THESIS

Induction Generator Characteristics

by

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INTRODUCTION.

It was pointed out as early as 1898 by several engineers, especially Charles P. Steinmetz, that the induction motor when driven at a speed above synchronism is capable of delivering electrical energy; also that its ability to act as a generator depends upon the fact that it must be supplied with a leading exciting current.

The application of the induction generator as a distinct generating unit has received very little attention.

The most notable example of the use of the induction generator in power plant equipment is found in the case of the Interborough Rapid Transit Co. of New York City. The power house contains nine units, each of 7500 k.w. capacity. Each unit contains a reciprocating engine exhausting into a low-pressure turbine. The generators connected to the reciprocating engines are of the usual synchronous type, but those connected to the low-pressure turbines are induction generators. Several similar installations not so important have been made for the purpose of increasing the output and efficiency of reciprocating engine-driven units.

Charles P. Steinmetz wrote in an article in the General Electric Review of Sept. 1916, "The induction generator is fully as practical as the synchronous generator. The only limitation of the induction generator is, that it is difficult to build for very low speeds such as 100 to 200 r.p.m., and thus at these speeds is expensive and of low power-factor. For speeds of 1800, 1200 and 900 r.p.m. the induction generator is well suited, and for large machines even 720 and 600 r.p.m. or the same speed at which induction motors are economical, may be employed."

A more recent example of the application of the induction generator principle is afforded in the regenerative braking of induction motor driven locomotives and mine hoists.

Recent questions and articles in the technical magazines point to the fact that few engineers are familiar with the operating characteristics of the induction generator. It is the object of this thesis to determine by test the operating characteristics of the induction generator and if possible to define its field.

THEORY OF OPERATION.

Since the induction motor principle is the basis of induction machinery, it is well to explain the theory of the induction generator by referring to the simple induction motor.

Consider first, the polyphase induction motor with the rotor at standstill. A voltage applied to the stator windings produces a rotating magnetic field which cuts the short circuited rotor bars, inducing currents in them. These rotor currents cause the rotor to revolve in the same direction as the magnetic field set up by the stator.

Under load, the difference between the speeds of the magnetic field and of the rotor is just sufficient to cause enough current to be induced in the rotor to produce the torque required for the load and to overcome the losses. An increase in the load causes a decrease in the rotor speed and consequently an increase in the rotor currents. Increasing the rotor currents demands a corresponding increase of the stator currents representing an increase of the power input.

The current supplied to the induction motor under load is made up of two components: the power component, that part of the current which is necessary to carry the load and to overcome the losses of the machine; and the quadration component, that part of the current which is necessary to overcome the reluctance of the circuit.

Now if the induction motor is considered running light and its losses supplied mechanically to the rotor shaft, the rotor will rotate at the speed of the magnetic field and will cut no flux lines. The current supplied to the stator windings in this case is a quadrature or exciting current with the exception of a very small power component absorbed by the stator resistance.

Again if still more torque is applied to the rotor shaft than is necessary to supply the losses, the rotor will be driven at a speed greater than that of the rotating magnetic field, causing the rotor to cut flux lines in a direction opposite to that explained above. Currents are therefore induced in the rotor in the opposite direction, representing power supplied to the stator. The induction motor then acts as a generator.

It is noted that in the foregoing discussion it was assumed that the induction motor was connected to a polyphase power supply at all times. Obviously it is essential that the induction motor receive exciting current which will produce the rotating magnetic field. This exciting current is obtained in practice from a polyphase alternator or synchronous motor.

TESTS.

The tests which follow were made on a Westinghouse Induction Motor, Type CW, with wound rotor and variable external rotor resistance, rated at 10 h.p., 110 volts, three phase, 60 cycles, 56.6 amperes per terminal, 850 r.p.m. at full load. The induction motor was direct-connected to a 7.5 k.w. direct-current machine which could be used either as a motor or as a generator.

Two 7.5 k.w. synchronous machines direct-connected to direct-current machines were available.

Since it was necessary in some of the tests to use municipal power with a frequency of 50 cycles, all the tests were run at 50 cycles to make the results uniform.

Three methods were used to put the induction generator in operation on the line:

1. With the induction motor and one of the synchronous machines connected together and the field synchronous machine excited, the synchronous machine was slowly brought up to speed by means of the direct-current machine direct-connected to it. The induction motor came up to speed with the alternator. A torque tending to drive the induction motor in the same direction was applied slowly by means of the d-c motor direct-connected to the induction motor shaft, until the rotor speed was slightly greater than synchronous speed. The induction motor was then

acting as a generator.

2. With the alternator driven at synchronous speed but with low voltage, the induction motor was connected to it. After the induction motor was almost up to speed the voltage was raised to normal. When the induction motor was up to speed the torque was applied as before to increase the speed of the induction motor rotor above synchronism.

3. The induction motor and alternator were both brought up to exact speed by means of the d-c machines. Knowing, from previous operations, that the phases were correctly connected, the switches connecting the two machines together were closed. If the speeds are correct the power demand will be very little when the machines are connected together; the current flow in a large system, however, might be excessive rendering this method prohibitive.

Any of the induction motor starting devices may be used to bring the induction motor up to speed before applying power to the rotor shaft.

EXCITATION TEST.

In this test the induction generator supplied power to a synchronous motor running light and received its excitation from the synchronous motor. Starting with a voltage above normal, the field current of the synchronous motor was reduced, thus reducing the voltage until the synchronous motor dropped out of step.

Curve sheet #1 shows the relation between the terminal volts and the exciting currents required by the induction generator and synchronous motor. It is noted that the curves are of the same shape, showing that the excitation of an induction generator is not far different from that of a synchronous machine.

Curve sheet #2 also shows that the power factor of the induction generator is practically constant for all voltages down to the point where the synchronous motor begins to drop out of step, as shown by the power currents curve on the same curve sheet.

RELATION BETWEEN SPEED AND FREQUENCY.

With the conditions the same as in the previous test, and the voltage held constant, the speed of the induction generator was varied and the frequency noted.

Curve sheet #3 shows that the frequency depends directly on the speed.

EFFECT OF INCREASING THE ROTOR RESISTANCE.

With the induction generator driving the synchronous motor running light at constant frequency and voltage, the rotor resistance was varied and the speed noted. Then a constant load was applied to the synchronous motor by means of the d-c generator connected to it. With the frequency and voltage constant, the rotor resistance was varied and readings taken as shown on the data sheet #2.

Curve sheet #4 shows the effect of the rotor resistance on the speed of the induction generator at no load and full load.

Curve sheet #5 shows the effect of the rotor resistance on the power input, torque, efficiency and speed when the induction generator is delivering a constant load.

It is noted that the power input, torque and speed increase and the efficiency decreases with increase of rotor resistance. The increase in the rotor resistance demands a greater induced voltage in the rotor to produce the required rotor current. The increase in the rotor voltage is obtained by speeding up the rotor so that it cuts more flux. On the other hand, the increase in the resistance increases the I^2R losses, thus increasing the power-input and torque and reducing the efficiency.

In this and the following tests the efficiency was taken as the ratio of the induction generator output to input. (See Appendix for method of determining input.)

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS.

NON-INDUCTIVE LOAD.

The induction generator furnished power to the synchronous motor running light and to a three-phase non-inductive load composed of an incandescent lamp bank. Readings of power and current were taken in the three circuits as shown on data sheet #4.

LEADING AND LAGGING LOADS.

To obtain leading and lagging loads a second synchronous motor was used. The first synchronous motor was allowed to float on the line. Its losses were supplied thru the d-c motor connected to it so that the current it supplied was all quadrature current. The second synchronous motor was loaded by means of the d-c generator connected to it, at practically constant power-factor, leading and lagging. Readings were taken as shown on data sheets# 5+6

It is well to note here that considerable difficulty was encountered in trying to keep conditions constant long enough to take readings.

Curve sheets #6 and #7 show that the total current and power factor is constant for a given load regardless of the kind of load.

Curve B, curve sheet #8, shows the variation of the induction generator exciting current for non-inductive, leading and lagging loads. Curve B also represents the quadrature current supplied by the synchronous motor when the induction generator is supplying a non-inductive load.

Curves A and C, curve sheet #8, show the variation of the synchronous motor quadrature current for lagging and leading loads respectively. In the case of the lagging load the synchronous motor supplied the lagging quadrature current required by the load in addition to that supplied to the induction generator. The leading load, however, supplied part of the induction generator exciting current, thus decreasing the amount supplied by the synchronous motor.

The total current, power-factor and exciting current of the induction generator are always constant for a given load. From the equation, Power = Volts x Amperes x Power-factor, it is readily seen that the input-output efficiency must also be constant for a given load. Curve sheet #9 plotted from the data obtained shows that, within the limit of error of the different tests, the efficiencies are the same for different types of loads.

COMPARISON OF THE OPERATION OF THE INDUCTION MOTOR AND INDUCTION GENERATOR.

Since it was impossible to get accurate slip measurements in the preceding load tests, another load test was made with the induction generator delivering power to the city mains.

A load test was also made on the induction machine running as a motor, by loading the d-c machine connected to it as a generator.

Curve sheet #10 shows the results of the two load tests. It is noted that the power-factor, current and efficiency for a given output were higher when the machine was operating as a motor than as a generator.

APPLICATION OF THE INDUCTION MOTOR CIRCLE

DIAGRAM TO THE INDUCTION GENERATOR.

To construct the induction motor circle diagram three readings are necessary; namely, the resistance of the stator windings at normal operating temperature, reading of current and power at normal voltage with the motor running idle, and readings of the current and power at normal voltage with the rotor blocked. Following is the data necessary for the construction of the circle diagram for the Westinghouse 10 h.p. induction motor.

	Running idle	Locked Rotor.
Volts.	110.	110
Amps. per terminal.	33.1	225
Watts	540	17000
Power-factor	8.57	39.7

Stator resistance per phase = .0332 ohms.

Referring to figure 1, the construction of the diagram is as follows:

Assuming a base line ON and with O as an origin, the no-load and locked power-factor lines, OC and OL respectively, were laid off. Selecting a convenient scale, the no-load and locked rotor currents were laid off on their respective lines locating points C and L. With its center on the line CP, the current circle was drawn through points C and L.

In the diagram thus constructed CE represents the power current necessary to supply the losses at no-load, including windage, friction and core loss. The no-load losses are assumed to be constant losses for all loads. LP represents the total power current supplying the copper losses of both rotor and stator, with rotor locked. The stator copper loss with locked rotor is $225^2 \times .0332 \times 3 = 5040$ Watts, and the corresponding power component of the current $= \frac{5040}{1.73 \times 110} = 26.5$ amperes = MP.

At any load current such as Oa, ab represents the output, bd and df the rotor and stator copper losses, and fg the constant losses. The efficiency, power-factor, current, output and slip are determined as follows:

$$\text{Efficiency} = \frac{ab}{ag}$$

$$\text{Power-factor} = \frac{ag}{aO}$$

$$\text{Current} = Oa$$

$$\text{Slip} = \frac{bd}{ad}$$

$$\text{Power output} = ab \times 1.73 \times 110 \text{ watts.}$$

Inasmuch as there is no abrupt change when the induction motor becomes a generator, it is evident that the current circle of the induction motor diagram when continued below the base line is the locus of the generator current.

For a given generator current Oa' the rotor and stator copper losses are represented by g'd' and d'f' and the output by a'b', the same as in the motor diagram; but the induction generator circle diagram does not include the losses in transforming mechanical energy into electrical energy in the rotor; that is the windage, friction and rotor core losses. f'b' therefore represents only the stator core loss.

The power-factor, slip current and output are determined as follows:

$$\text{Power-factor} = \frac{a'g'}{a'O}$$

$$\text{Slip} = \frac{b'd'}{a'd'}$$

$$\text{Current} = Oa'$$

$$\text{Output} = a'b' \times 1.73 \times 110 \text{ Watts.}$$

The efficiency $\frac{a'b'}{a'g'}$ is however only the electrical efficiency. To obtain the true input-output efficiency, the windage, friction and rotor core losses must be added to the losses obtained from the circle diagram. The windage and friction losses can be determined by test. The rotor core loss is small for normal operation and may be neglected.

It is noted from the diagram that the maximum output of the induction generator is higher than that of the induction motor.

CONCLUSIONS.

The Induction Generator requires a quadrature exciting current which varies slightly with the output but is independant of the power-factor of the load.

The output of the induction generators depends on the slip above synchronism.

The power-factor at which the induction generator operates is fixed by its slip and its constants, and not by the character of the load.

For loads having a power-factor different from that of the generator, the synchronous machine which supplies the exciting current must also supply the additional leading or lagging component demanded by the load.

The induction generator is free from hunting and will not supply current on short circuit.

The efficiency of the induction generator is lower than that of an alternator of the same rating.

The input-output efficiency of the induction generator is misleading especially when the power-factor of the load is different from that of the induction generator. The I^2R losses in the synchronous machine due to the quadrature currents required should be regarded as part of the induction generator losses in determining the efficiency,

The ideal field of the induction generator requires conditions of high power factor, high speed, large output and low frequency.

The conditions are best suited in large stations with steam turbine or high head water wheel drive.

The ideal operating condition is afforded when the induction generator is driven by an exhaust-steam turbine which receives its steam from a reciprocating engine direct-connected to an alternator.

An inefficient, but important field is found in the application of the induction generator in constant-speed braking of electric, induction-motor-driven locomotives.

APPENDIX.

DETERMINATION OF THE LOSSES OF THE D-C MACHINE CONNECTED TO THE INDUCTION MOTOR.

The losses in a d-c dynamo are I^2R losses and stray power losses. The I^2R losses depend upon the armature and field currents; the stray power losses depend principally upon the speed and field current, the other factors being too small to consider.

To determine the I^2R losses the armature and field currents were measured separately so that the I^2R losses in the field need not be considered. The armature resistance was determined and a curve plotted (curve A, appendix) showing the relation between the watts loss and armature currents so that the losses at any current can be readily determined.

By running the motor light at constant speed and varying the field current, the stray power loss was determined for speeds of 800 and 760 r.p.m. Two curves (curve sheet B, appendix) were plotted showing the relation between the stray power loss and the field current at 800 and 760 r.p.m. Between 800 and 760 r.p.m. values were easily estimated for every 10 r.p.m. and the corresponding curves drawn. The stray power loss curve sheet only contains values for speeds between 800 and 760 r.p.m. For speeds outside of this range see the accompanying data sheet.

EFFECT OF CHANGING ROTOR RESISTANCE.

Induction Generator loaded.

110 volts 50 cycles.

Induction Generator.

Amps.	Total Watts.	Rotor resist. per phase.	Power factor.	Efficiency.	Torque ft.lbs.
44.6	4550.	.0824	53.6	79.5	51.2
44.	4385.	.1745	52.4	76.5	50.2
44.	4355.	.2625	52.	73.	51.7
44.	4360.	.3405	52.	71.	52.85
44.	4350.	.4215	52.	68.5	54.7
44.	4350.	.5645	52.	63.9	59.4
44.	4350.	.7725	52.	58.1	66.
44.	4350.	.9475	52.	53.3	72.3

RELATION BETWEEN SPEED AND FREQUENCY.
Synchronous Motor running light.
110 volts.

Frequency. cycles.	Speed. r.p.m.
45.5	690.
47.75	720.
50.	760.
53.25	805.
55.25	840.
58.	885.
62.	947.
66.	1000.

RELATION BETWEEN SPEED AND ROTOR RESISTANCE.
Synchronous Motor running light.
110 volts 50 cycles.

Rotor resistance per phase. ohms.	Speed. r.p.m.
.0824	760.
.1745	765.
.2625	773.
.3405	782.
.4215	787.
.5645	800.
.7725	810.
.9475	835.

INDUCTION GENERATOR EXCITATION (cont.).

Synchronous motor running light.

50 cycles.

Power factor.	Power Current.	Exciting Current.
12.4	5.5	44.2
11.95	4.5	37.7
11.65	3.9	33.5
11.84	3.5	29.5
11.88	3.1	26.1
12.3	2.8	22.8
12.53	2.5	20.1
13.37	2.4	17.5
14.75	2.3	15.1
16.	2.2	13.3
19.	2.1	10.8
27.	2.2	8.05
41.7	2.9	6.27
49.3	2.9	5.13

INDUCTION GENERATOR EXCITATION.

Synchronous motor running light.
50 cycles.

Synchronous motor field current.	Volts.	Amperes.	Watts. +	Watts. −	Total Watts.
6.18	127.5	44.5	3460.	2246.	1214.
5.4	117.	38.	2680.	1760.	920.
4.97	110.	33.8	2230.	1480.	750.
4.4	101.	29.7	1810.	1195.	615.
4.	93.3	26.3	1480.	975.	505.
3.55	84.	23.	1180.	773.	410.
3.15	75.	20.3	930.	600.	330.
2.8	66.	17.7	730.	457.	270.
2.37	56.3	15.3	543.	322.	220.
2.	49.5	13.5	420.	235.	185.
1.63	40.	11.	285.	140.	145.
1.2	29.5	8.35	180.	65.	115.
1.	23.1	6.9	130.	25.	115.
.7	15.9	5.9	90.	10.	80.

EFFECT OF CHANGING ROTOR RESISTANCE (cont.)

Induction Generator loaded.

110 volts 50 cycles.

Driving Motor.

Volts.	Armature current.	Field current.	Losses. watts.	Watts Output.	Speed. r.p.m.
116.	53.5	1.86	603.	5607.	770.
115.	55.3	1.66	626.	5734.	804.
115.	57.5	1.54	643.	5967.	830.
115.	59.2	1.46	669.	6141.	860.
115.	61.3	1.4	699.	6351.	890.
114.3	66.3	1.2	771.	6809.	942.
114.	73.5	1.03	888.	7487.	1026.
114.	82.6	.9	1253.	8162.	1110.

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS.

Non-Inductive load.

110 volts 50 cycles.

Non-Inductive load.			Synchronous Motor.		
Watts	Watts	Total Watts	Watts	Total Current	Quadrature Current.
116.	120.	236.	960.	35.3	34.8
306.	228.	534.	970.	35.5	35.1
460.	460.	920.	1000.	36.	35.6
683.	692.	1375.	1000.	36.2	35.8
915.	920.	1835.	1000.	36.8	36.4
1150.	1146.	2296.	1020.	37.	36.5
1380.	1380.	2760.	1050.	38.	37.5
1600.	1610.	3210.	1100.	38.5	38.
1826.	1840.	3666.	1120.	39.4	38.9
2060.	2074.	4134.	1150.	40.2	39.7
2280.	2290.	4570.	1120.	41.	40.5
2500.	2514.	5014.	1250.	42.1	41.6
2726.	2730.	5456.	1300.	43.	42.5

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS. (cont.).

Non-Inductive load.

110 volts 50 cycles.

Induction Generator.

Total Watts.	Amps.	Power factor.	Efficiency.	Exciting current.
1230.	35.2	18.4	66.7	34.6
1540.	36.	22.5	71.	35.1
1970.	37.	28.	75.	35.5
2440.	37.6	34.1	77.8	35.3
2960.	39.1	39.8	80.3	35.9
3360.	40.5	43.6	79.5	36.4
3872.	42.1	48.3	81.1	36.9
4320.	44.	51.5	80.4	38.
4836.	46.	55.1	80.3	38.4
5380.	48.2	58.7	81.5	40.7
5880.	50.2	61.6	81.5	42.1
6420.	53.	63.6	80.8	40.9
6840.	55.2	65.1	78.4	41.9

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS (cont)

Non-Inductive load.

110 volts 50 cycles.

Driving Motor.

Volts	Armature current.	Field current.	Armature input watts.	Losses. watts.	Output. watts.
113.	19.5	2.07	2200.	357.	1843.
112.7	22.5	2.05	2535.	365.	2170.
111.7	27.	2.	3020.	387.	2633.
111.5	31.7	1.9	3540.	406.	3134.
111.4	37.	1.86	4125.	438.	3687.
111.	42.3	1.81	4700.	478.	4222.
111.	48.	1.77	5330.	533.	4767.
110.3	54.	1.73	5960.	591.	5369.
110.	60.8	1.68	6690.	674.	6016.
109.7	67.	1.66	7350.	755.	6595.
109.	74.	1.65	8070.	863.	7207.
108.	83.	1.63	8960.	1013.	7947.
107.5	92.	1.58	9900.	1180.	8720.

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS (cont.)

Leading load.

110 volts 50 cycles.

Inductive load.

Amps.	Watts.	Watts.	Total watts.	Power factor.	Synchronous motor quadrature current.
4.2	440.	210.	650.	81.4	32.
6.4	680.	320.	1000.	82.	31.5
9.3	1000.	450.	1450.	82.	30.
12.	1250.	580.	1830.	80.	28.
15.	1640.	760.	2400.	84.1	27.5
18.	1980.	900.	2880.	84.	27.
21.	2280.	1100.	3380.	84.6	26.5
23.4	2520.	1170.	3690.	82.9	25.
27.8	3000.	1400.	4400.	83.	24.
30.7	3320.	1580.	4900.	84.	25.
35.	3800.	1790.	5590.	83,9	23.5
38.2	4140.	1952.	6090.	83.7	23.5

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS (cont.)

Leading load.

110 volts 50 cycles.

Induction Generator.

Total watts.	Amps.	Power factor.	Efficiency	Exciting current.
970.	34.3	14.9	61.4	33.9
1300.	35.	19.5	66.7	34.3
1790.	36.	26.2	72.8	34.7
2280.	36.5	32.9	79.4	34.5
2800.	38.6	38.1	80.2	35.6
3170.	39.6	42.1	78.1	35.9
3710.	41.4	47.1	79.	36.6
4070.	42.5	50.3	79.8	36.7
4840.	45.5	55.9	79.7	37.7
5360.	48.5	58.1	79.8	40.
6080.	51.5	62.0	7.89	37.2
6680.	54.5	64.5	77.8	41.7

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS (cont.)

Leading Load.

110 volts 50 cycles.

Driving Motor.

Volts.	Armature current.	Field current.	Armature input. watts.	Losses watts.	Output. watts.
116.	16.7	2.2	1939.	360.	1579.
115.5	20.1	2.2	2320.	370.	1950.
115.	16.	2.2	1840.	360.	1480.
114.	25.	2.1	2850.	390.	2460.
114.	28.7	2.	3270.	400.	2870.
113.	34.7	1.9	3920.	430.	3490.
113.	40.	1.85	4520.	460.	4060.
113.5	46.	1.85	5220.	520.	4200.
114.	49.5	1.85	5650.	550.	5100.
113.	59.5	1.77	6730.	660.	6070.
112.3	66.5	1.71	7460.	750.	6710.
112.	77.	1.65	8620.	910.	7710.
110.	88.	1.55	9690.	1100.	8590.

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS (cont.)

Lagging load.

110 volts 50 cycles.

Amps.	Inductive load Watts. +	Watts. +	Total watts.	Power factor.	Synchronous motor quadrature current.
4.	160.	360.	520.	68.3	36.5
7.8	340.	820.	1160.	78.	39.
11.7	560.	1270.	1830.	82.2	42.05
16.	780.	1750.	2530.	83.	45.4
19.7	920.	2120.	3040.	81.	48.
23.1	1120.	2520.	3640.	82.9	51.4
26.3	1268.	2820.	4088.	81.9	53.6
29.3	1400.	3144.	4544.	81.5	56.4
32.5	1520.	3500.	5020.	81.1	60.
35.7	1640.	3860.	5500.	81.	63.5

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS (cont.)

Lagging load.

110 volts 50 cycles.

Induction Generator.

Total Watts.	Amps.	Power factor.	Efficiency	Exciting current.
860.	35.5	12.9	60.	34.7
1510.	35.6	22.3	69.2	34.7
2240.	37.3	31.55	75.5	35.4
2990.	39.3	40.	77.	36.
3570.	41.	45.8	79.	36.4
4220.	44.	50.9	79.5	38.
4700.	45.7	54.	78.6	38.5
5310.	48.4	57.7	79.	39.5
5880.	51.	60.6	78.3	40.6
6500.	54.	63.	76.8	43.

EFFECT OF NON-INDUCTIVE, LEADING AND LAGGING LOADS (cont.).

Lagging load.

110 volts 50 cycles.

Driving Motor.

Volts	Armature current.	Field current.	Armature input watts.	Losses. watts.	Output. watts.
111.5	16.	2.08	1783.	347.	1436.
111.	23.	2.	2550.	368.	2182.
110.6	30.4	1.87	3360.	396.	2964.
110.	39.5	1.81	4350.	456.	3894.
110.	45.6	1.8	5020.	506.	4514.
110.	53.6	1.75	5900.	593.	5307.
109.	61.	1.65	6650.	673.	5977.
108.5	69.	1.61	7500.	780.	6720.
108.	78.	1.56	8420.	915.	7505.
107.5	89.	1.49	9570.	1110.	8460.

INDUCTION GENERATOR LOAD TEST.

110 volts 50.5 cycles.

Induction Generator.

Amps.	Watts. −	Watts. +	Total Watts. output.	Power factor.	Efficiency.
32.7	1670.	2180.	510.	8.2	44.2
33.5	1280.	2560.	1280.	20.1	65.5
34.7	1040.	2880.	1840.	27.9	71.5
36.	760.	3240.	2480.	36.2	75.9
37.6	500.	3540.	3040.	42.5	76.6
39.	280.	3820.	3540.	47.7	77.
41.4	# 20.	4160.	4140.	52.5	77.8
46.	450.	4840.	5290.	60.4	78.5
48.9	720.	5240.	5960.	64.	78.
52.	960.	5600.	6560.	66.2	76.
53.5	1100.	5840.	6940.	68.1	75.1

Reverse.

INDUCTION GENERATOR LOAD TEST (cont.)

110 volts 50.5 cycles.

Induction Generator (cont.)

Torque	Slip r.p.m.	Speed r.p.m.	% Slip.
10.7	5.	765.	.6
18.1	9.	769.	1.2
24.8	12.	772.	1.6
30.2	13.	773.	1.7
36.3	19.	779.	2.5
42.	21.	781.	2.8
48.3	24.	784.	3.2
60.8	30.	790.	4.1
68.5	34.	794.	4.5
77.2	37.	797.	5.

INDUCTION GENERATOR LOAD TEST (cont.)

110 volts 50.5 cycles.

Driving Motor.

Volts.	Armature current.	Field current.	Armature input. watts.	Losses watts.	Output. watts.
113.5	13.1	2.1	1487.	335.	1152.
113.	20.4	1.97	2305.	349.	1956.
113.5	26.	1.95	2950.	373.	2577.
113.	32.6	1.89	3680.	410.	3270.
113.	39.2	1.84	4430.	460.	3970.
113.	45.2	1.8	5110.	511.	4600.
113.	52.2	1.75	5900.	580.	5320.
113.	66.3	1.67	7490.	750.	6740.
112.7	76.9	1.63	8560.	919.	7641.
112.	86.9	1.57	9730.	1084.	8646.
11.5	93.6	1.44	10440.	1200.	9240.

INDUCTION MOTOR LOAD TEST.

110 volts. 50.5 cycles.

Induction Motor.

Watts. −	Watts. +	Total watts input.	Amps.	Power factor.
.790	2.790	2.000	34.2	30.7
.45	3.160	2.710	35.5	40.1
.114	3.520	3.410	37.2	48.1
# .260	3.920	4.180	39.4	55.7
.552	4.352	4.904	42.6	60.5
.640	4.520	5.160	43.6	62.2
.960	4.920	5.880	46.5	66.4
1.250	5.280	6.530	49.3	69.6
1.560	5.700	7.260	52.6	72.6
1.650	5.828	7.480	53.6	73.4
1.948	6.200	8.150	57.6	74.4
2.130	6.440	8.570	60.	75.
2.480	6.970	9.450	64.5	77.

Reverse.

INDUCTION MOTOR LOAD TEST (cont.)

110 volts 50.5 cycles.

Induction Motor (cont.)

Efficiency.	Torque ft.x lbs.	Slip	Speed r.p.m.	% Slip.
71.5	13.4	10.7	749.	1.4
77.4	19.8	14.3	746.	1.9
80.	25.8	17.9	742.	2.4
81.	32.3	22.2	738.	2.9
81.6	38.3	24.7	735.	3.3
82.1	40.7	26.9	733.	3.5
82.2	46.7	30.	730.	4.
82.1	51.9	33.4	727.	4.4
82.1	58.3	38.7	721.	5.1
81.3	59.5	40.	720.	5.2
81.4	65.3	45.1	715.	5.9
81.	68.7	48.	712.	6.3
79.6	75.	54.5	706.	7.1

INDUCTION MOTOR LOAD TEST (cont.)

110 volts 50.5 cycles.

Generator.

Volts.	Armature current.	Armature output watts.	Motor output watts.	Gen. field.	Losses. watts.
110.	9.8	1078.	1429.	2.4	351.
109.	15.9	1730.	2094.	2.4	364.
108.	21.7	2340.	2722.	2.4	382.
106.3	28.	2980.	3390.	2.4	410.
106.5	33.3	3550.	4007.	2.57	457.
110.	34.2	3760.	4241.	2.8	481.
107.5	40.2	4320.	4846.	2.77	526.
105.	45.7	4800.	5357.	2.7	557.
103.	52.	5350.	5968.	2.68	618.
101.5	53.7	5450.	6081.	2.6	631.
98.2	60.3	5920.	6625.	2.6	705.
97.	64.	6200.	6952.	2.6	752.
94.	71.	6680.	7527.	2.6	847.

STRAY POWER LOSS OF DRIVING MOTOR.

Field	Speed	Armature volts	Armature amps.	Stray Power Watts.
1.86	770.	104.5	2.9	303.
1.66	804.	104.5	2.9	303.
1.54	830.	104.	2.87	298.
1.46	860.	104.2	2.9	302.
1.4	890.	104.8	2.9	304.
1.2	942.	102.5	3.	308.
1.03	1025.	101.	3.15	318.
.9	1110.	99.4	3.3	326.
1.	760.	74.	2.9	215.
1.05	760.	75.	2.84	213.
1.1	760.	77.	2.8	216.
1.2	760.	81.5	2.8	228.
1.3	760.	84.5	2.8	237.
1.4	760.	88.3	2.75	243.
1.5	760.	92.7	2.8	260.
1.6	760.	96.3	2.8	270.
1.7	760.	99.	2.8	277.
1.8	760.	102.	2.8	286.
1.9	760.	105.	2.86	300.
2.	760.	107.	2.9	310.
2.1	760.	109.	2.92	318.

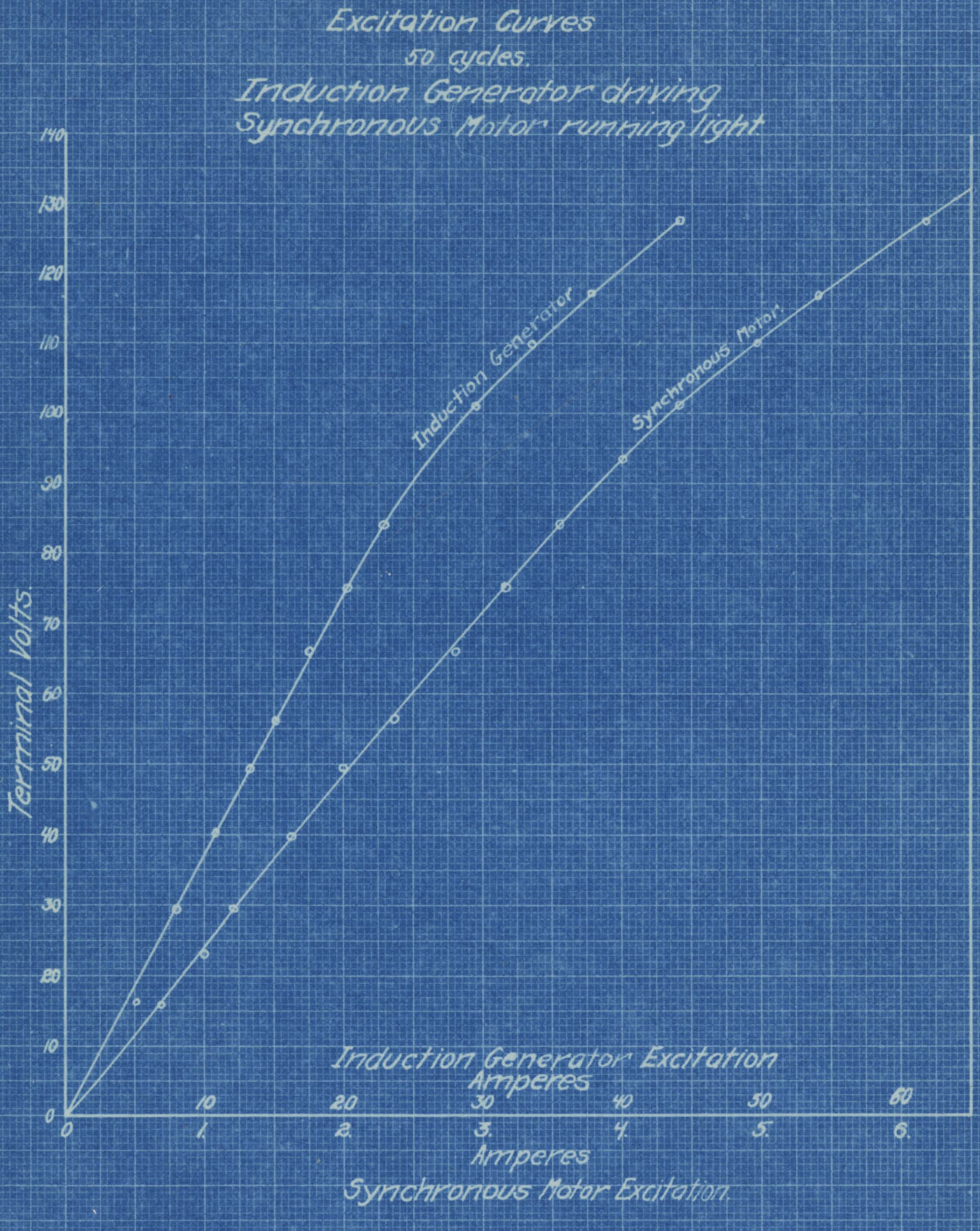
STRAY POWER LOSS OF DRIVING MOTOR.

Field.	Speed.	Armature volts.	Armature amps.	Stray Power Watts.
2.2	760.	112.5	2.97	334.
2.3	760.	114.	3.	342.
2.4	760.	116.	3.02	350.
2.6	760.	119.	3.15	375.
2.4	800.	122.	3.17	387.
2.2	800.	119.5	3.05	364.
2.	800.	114.5	2.95	348.
1.9	800.	112.5	2.95	332.
1.8	800.	110.	2.9	319.
1.7	800.	107.5	2.87	308.
1.6	800.	105.	2.85	299.
1.5	800.	101.5	2.8	284.
1.4	800.	97.5	2.8	273.
1.3	800.	94.	2.8	263.
1.2	800.	89.7	2.8	251.
1.1	800.	85.	2.8	238.
1.	800.	79.3	2.8	222.
2.4	749.	113.	3.1	341.
2.4	746.	113.	2.98	337.
2.4	742.	113.	2.94	332.
2.4	738.	112.5	2.94	330.
2.57	735.	113.	3.02	343.

STRAY POWER LOSS OF DRIVING MOTOR.

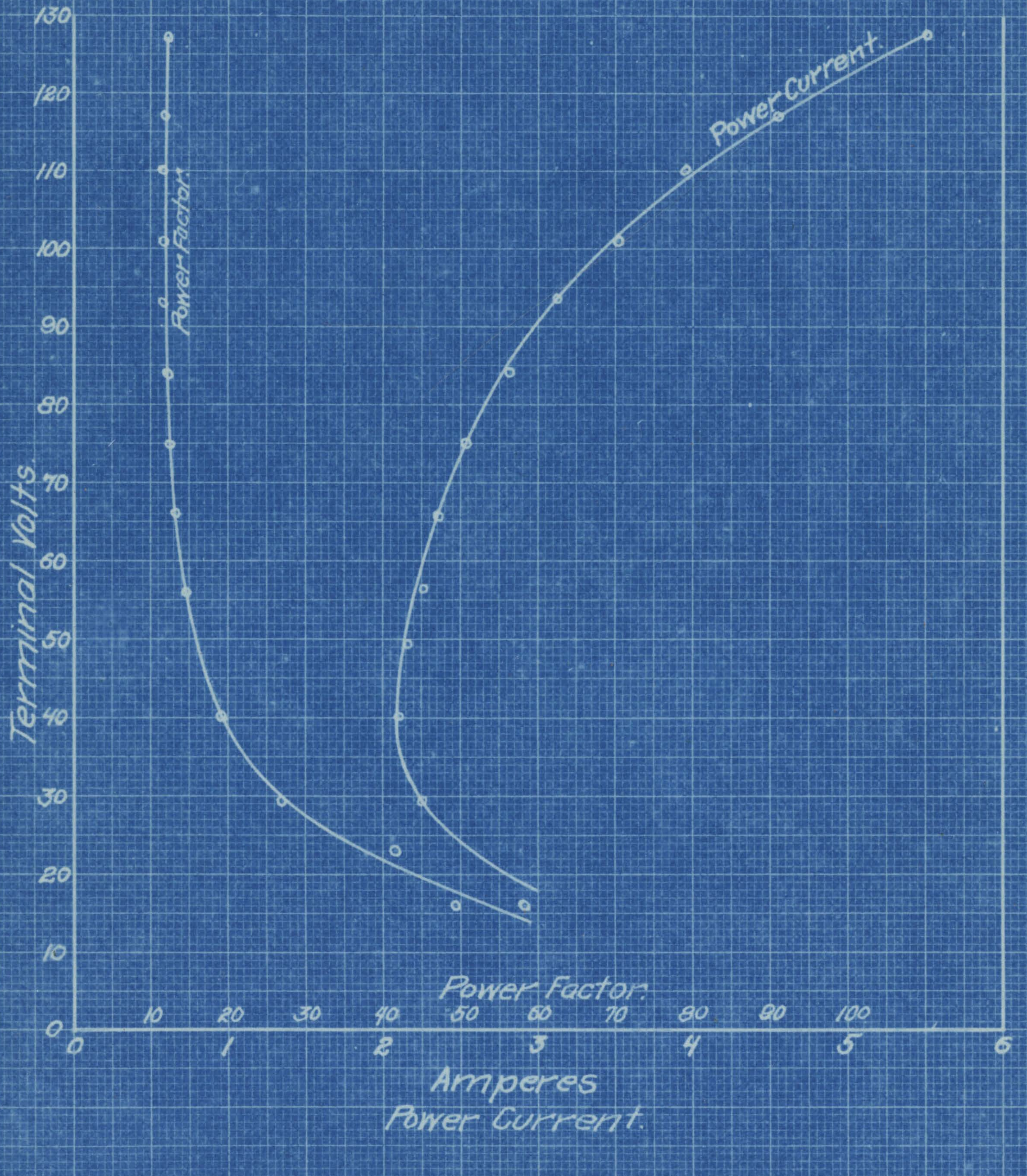
Field.	Speed.	Armature volts.	Armature amps.	Stray Power Watts.
2.8	733.	112.	3.22	361.
2.77	730.	112.	3.18	356.
2.7	727.	111.	3.12	347.
2.68	721.	112.	3.02	338.
2.6	720.	112.	2.96	331.
2.6	715.	112.	2.91	325.
2.6	712.	113.	2.85	322.
2.6	706.	113.	2.81	317.

Armature losses being less than .3%, were neglected.

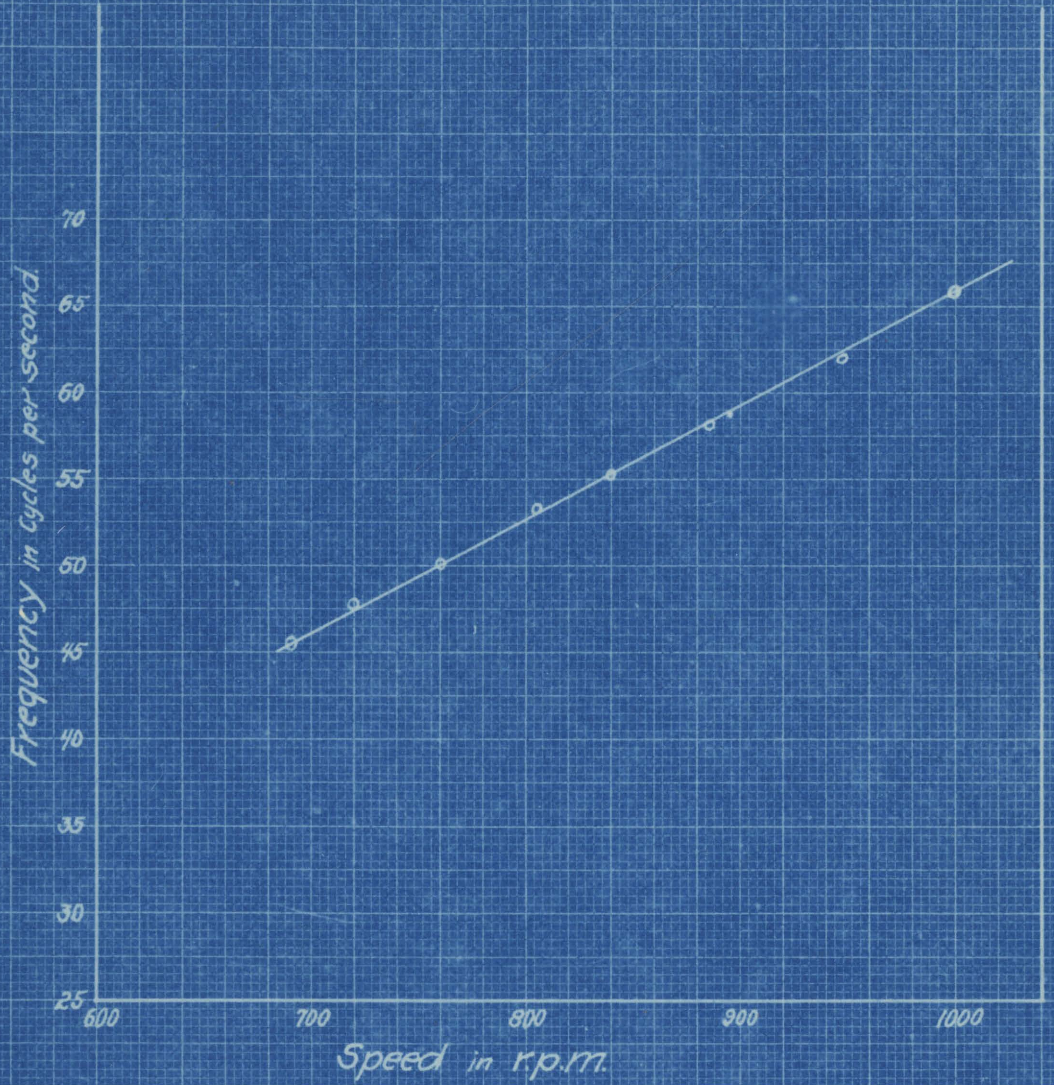


Excitation Curves
50 cycles.
Induction Generator driving
Synchronous Motor running light.
Terminal Volts.
Induction Generator
Synchronous Motor
Induction Generator Excitation
Amperes
Amperes
Synchronous Motor Excitation.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
1.
2.
3.
4.
5.
6.

Power Factor and Power Current Curves of Induction Generator driving the Synchronous Motor running light 50 cycles

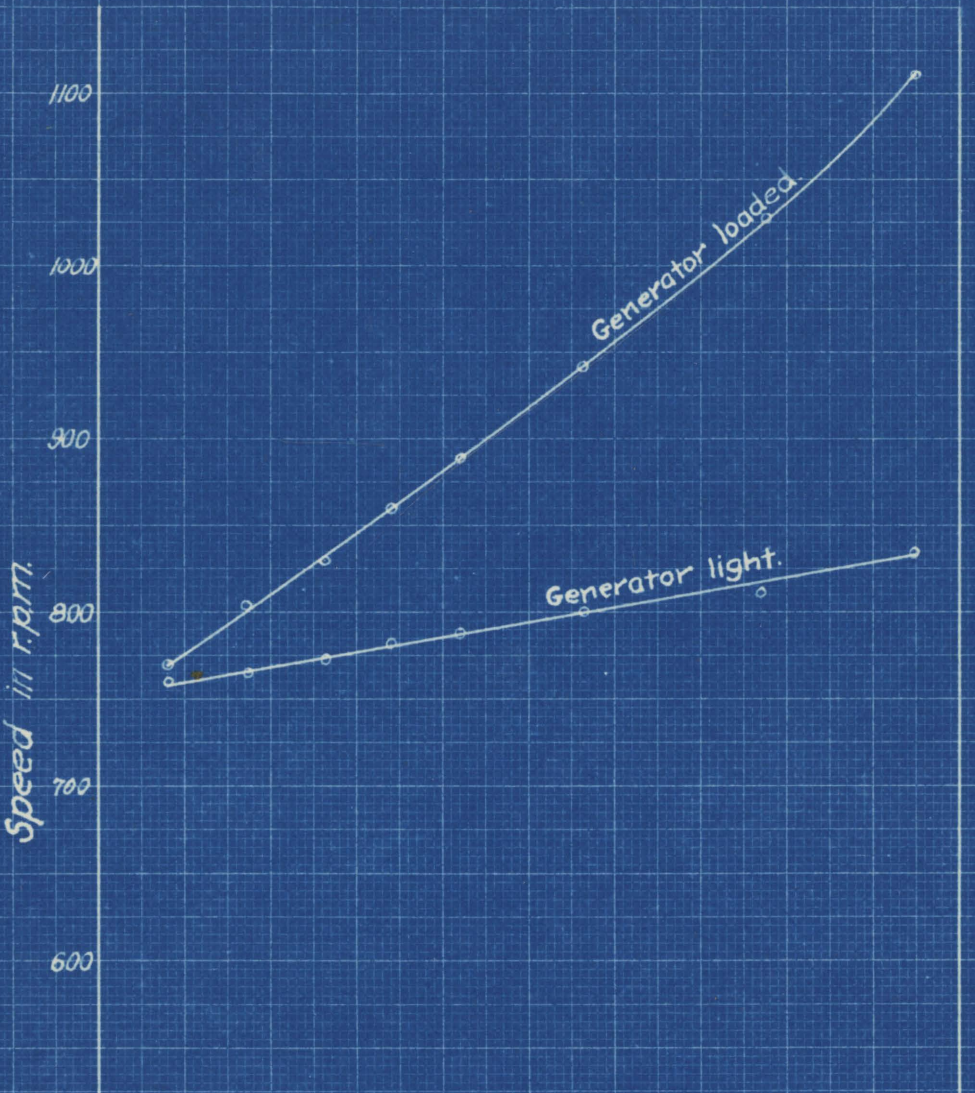


Relation between the frequency and speed of the Induction Generator. 110 volts



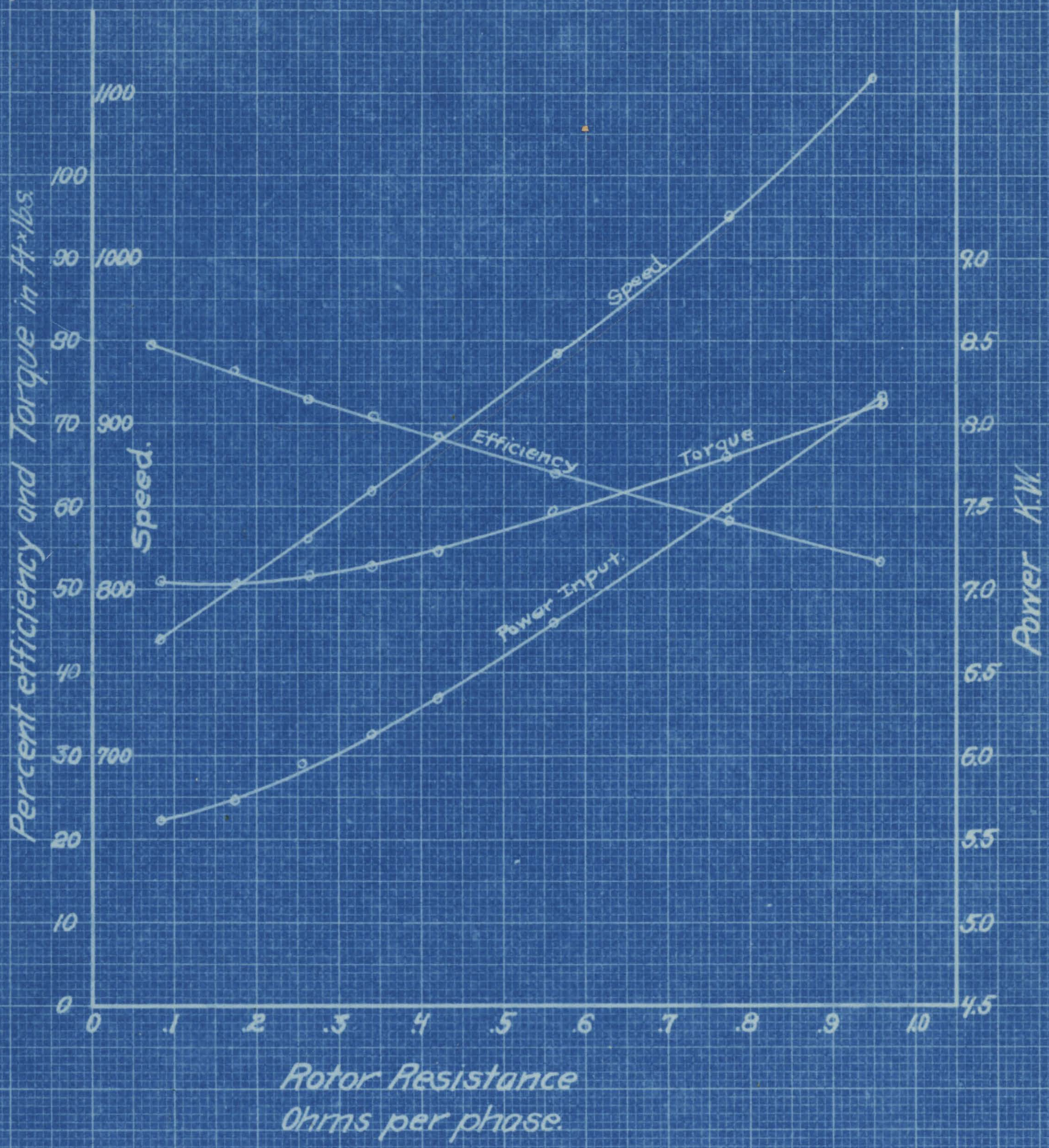
Effect of Rotor Resistance on the Speed of the Induction Generator.

110 volts - 50 cycles.

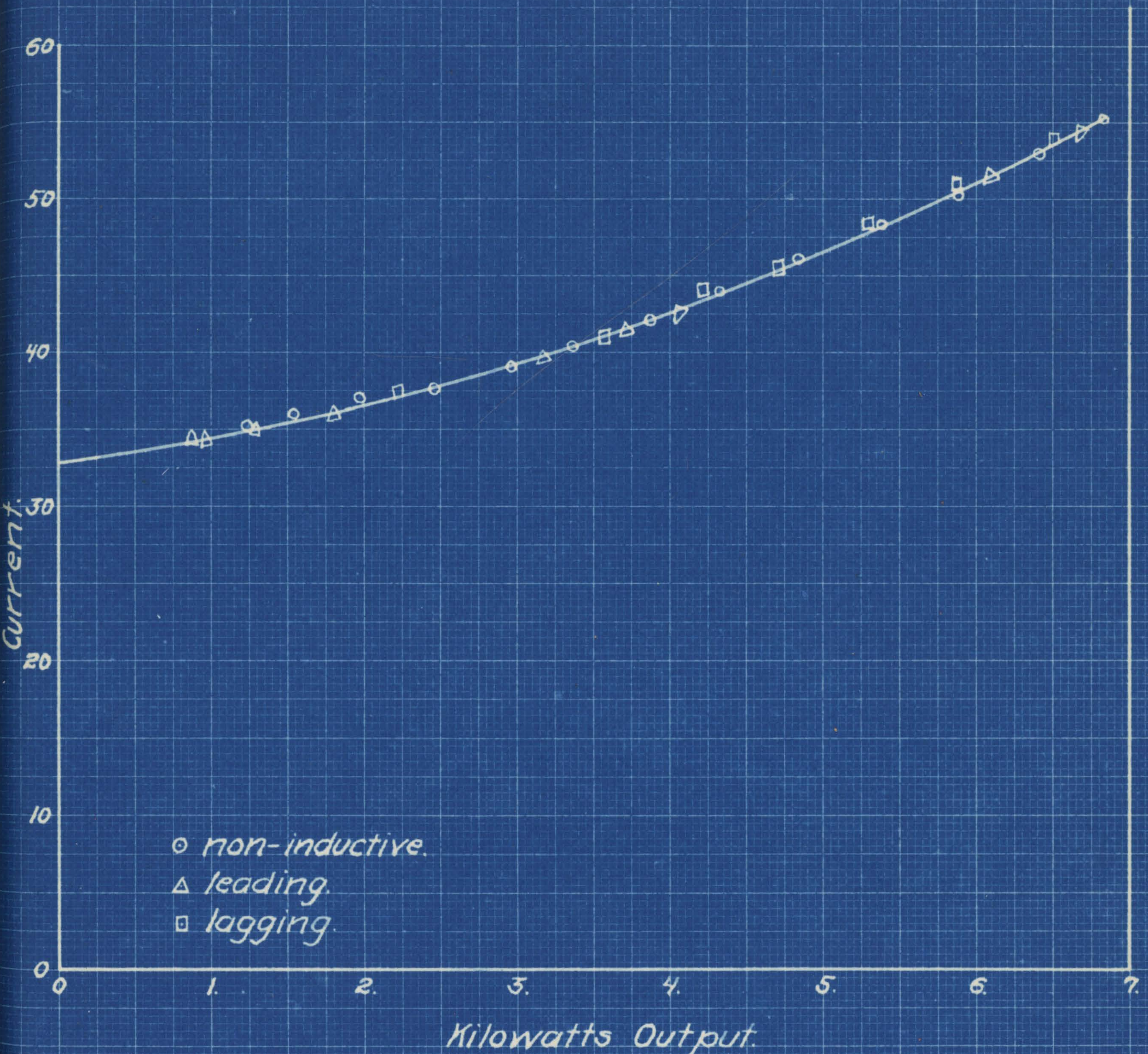


Rotor Resistance.
Ohms per Phase.

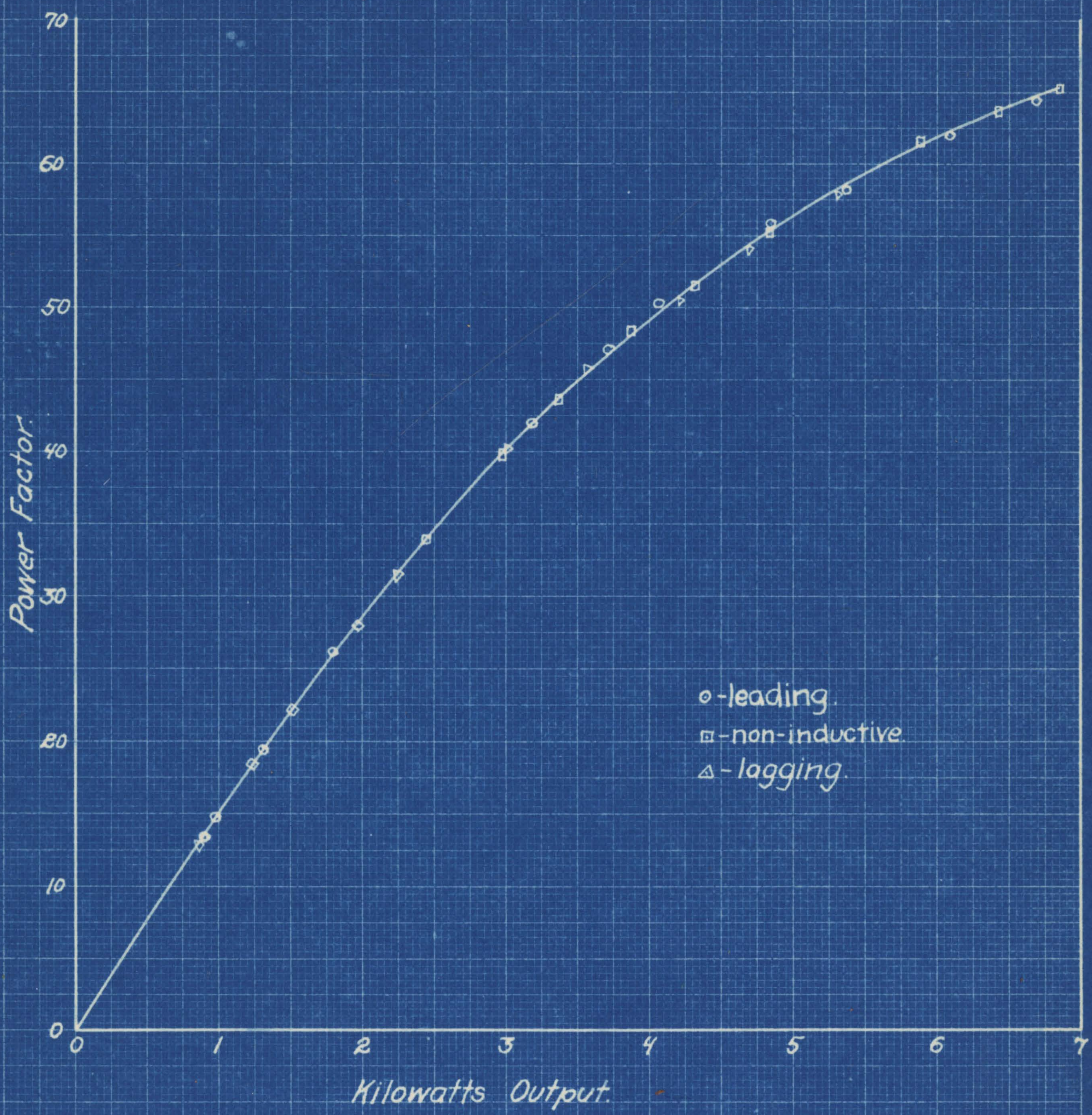
Effect of the Rotor Resistance on the speed, torque, power input and efficiency of the Induction Generator at constant load. 110 volts, 50 cycles.



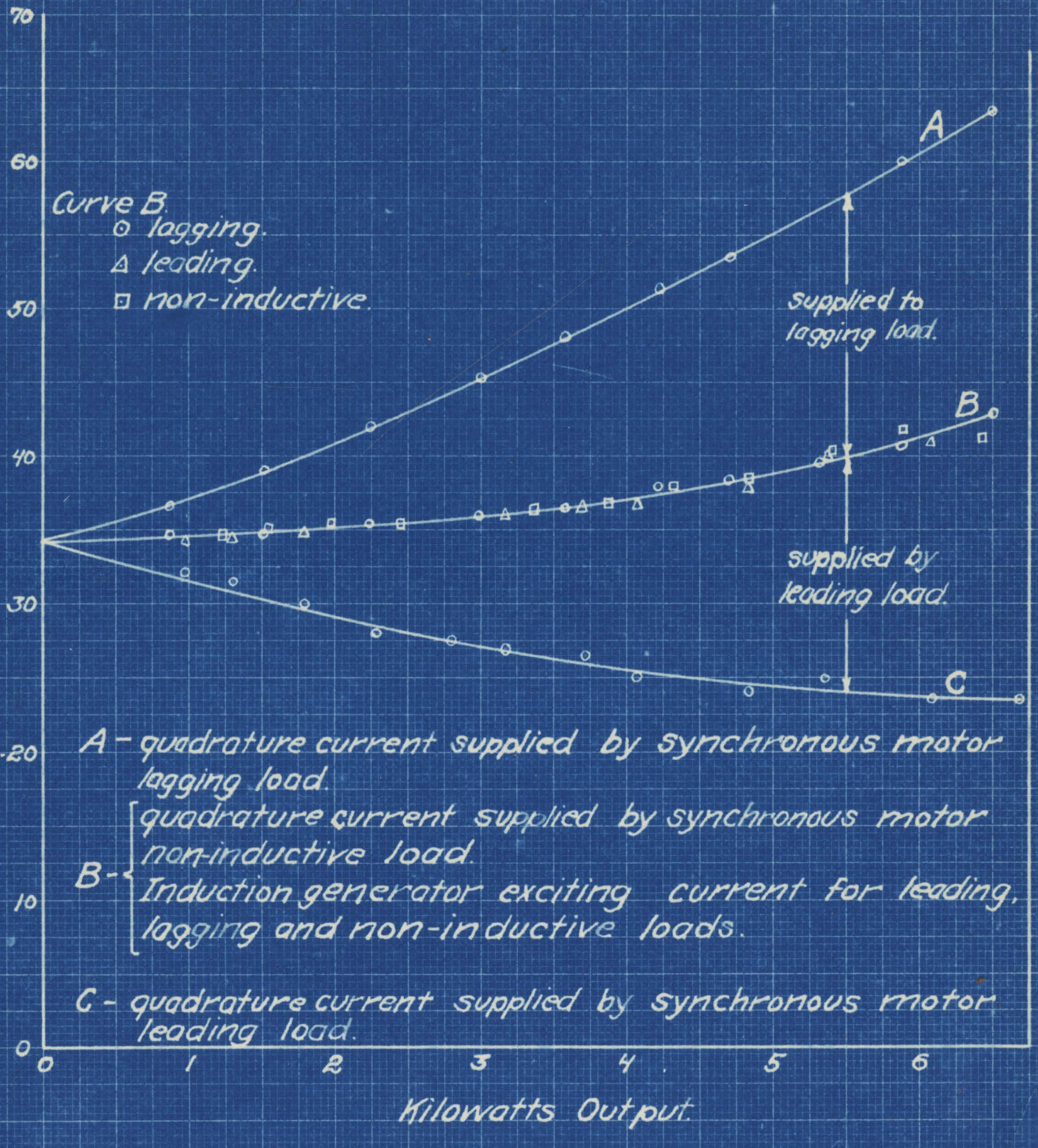
Induction Generator Load Current for leading, lagging and non-inductive loads. 110 volts - 50 cycles.



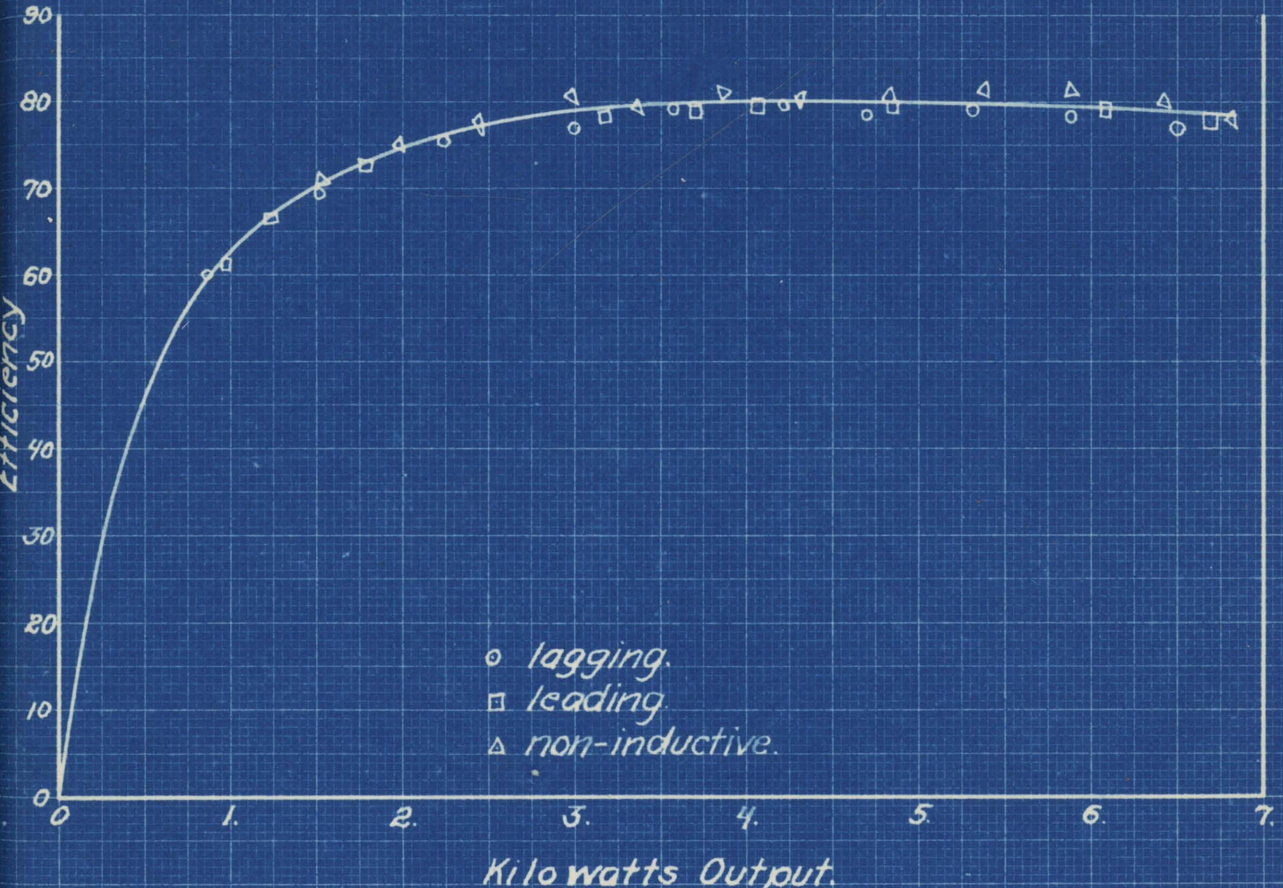
Induction Generator Power Factor for leading-lagging and non-inductive loads. 110 volts, 50 cycles.

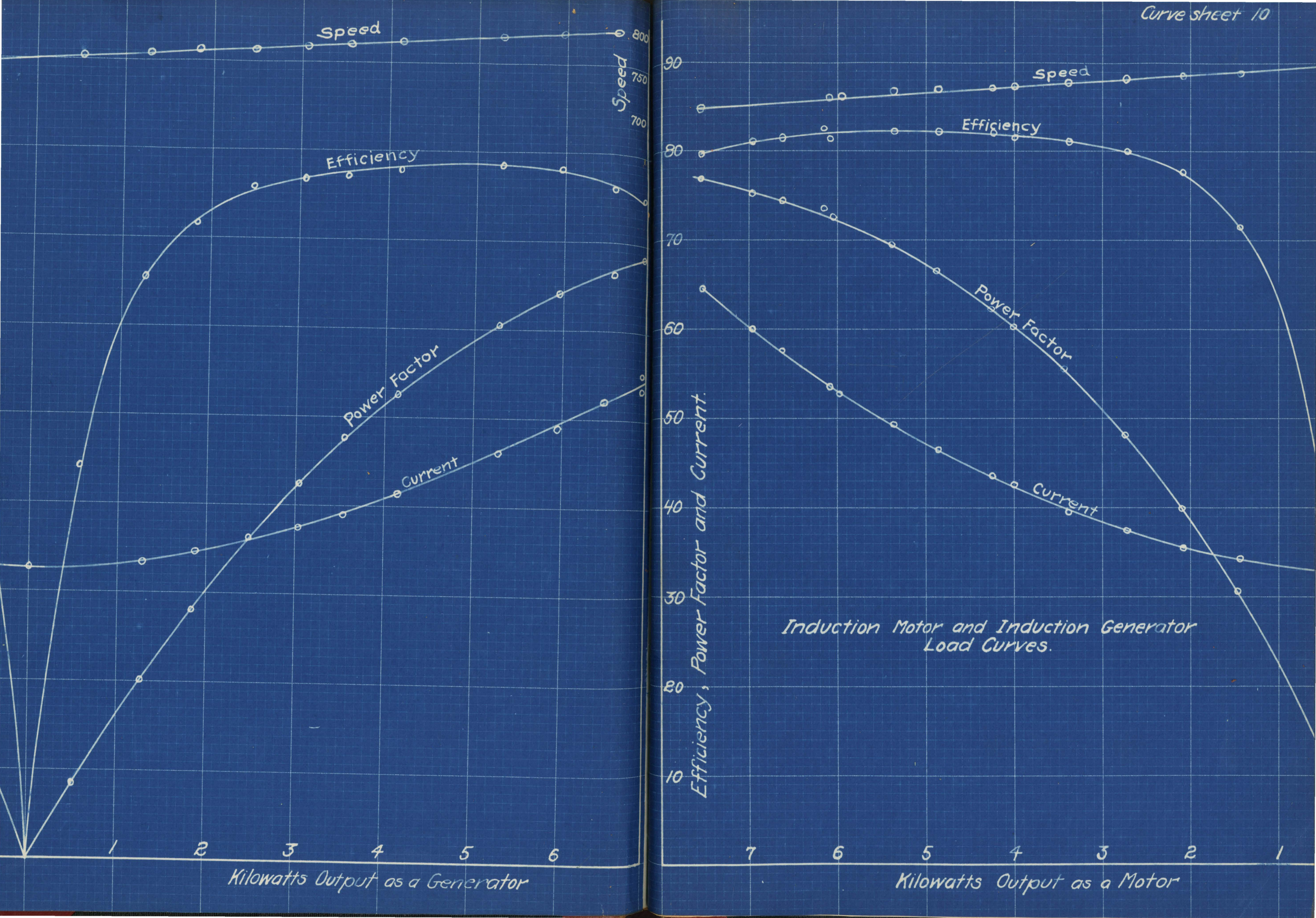


Quadrature and Exciting Current Curves
Induction Generator loaded with leading
lagging and non-inductive loads.
Synchronous motor supplying quadrature
current. 110 volts.- 50 cycles.



Induction Generator Efficiency for leading, lagging and non-inductive loads.

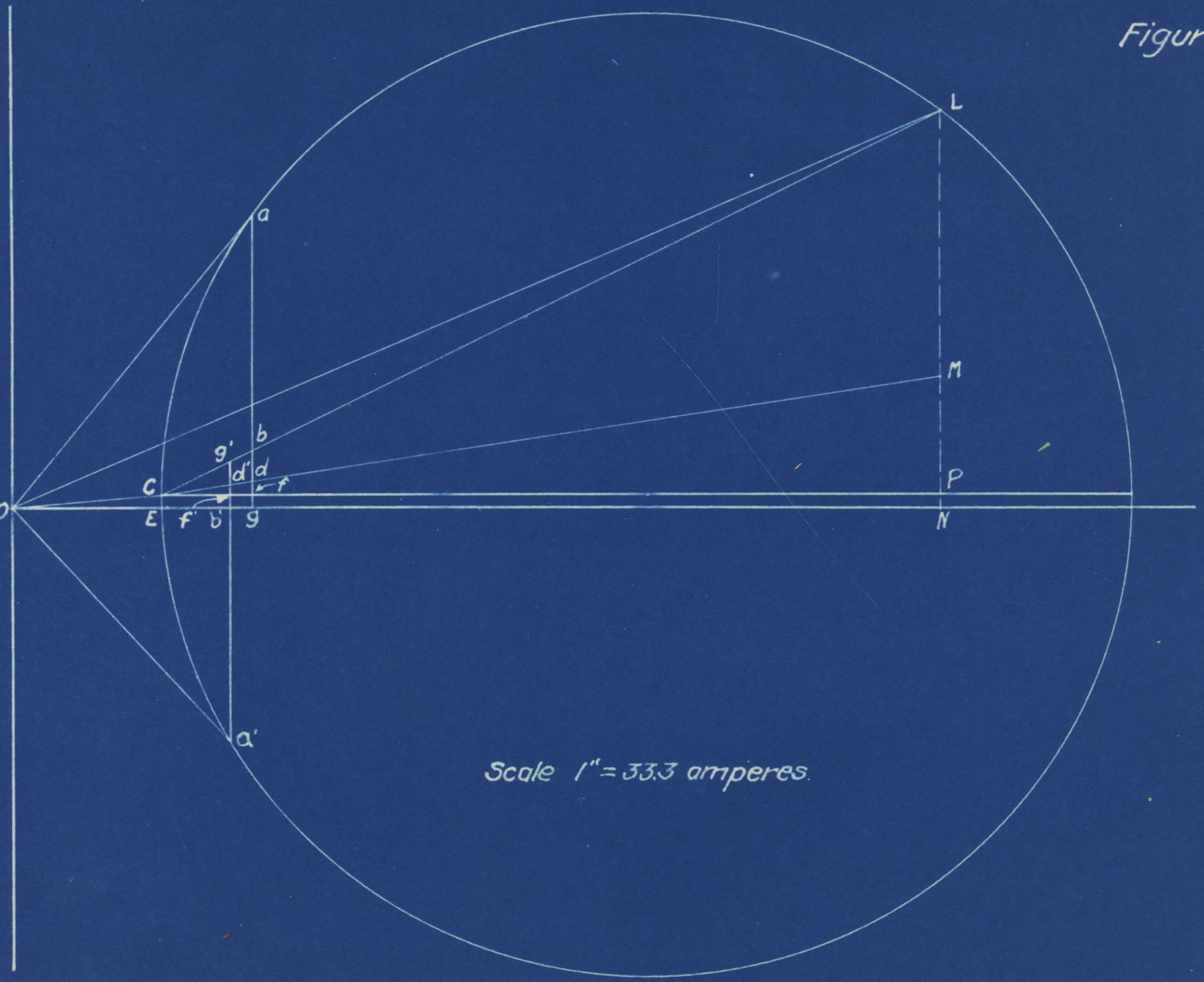




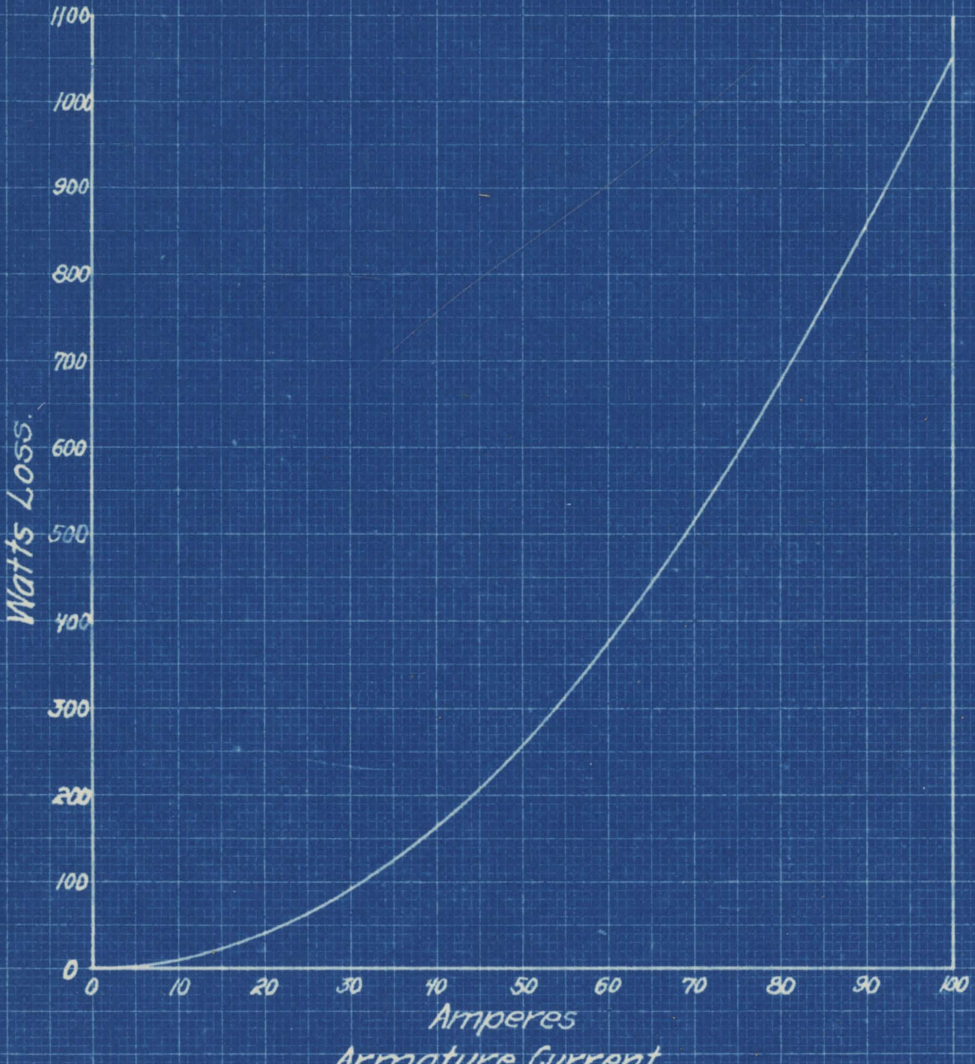
Curve sheet 10
Speed
Efficiency
Power Factor
Current
800
750
700
Speed
1 2 3 4 5 6
Kilowatts Output as a Generator
90
80
70
60
50
40
30
20
10
Efficiency, Power Factor and Current.
Speed
Efficiency
Power Factor
Current
Induction Motor and Induction Generator
Load Curves.
7 6 5 4 3 2 1
Kilowatts Output as a Motor

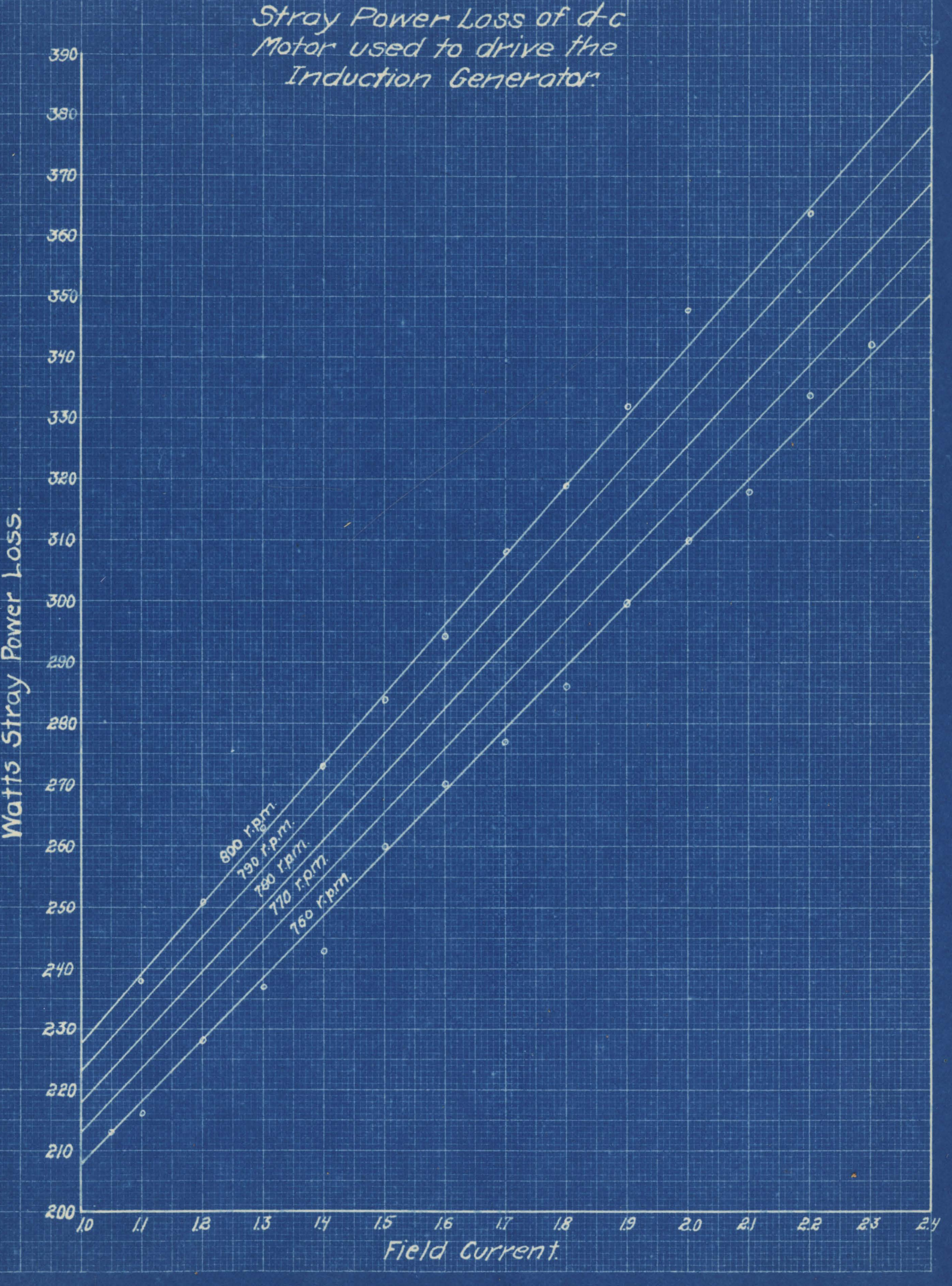
CIRCLE DIAGRAM.

Figure 1.



Loss in the armature of the d-c Motor used to drive the Induction Generator.




Stray Power Loss of d-c Motor used to drive the Induction Generator.
Watts Stray Power Loss.
Field Current.
800 r.p.m.
790 r.p.m.
780 r.p.m.
770 r.p.m.
760 r.p.m.
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4