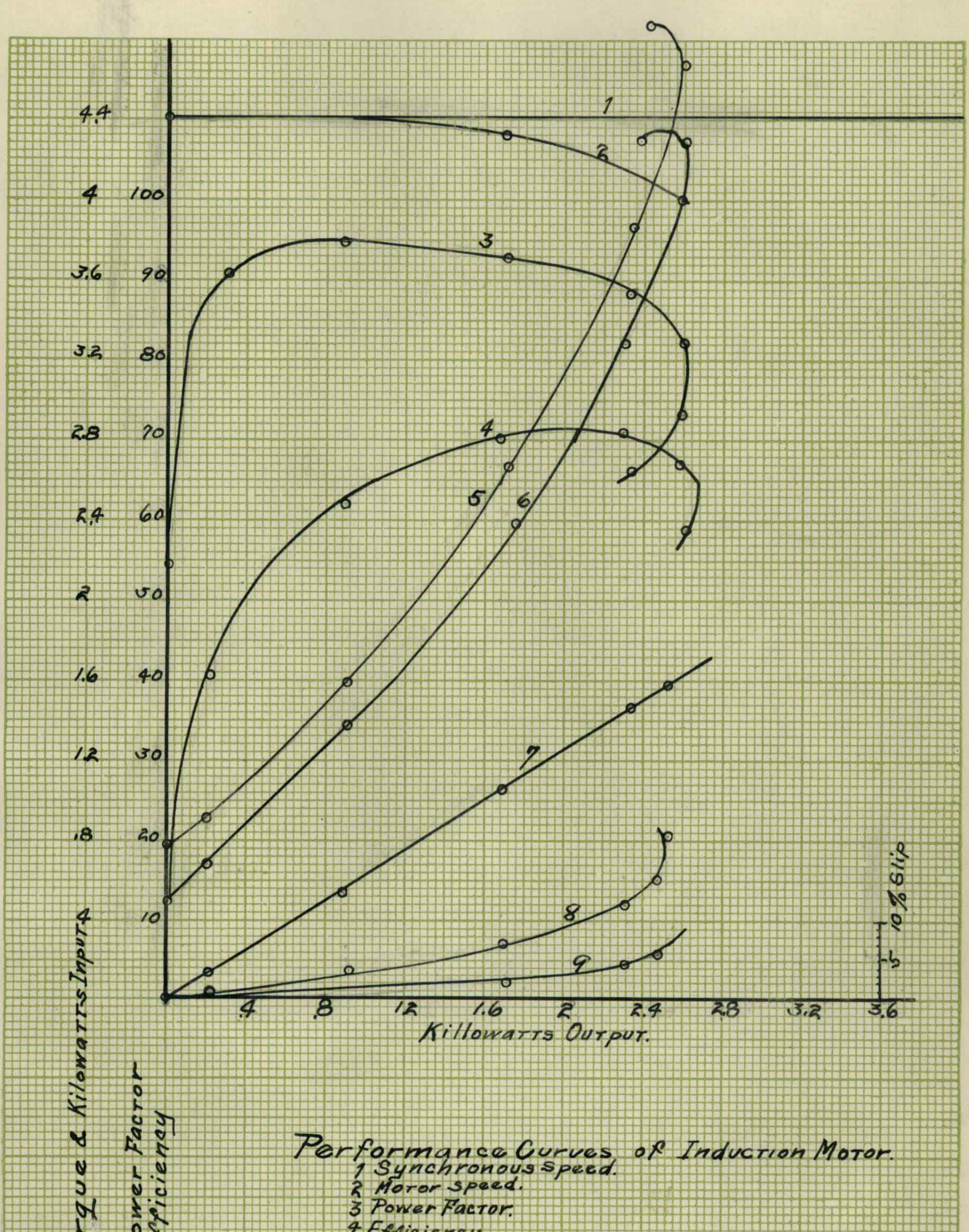

4.4
4 100
3.6 90
3.2 80
2.8 70
2.4 60
2 50
1.6 40
1.2 30
.8 20
.4 10
.4 .8 1.2 1.6 2 2.4 2.8 3.2 3.6
Killowatts Output.
10% Slip
5
1
2
3
4
5
6
7
8
9
Torque & Kilowatts Input
Power Factor
Efficiency
Performance Curves of Induction Motor.
1 Synchronous Speed.
2 Motor Speed.
3 Power Factor.
4 Efficiency.
5 Apparent Kilowatts.
6 True Kilowatts.
7 Killowatts Output
8 Torque.
9 Slip.

Plate VII

Circle Diagram.

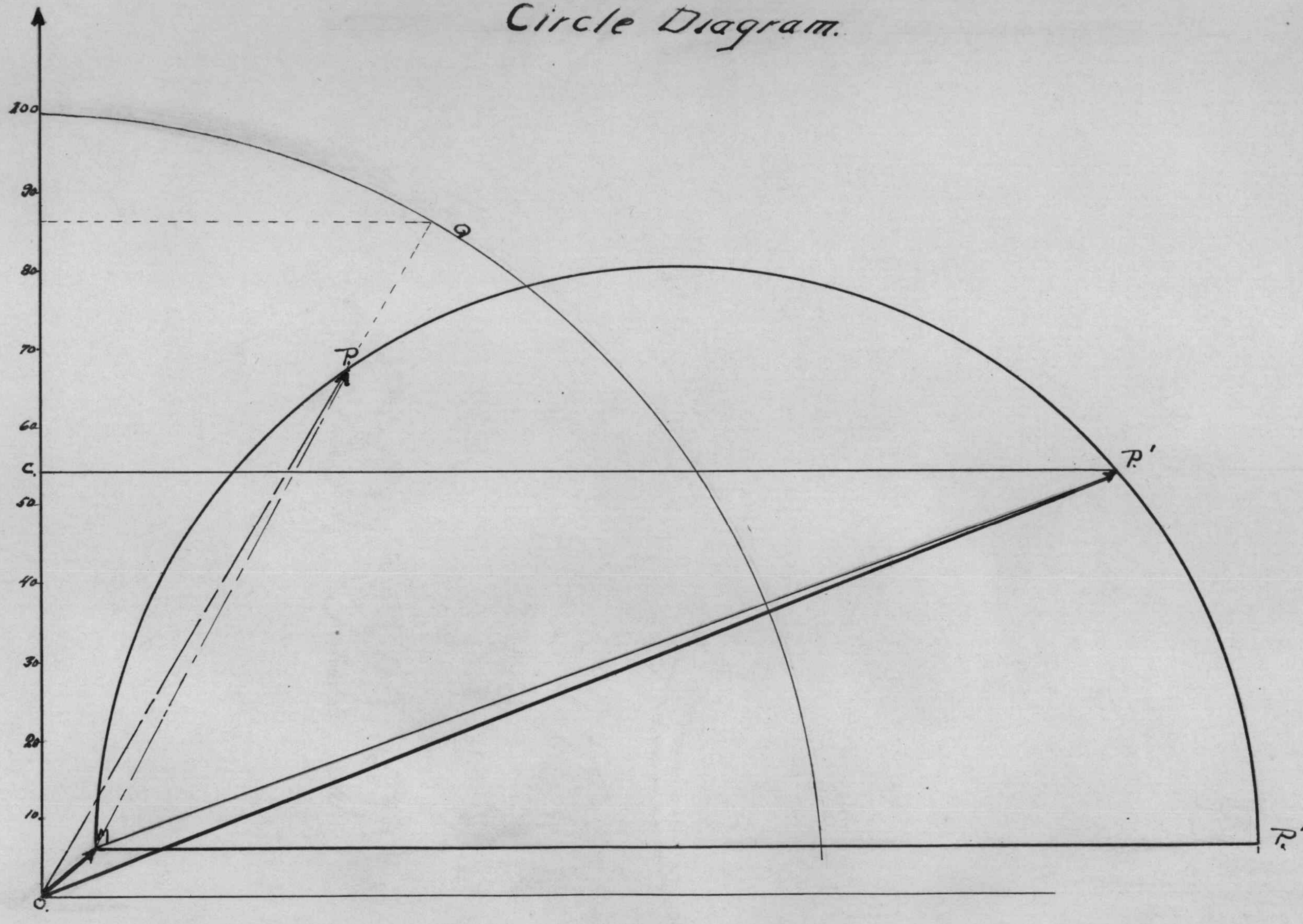


Plate VIII

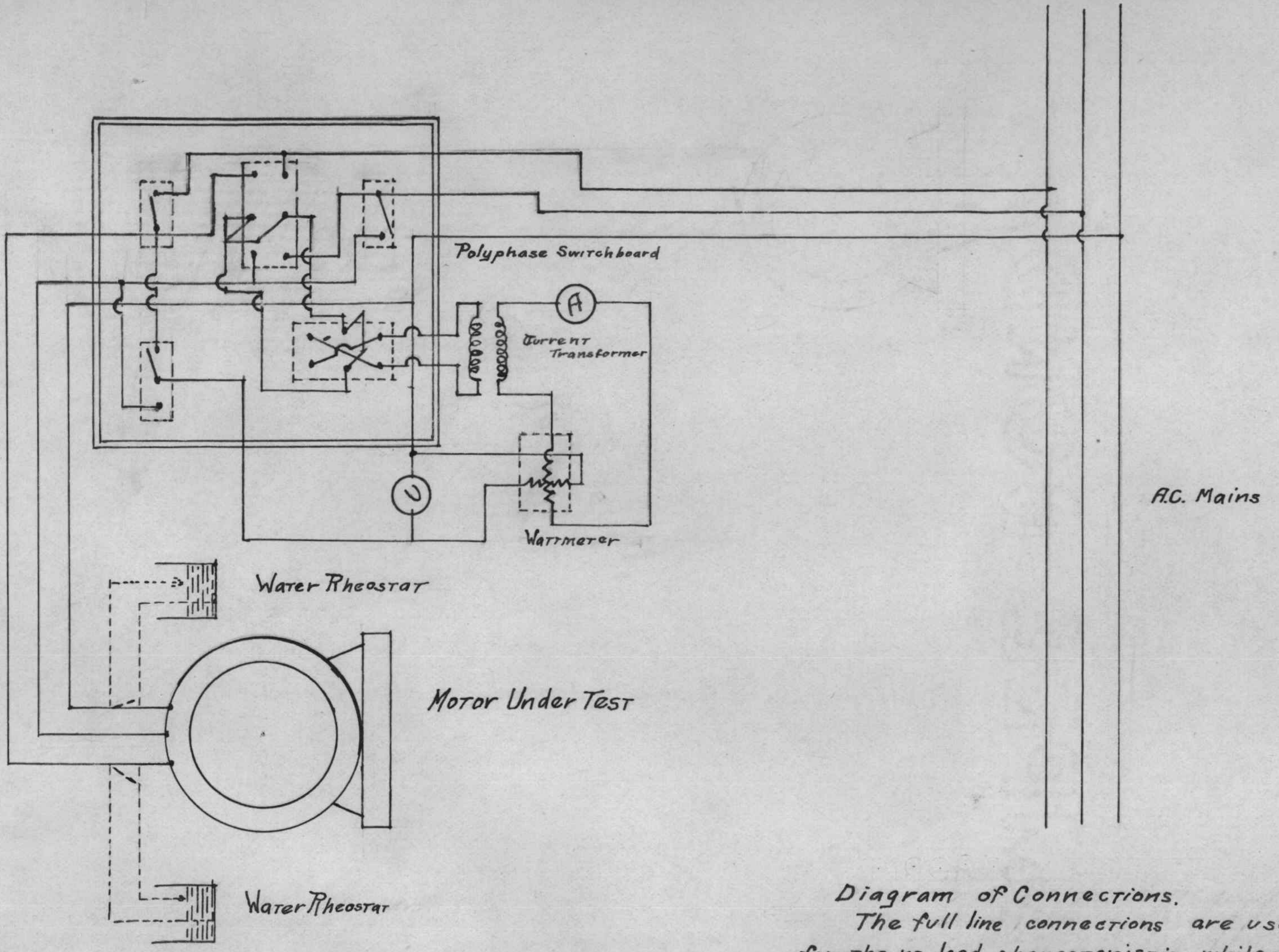


Diagram of Connections.
The full line connections are used for the no load characteristic while for the locked saturation curve the dotted connections are also used.

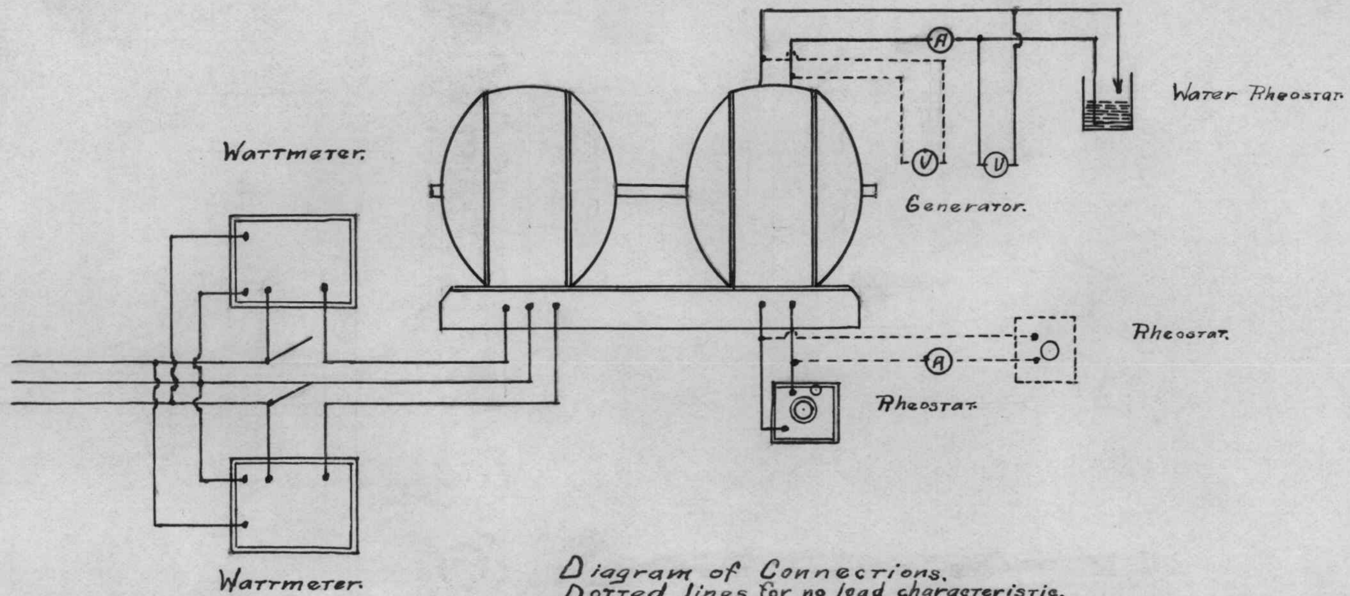


Diagram of Connections.
Dotted lines for no load characteristic.
Full lines for load and efficiency curves.

CONCLUSION.

The no-load characteristic of the generator(Plate 1) is practically a straight line and therefore has but little flat of curve for satisfactory opperation. This is probably due to large air gap and too much iron in the poles. With an excess of iron the saturation point is not reached until the field current is far abouve that rated for the generator.

If the strength of the field is increased by over excitation better operating conditions are obtained but then a voltage much higher than the normal voltage is generated.

The load characteristic (Plates 2,4) is not what the generator should have to opperate satisfactorily as it falls far too soon and too rapidly. It turns down sharply before three fourths load is obtained. This is due to its poor excitation characteristic as the armature reactions are not sufficiently compensated for by the field windings. This defect could be greatly lessened by by the proper compounding of the field.

The performance curves (Plates 3,7,8) of the induction motor are in keeping with the best practice and the behavior of the machine tends to verify them.

This motor connected to a direct current generator with good regulation would full-fill the requirments of a practical motor generator set.

FINIS