TEST ON ROTARY CONVERTER

THESIS

UNDER DR. CHAS. A. PERKINS

FOR

THE DEGREE, OF BACHELOR OF

SCIENCE IN ELECTRICAL ENGINEERING

BY

BERNIE MARTIN & D. DANEY MILLER.

MAY - 1909.

I. Calibration of D. C. Instruments----------Page 5
II. " " A. C. "---------- " 9
III. Resistance of Field---------- " 9
IV. " " Armature---------- " 9
V. Stray Power Losses---------- " 14
VI. Armature Current- Field Current---------- " 14
VII. Brush and Brush Contact Losses---------- " 16-19
VIII. Efficiency, (Calculated)---------- " 25
IX. Flux Distribution---------- " 25
X. Phase Characteristics---------- " 29
XI. Voltage Relations---------- " 33
XII. Phase Lag---------- " 37
XIII. Heat Run---------- " 39
XIV. Saturation Curve---------- " 40
XV. Short-Circuit Characteristic---------- " "
XVI. Inductance of Armature (Calculated)---------- " "
XVII. Armature Winding, Diagram No. II

A synchronous converter or rotary converter as it is generally called, is a machine used primarily for the purpose of converting alternating current into direct current.
A machine of this type may be driven by an engine or turbine and thus act as a generator, delivering alternating current or direct current or both; it may be driven as an alternating current motor, direct current motor or both; it may be used as a synchronous alternating current motor to drive a direct current generator (i.e. a motor generator set), but the most important use of the machine is to act as a rotary converter.

The purpose of the following experiments and tests was to determine with a fair degree of accuracy, the behavior of the rotary converter in the Labratory of the University of Tennessee.

Description of Machine.

The machine was manufactured by the General Electric Company. It is a six ring, sixty cycle machine rated at seven and one-half kilowatts. The rated speed is 1800 R. P. M.; current output 47-68 amperes and corresponding voltage of 160-110. The machine has ninety-six (96) commutator bars, four (4) field spool; each spool having 1260 turnsof 0.051" diameter copper wire. The armature has forty-eight (48) slots; each slot containing twelve inductors of No. 10 wire (B. and S. gauge). The winding is of the multiple-drum type

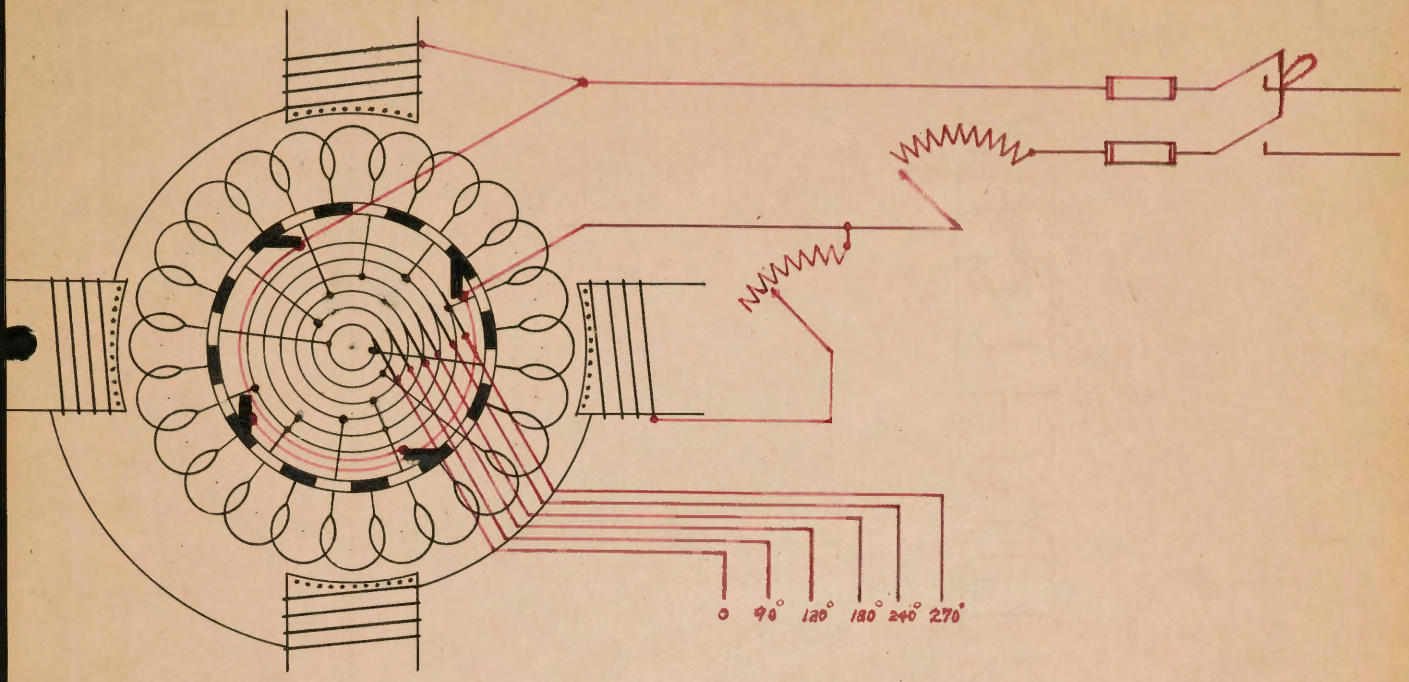


Diagram Nº I

External Connections and Taps for Rotary Converter

and commutates every three turns. A diagram of the armature winding is shown on Diagram No. II.

The type of winding (i.e. lap or wave) was determined by sending a current from one set of brushes to the next set thru the armature (the other two sets of brushes being taken off the commutator) and then taking a low reading voltmeter and slipping one lead under one of the sets of brushes so that it is in direct contact with the commutator bars and then moving the other lead from one consecutive commutator bar to the next and noting the drop of voltage. If the drop had increased gradually it would have shown that the winding was lap, but as it was, the drop in voltage decreased and then increased depending on whether the contact was under a brush position or between, which showed that the winding was wave.

The machine has six rings so that different phase currents may be obtained. To do this, taps are brought out to the rings at 0, 90, 120, 180, 240, and 270 electrical degreesapart. This gives symmetrical single, two and three phase currents.

Instruments.

The instruments used for the various tests were carefully calibrated and correction curves drawn for each (See plates I and II).

The D. C. instruments were calibrated by comparisonwith the Standard voltmeter. This was done by calibrating Millivoltmeters No. I and II as voltmeters and then using these instruments with shunts as standard ammeters.

Armature Winding of 4 Pole Rotary Converter
Drum duplex wave winding; single reëntrant
front pitch = 46, back pitch = 46, commutator
pitch = 46, 576 inductors, each coil (shown
in heavy black lines, see fig.) consists of three
wires. 48 slots, 96 commutator bars.
For the sake of simplicity in drawing, only
half the commutator bars and half the
inductors and connections are shown.
A.C. connections tapped off as shown.

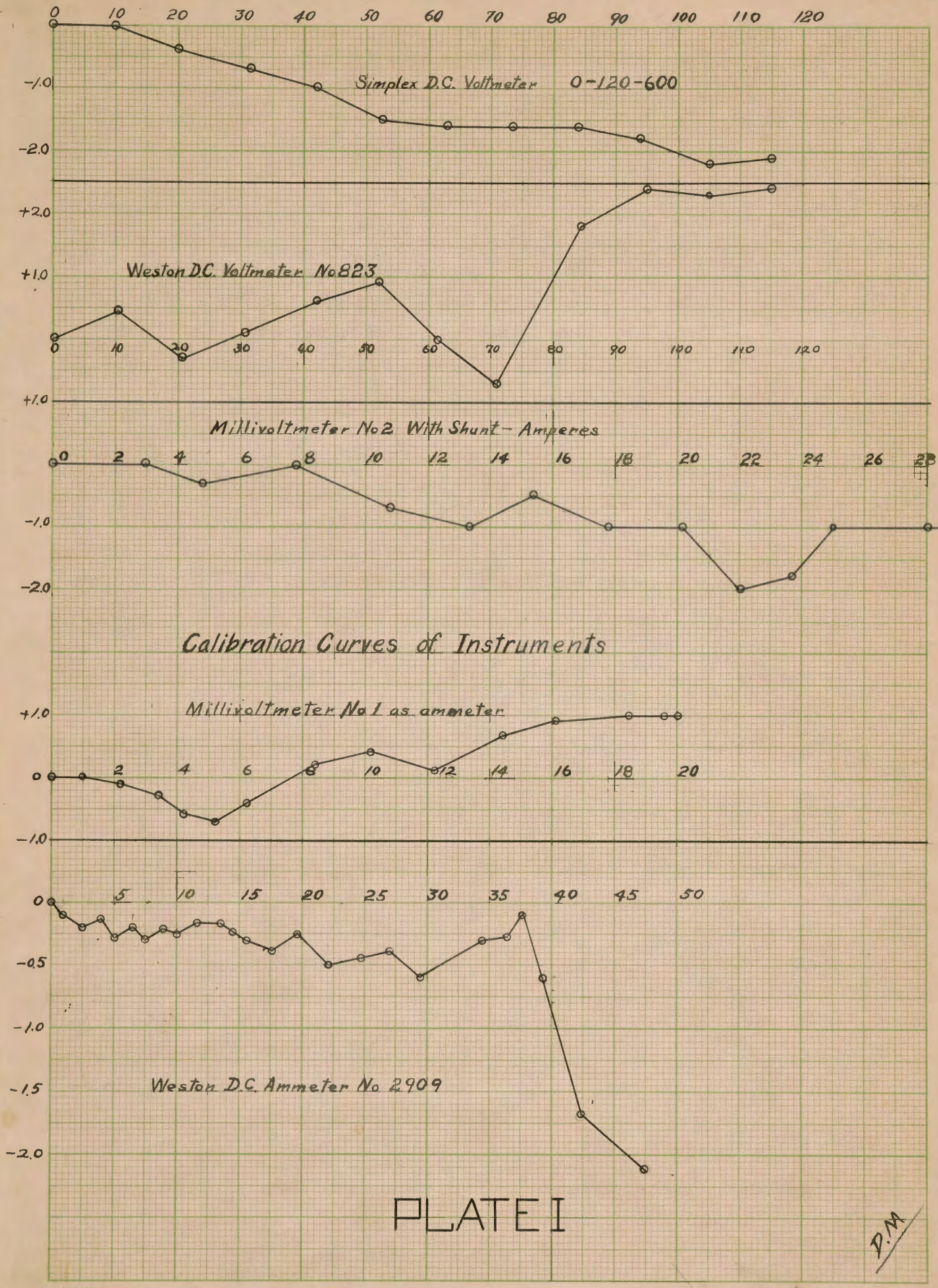

0 10 20 30 40 50 60 70 80 90 100 110 120
-1.0
-2.0
Simplex D.C. Voltmeter 0-120-600
+2.0
+1.0
Weston D.C. Voltmeter No 823
0 10 20 30 40 50 60 70 80 90 100 110 120
+1.0
Millivoltmeter No 2 With Shunt - Amperes
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
-1.0
-2.0
Calibration Curves of Instruments
Millivoltmeter No 1 as ammeter
+1.0
0 2 4 6 8 10 12 14 16 18 20
-1.0
0 5 10 15 20 25 30 35 40 45 50
-0.5
-1.0
-1.5
Weston D.C. Ammeter No 2909
-2.0

PLATE I

D.M.

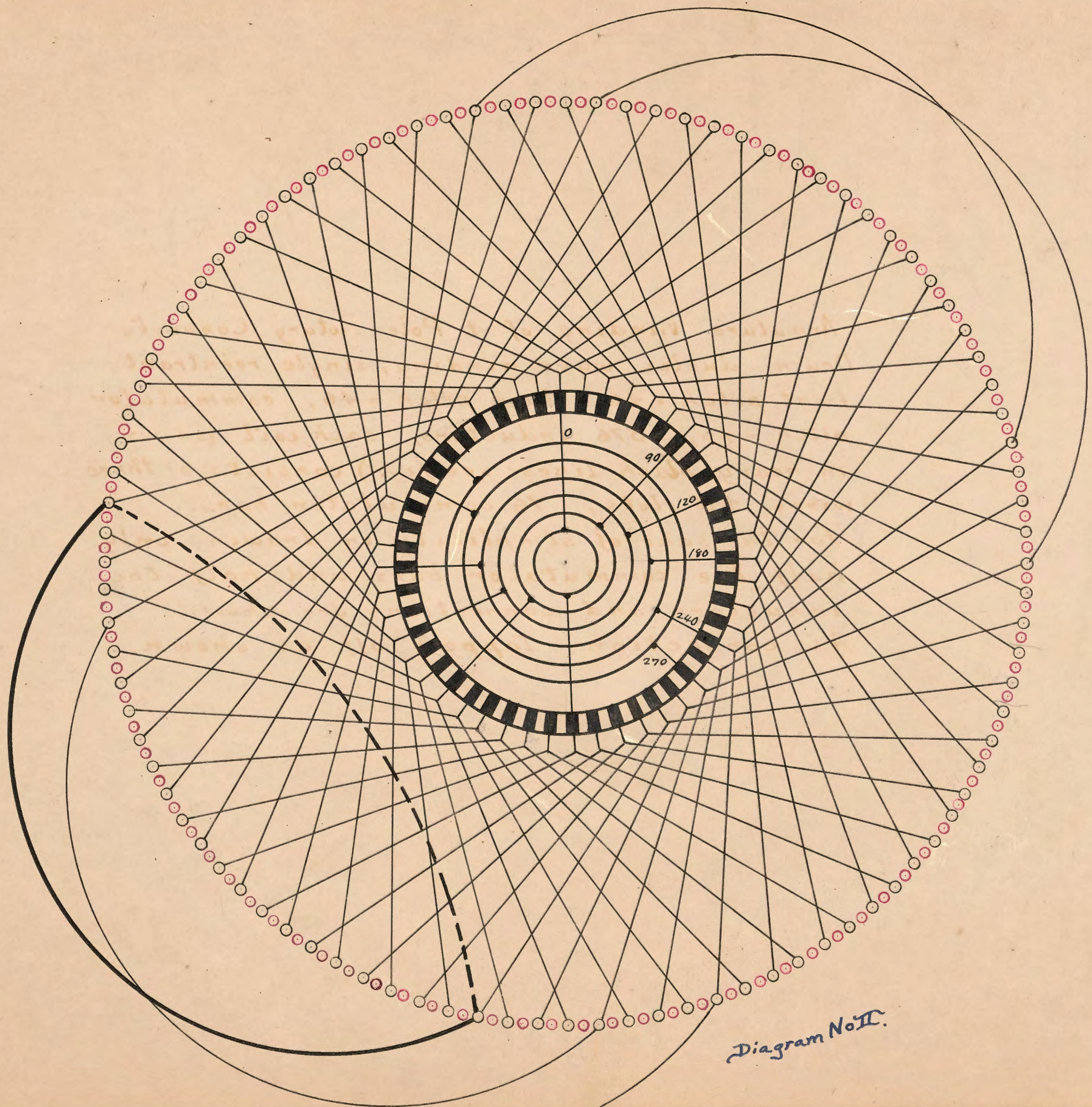


Diagram No II.

Martin

4

The A. C. instruments were calibrated by comparison with standard D. C. instruments; both being connected to a Multi-cellular voltmeter, which deflects equally for the same values of D. C. current and A. C. current. In calibrating the A. C. ammeters, the resistance (See Diagram No. III) was adjusted until the Multi-cellular Voltmeter gave the same deflection for A. C. and D. C. currents. The respective readings of the two readings being taken, a correction curve was then drawn.

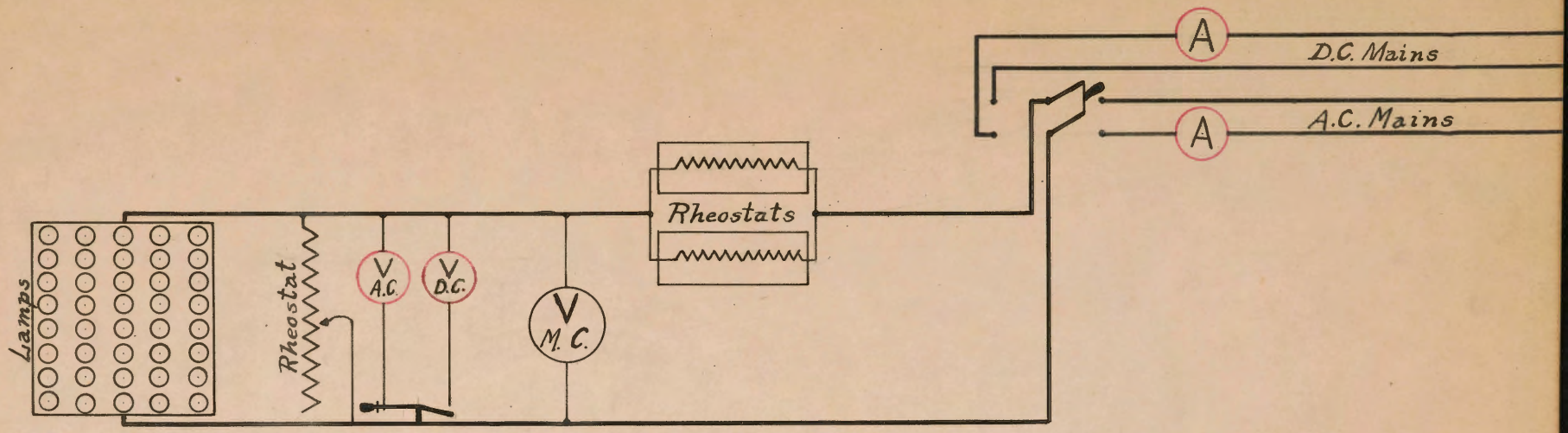
The A. C. voltmeter was calibrated in the same way, except that the lamps (See Diagram No. III) were changed instead of the rheostats to get the same deflections.

Resistance of Field.

The resistance of the field was determined by the drop of voltage method; i.e. (E) and (I) were measured and (R) calculated by Ohms Law ($R=\frac{E}{I}$). This resistance was checked by the Wheatstone-Bridge. The instruments used were the Milli-voltmeter No. 2 with shunt for current measurment and the Simplex 120 - 600 volt, voltmeter. The data of the test may be found on Page 12

Resistance of Armature.

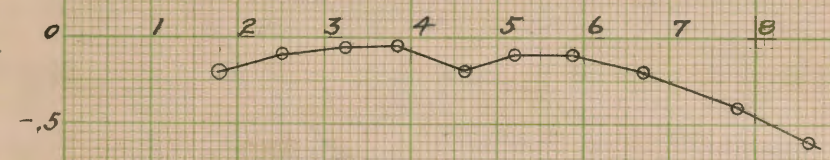
The resistance of the armature was found by the drop of voltage method. Great care was taken as regards instruments and observations. The results were identical to one-thousandth of an ohm, which shows a fair degree of accuracy. Milli-voltmeter No. II with shunt was used asan ammeter and Milli-



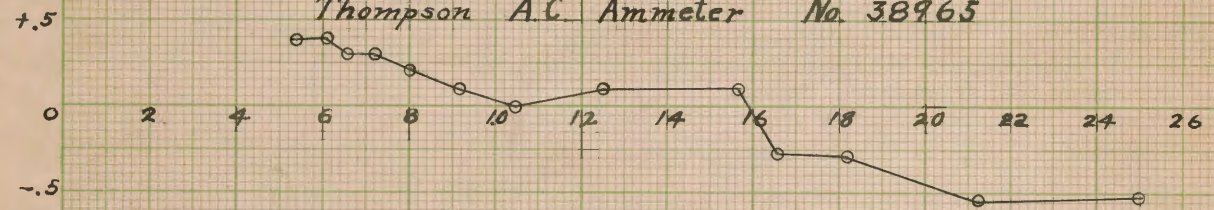
Calibration of Instruments

Diagram № III

Thompson A.C. Ammeter No. 42221



Thompson A.C. Ammeter No. 38965



Thompson A.C. Voltmeter No 145086



PLATE Ia

Resistance of Field				
Current	Correction	Volts	Correction	Resistance
2.30	2.30	88.00	86.30	37.51
2.04	2.04	78.30	76.70	37.59
1.79	1.79	69.10	67.50	37.69
1.54	1.54	59.20	57.60	37.41
1.28	1.28	49.70	48.30	37.73
1.04	1.04	39.90	38.90	37.40
1.29	1.29	49.70	48.30	37.50
1.78	1.78	69.00	67.00	37.53
Room Temp. 66°F			Average R =	37.55

Resistance of Armature				
Current	Correct	Volts	Correct	Resistance
4.62	4.59	0.240	0.224	0.0481
10.80	10.73	0.525	0.518	0.0483
14.30	14.22	0.695	0.693	0.0484
19.00	18.90	0.905	0.908	0.0480
21.20	21.06	1.020	1.024	0.0485
24.00	23.84	1.160	1.162	0.0487
27.80	27.70	1.380	1.384	0.0489
Room Temp. 66°F			Average =	0.0484

voltmeter No. I with its series multiplier for the voltage drop. The data of this test may be found on Page 13

Stray Power Losses.

The stray losses of the machine are the losses that cannot be measured directly. They are due to friction, windage and core losses. They are;-the ammount of power that it takes to run the machine at zero load minus the copper loss of the armature. To find these losses it is necessary therefore to measure the externalapplied voltage; the armature current and resistance of armature. The losses are then calculated by the formula $E_{Ia}-\overline{R_{Ia}}^{2}$=watts loss.

These losses may be determined under different conditions: i.e. change of field and therefore speed fluctuation, or at constant speed. When determined at constant speed, the field must necessarily be changed with different loads. This must be done because the demagnetizing action of the armature currents on the field, which weakens the field and therefore causes the speed to rise. As the efficiency of the machine was desired at constant speed or rated conditions, the stray losses were determined at constant speed. Now under these running conditions, the stray losses must be known with various field excitations. To keep the speed constant and obtain different field excitations, resistance was put in series with the armature and readings taken between armature current and field current and curve drawn (See Plate II). A Tuning-fork was used to enable us to adjust the resistance to the proper point for a constant speed of 1800 R. P. M. The

Stray Losses				
I_a (cor.)	I_f (cor.)	E_x	R.P.M.	Losses
10.10	0.605	114	1800	1151
8.80	0.795	"	"	1003
8.44	0.860	"	"	962
8.20	0.935	"	"	934
7.88	0.991	"	"	898
7.67	1.050	"	"	873
7.50	1.115	"	"	852
7.13	1.210	"	"	813
6.79	1.320	"	"	774
6.63	1.375	"	"	755
Losses = $E_x I_a - R I_a^2$				

See Plate III

tuning-fork was used in all experiments in this thesis where a constant speed was desired.

After drawing the curve (Plate II), the stray losses are then found for any load current. The data for this test is on Page 15 and the stray loss curve for different loads on Plate III.

Field Losses.

Given any certain armature or load current, the corresponding field current is found from Plate II, and then the field loss calculated from the formula:- watts loss = $R_f I_f^2$. The field-loss curve for any load may be found on Plate III.

Armature Copper Losses.

The armature losses are calculated for any assumed load current, from the formula:- watts loss = $R_a I_a^2$. The curve of armature copper losses may be found on Plate IV.

Brush and Brush-Contact Losses.

These losses were first determined by revolving the armature mechanically, taking the drop between positive and negative brushes as a current was forced thru the armature and then calculating the loss from the equation:- watts loss = $I(R'-R)$ where (R) is the resistance of the armature alone and (R') is the armature resistance including brushes. This method was in considerable error, as was found later, because of the drop in the armature due to residual magnetism which was

Relation between Ia and If at constant speed						
Ia	Correct	If	Correct	Ex	Correct	Speed
97.00	96.60	1.51	1.505	116	114	1800
86.00	85.70	1.46	1.453	"	"	"
83.00	82.80	1.43	1.422	"	"	"
77.00	77.00	1.41	1.401	"	"	"
65.20	65.00	1.32	1.310	"	"	"
55.30	54.70	1.26	1.250	"	"	"
48.00	47.40	1.23	1.220	"	"	"
37.50	37.20	1.18	1.172	"	"	"
29.50	29.30	1.13	1.122	"	"	"
20.00	20.10	1.12	1.112	"	"	"
13.20	13.22	1.11	1.102	"	"	"
9.80	9.83	1.105	1.098	"	"	"
8.20	8.21	1.10	1.093	"	"	"

See Plate II

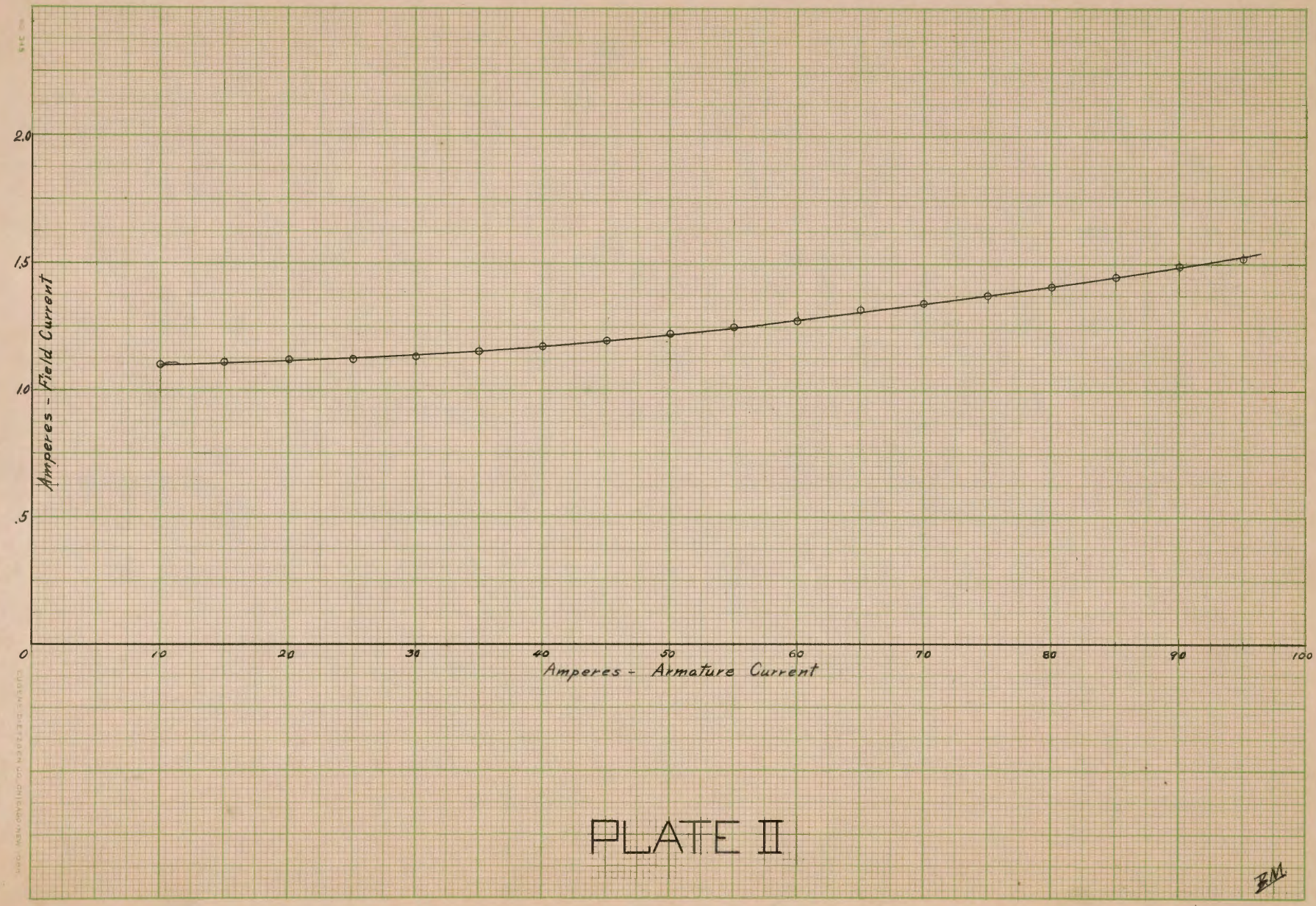

2.0
1.5
1.0
.5
0
Amperes - Field Current
10
20
30
40
50
60
70
80
90
100
Amperes - Armature Current

PLATE II

81

included in our measurments. Although these losses were again determined, it was decided to let the results of the first determination remain in this thesis. The data may be found on Page 20 and the curves on Plate IV.

True Brush and Brush-contact Losses.

The true losses were finally determined by rotating the armature by belting it to an induction motor and two of the single carbon bars of one set of brushes were carefully insulated from each other. A direct current was then sent thru the two brushes in series, the commutator bars closing the circuit. The drop of voltage was then taken in the two brushes with various currents or from zero current up to a current density of 25% overload for a single carbon brush. A curve was then drawn between the current and the drop and it was practically a straight line (See Page 23 and Plate IVa)

Now there were three bars of carbon in each brush set and four brush sets connected in pairs which are in parallel. Therefore each carbon bar carries one-sixth of the load current, so that by multiplying the (RI) drop by six times the current, we get the $\overline{RI}^2$ loss of brush and brush contact. The data of this experiment may be found on Page 21 and the loss curve on Plate IVa.

Total Losses

The total losses of the machine for any given load are the stray losses at that load plus the field, armature and

Brush and Brush-Contact Loss			
Ia (Cor)	Volts	Correct	RI^2 + Brush Losses
91.0	10.5	11.0	1001.0
79.0	8.5	8.9	704.0
72.0	7.7	8.1	583.0
61.0	6.9	7.2	439.0
47.0	6.0	6.3	296.0
32.0	4.9	5.2	166.0
22.0	4.5	4.7	103.0
15.5	4.3	4.5	70.0
10.5	4.2	4.4	46.2

These losses are in error because of drop due to residual magnetism

See Plate IV

True Brush & Brush Contact Losses

Brush Drop		
I (corr)	RI	Speed
12.4	2.43	1800
10.2	2.13	"
9.0	1.90	"
7.70	1.76	"
6.20	1.56	"
5.20	1.40	"
4.10	1.30	"
3.20	1.20	"
2.00	1.06	"
1.20	0.83	"
0.90	0.80	"
		"

Brush Losses	
Load	RI^2
12.00	11.76
18.00	19.80
24.00	30.00
30.00	41.10
36.00	54.00
42.00	69.30
48.00	84.96
54.00	103.68
60.00	123.00
66.00	149.82
72.00	165.60

See Plate IVa

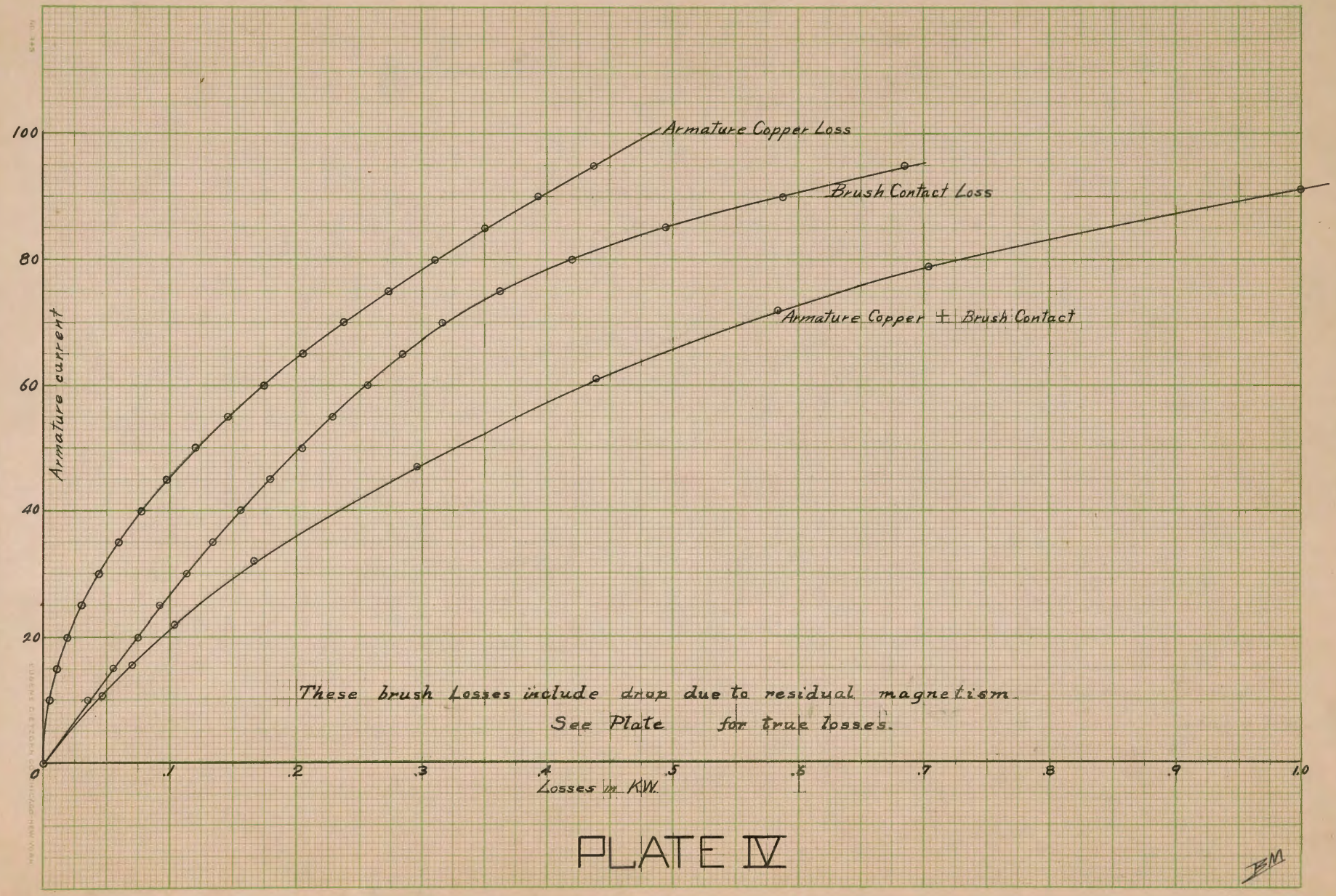


PLATE IV

EM

22

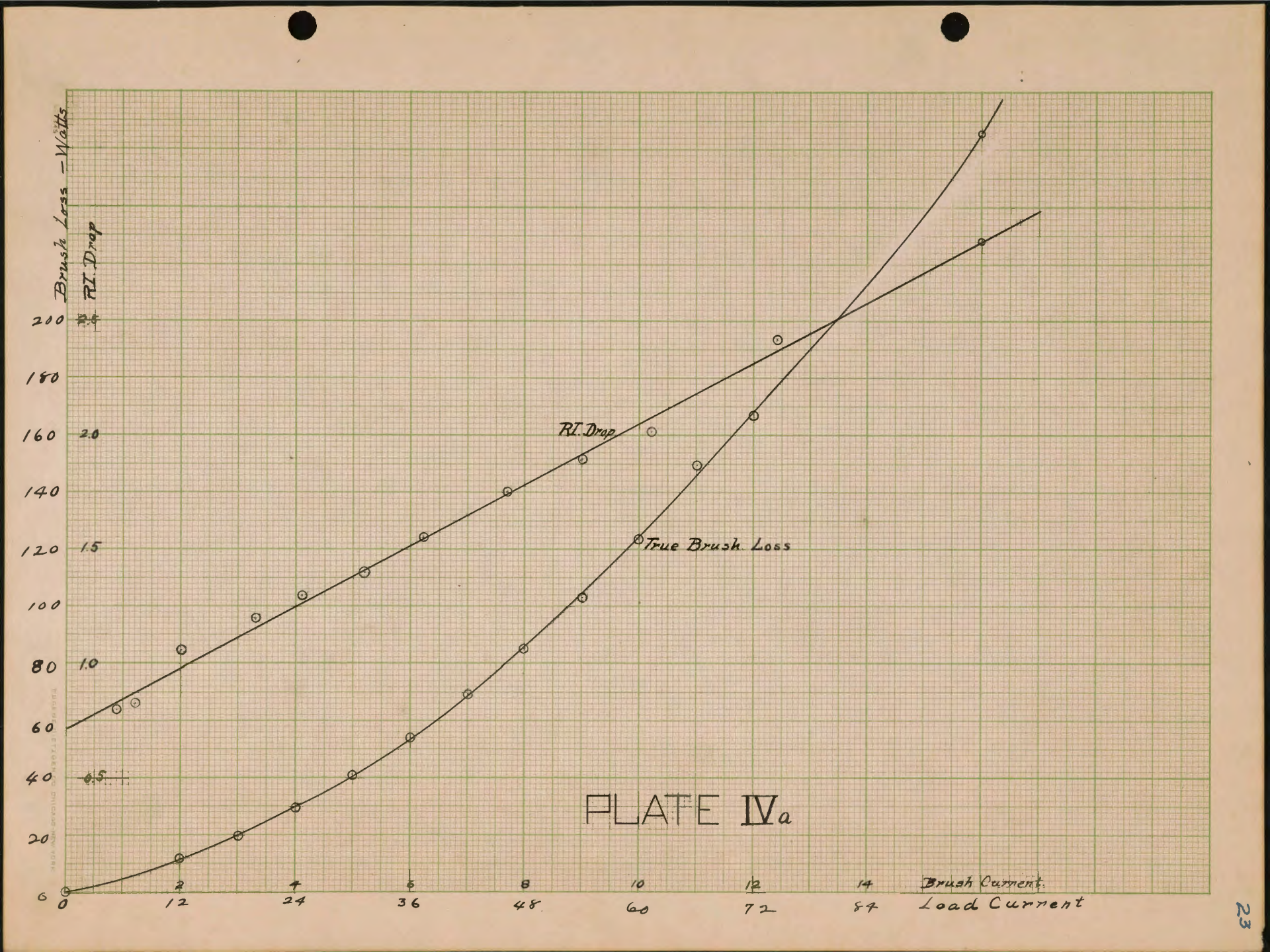

Brush Loss — Watts
RI. Drop
200
180
160
140
120
100
80
60
40
20
0
2.0
1.5
1.0
0.5
RI. Drop
True Brush Loss
0
12
24
36
48
60
72
84
2
4
6
8
10
12
14
Brush Current.
Load Current

PLATE IVa

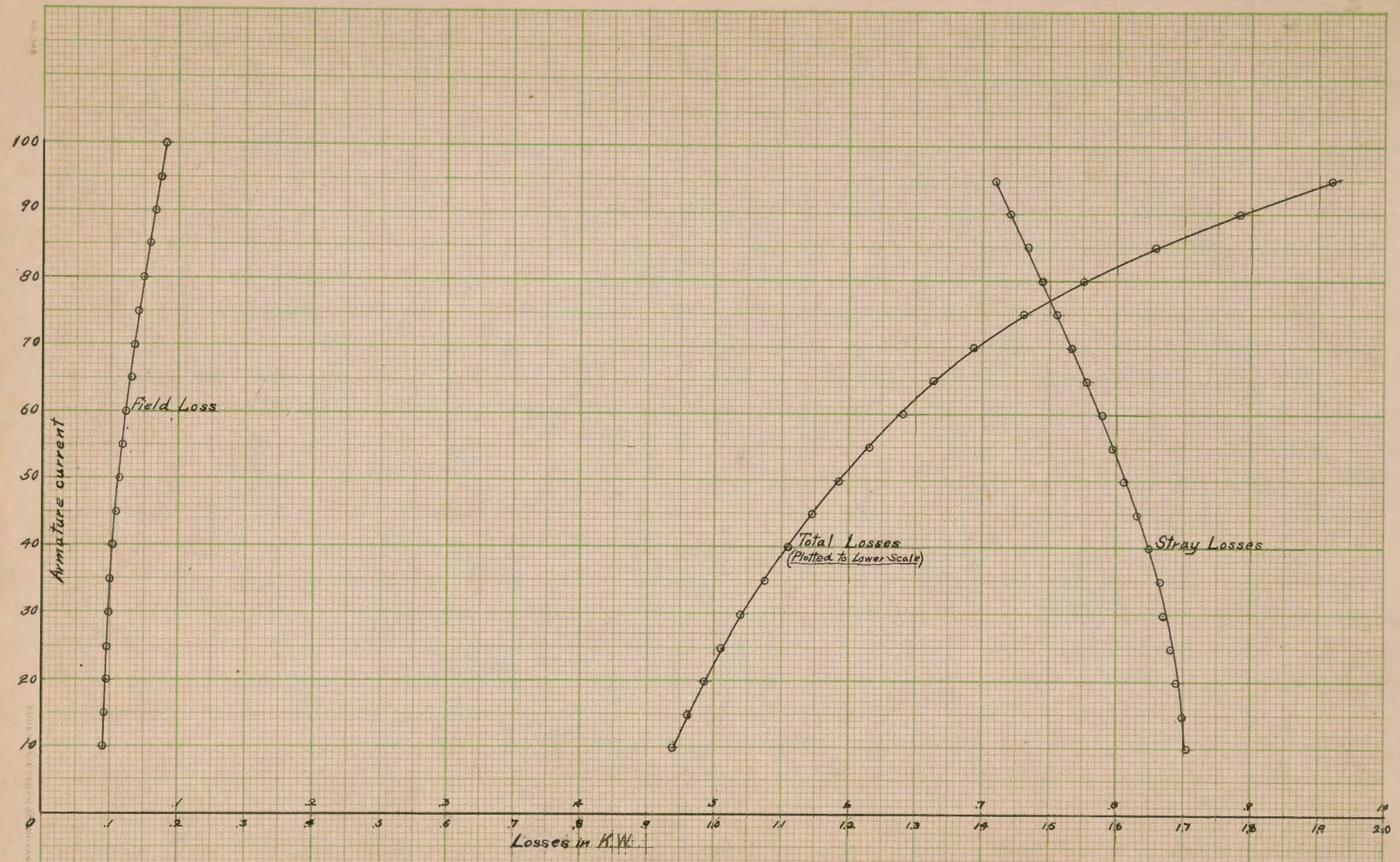

Armature current
100
90
80
70
60
50
40
30
20
10
0
Field Loss
Total Losses
(Plotted to Lower Scale)
Stray Losses
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Losses in K.W.

PLATE III

B.M.

and brush losses at that load. These losses were determined as explained with the condition of constant speed. A curve showing the total losses at any load may be found on Plate III

Efficiency.

Knowing the various lossed of the machine, the efficiency is calculated from the formula:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input-Losses}}{\text{Input}}$$

Two sheets of efficiency data will be found in this thesis and also two efficiency curves. The data on Page 26 is in error because of the mistake in brush losses which effects the total losses, output and efficiency. The true data for the efficiency curve is the one shown in red ink on Plate V. The machine shows a wide range of high efficiency with outputs of from seven to ten kilowatts.

Flux Distribution.

At any point under a field pole, the E. M. F. in any one wire is proportional to the flux density at that point, therefore if the instantaneous values of the E. M. F. can be found for different positions of the wire as it passes under the field pole, an E. M. F. curve may be drawn which shows the flux distribution.

To get these instantaneous values a Parse disk consisting of one solid metal disk and one of wood fibre was mounted side by side on the end of the armature shaft. The wood fibre disk has one metal element on its circumference which is joined to the copper disk. Two insulated brushes rub against these

Efficiency of Converter

		Losses											
Ia	If	Stray	Brush	Field	Arma.	Total Losses	Input	Output	Eff.	Ra	Rf	Speed	Ex
10	1.100	852	35	45.4	4.8	937	1140	203	17.8	0.0484	37.55	1800	114
15	1.110	849	55	46.2	10.9	961	1710	749	43.8	"	"	"	"
20	1.120	845	75	47.0	19.4	986	2280	1294	56.4	"	"	"	"
25	1.125	840	92	47.5	30.3	1010	2850	1840	64.6	"	"	"	"
30	1.135	835	113	48.3	43.6	1040	3420	2380	69.9	"	"	"	"
35	1.152	832	134	49.7	59.3	1075	3990	2915	72.8	"	"	"	"
40	1.175	824	156	51.9	77.4	1109	4560	3451	75.7	"	"	"	"
45	1.200	815	180	54.0	97.2	1146	5130	3984	77.8	"	"	"	"
50	1.225	805	204	56.3	120.6	1186	5700	4514	79.1	"	"	"	"
55	1.250	797	228	58.8	146.4	1230	6270	5040	80.5	"	"	"	"
60	1.275	790	256	61.0	174.2	1281	6840	5559	81.2	"	"	"	"
65	1.320	773	284	65.3	204.5	1327	7410	6083	82.1	"	"	"	"
70	1.340	768	316	67.3	237.0	1388	7980	6592	82.6	"	"	"	"
75	1.375	755	362	70.9	273	1461	8550	7089	82.9	"	"	"	"
80	1.410	745	420	74.6	310	1550	9120	7570	83.1	"	"	"	"
85	1.450	733	495	78.9	350	1657	9690	8033	82.8	"	"	"	"
90	1.490	720	587	83.3	392	1783	10260	8478	82.7	"	"	"	"
95	1.520	710	685	86.7	437	1919	10830	8911	82.5	"	"	"	"
100	1.560	700	775	91.3	484	2050	11400	9350	82.0	"	"	"	"

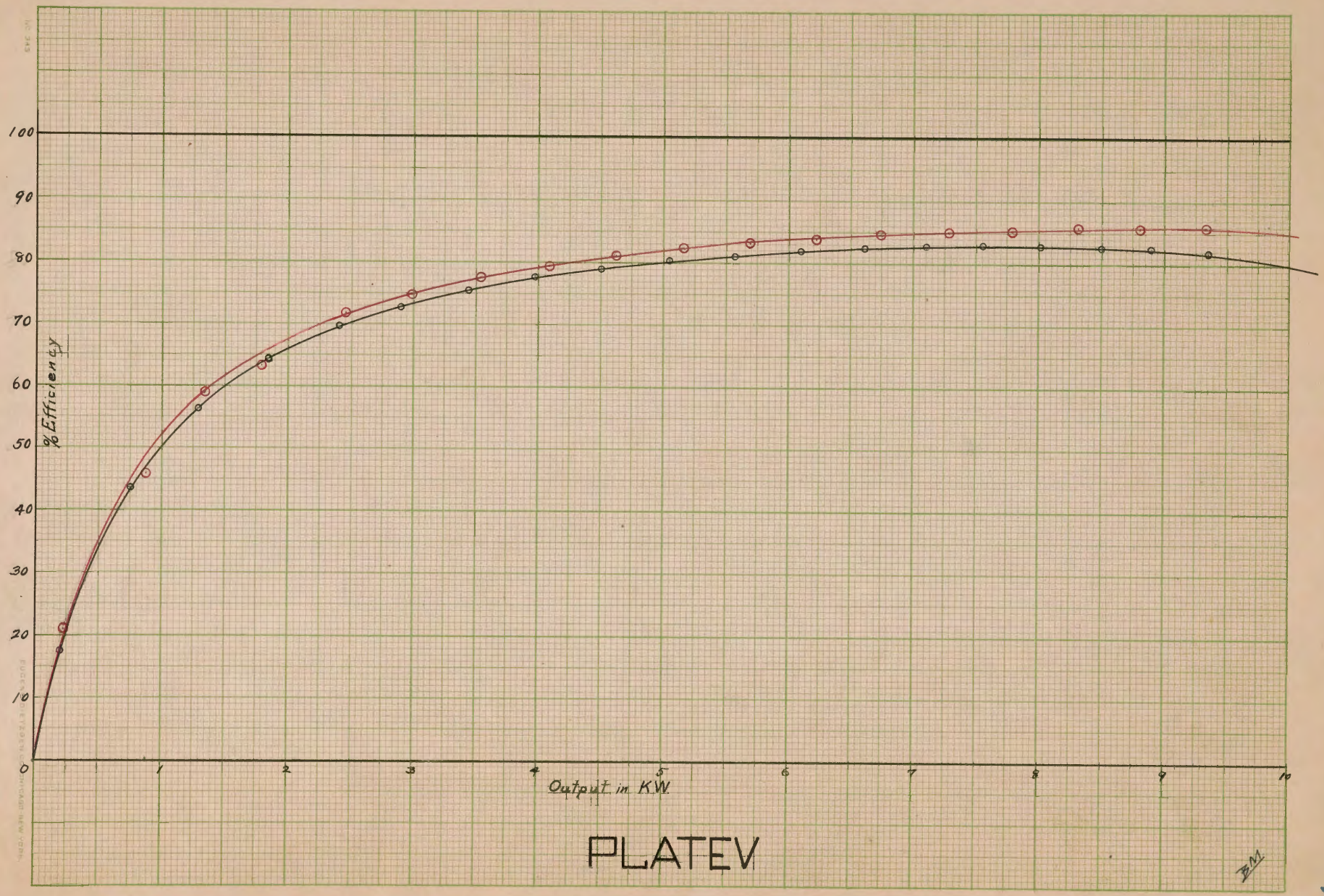
See next sheet for true efficiency Error here in the Brush Losses

See Plate V

True Efficiency of Converter

		Losses											
Ia	If	Stray	Brush	Field	Arma.	Total Losses	Input	Output	Eff.	Ra	Rf	Speed	Ex.
10	1.100	852	9.7	45.4	4.8	912.0	1140	228	20.1	0.0484	37.55	1800	114
15	1.110	849	18.0	46.2	10.9	924.0	1710	786	45.8	"	"	"	"
20	1.120	845	21.5	47.0	19.4	933.0	2280	1347	59.0	"	"	"	"
25	1.125	840	32.0	47.5	30.3	950.0	2850	1800	63.1	"	"	"	"
30	1.135	835	40.0	48.3	43.6	967.0	3420	2453	71.8	"	"	"	"
35	1.152	832	52.0	49.7	59.3	993.0	3990	2997	74.9	"	"	"	"
40	1.175	824	63.5	51.9	77.4	1019.0	4560	3543	77.6	"	"	"	"
45	1.200	815	78.0	54.0	97.2	1044.0	5130	4086	79.4	"	"	"	"
50	1.225	805	92.0	56.3	120.6	1074.0	5700	4626	81.0	"	"	"	"
55	1.250	797	108.0	58.8	146.4	1110.0	6270	5160	82.1	"	"	"	"
60	1.275	790	124.0	61.0	174.2	1149.0	6840	5691	83.1	"	"	"	"
65	1.320	773	142.0	65.3	204.5	1185.0	7410	6225	83.9	"	"	"	"
70	1.340	768	160.0	67.3	237.0	1232.0	7980	6748	84.6	"	"	"	"
75	1.375	755	180.0	70.9	273.0	1279.0	8550	7271	84.9	"	"	"	"
80	1.410	745	198.0	74.6	310.0	1328.0	9120	7792	85.2	"	"	"	"
85	1.450	733	218.0	78.9	350.0	1380.0	9690	8310	85.7	"	"	"	"
90	1.490	720	237.0	83.3	392.0	1452.0	10260	8808	85.8	"	"	"	"
95	1.520	710	260.0	86.7	437.0	1494.0	10830	9336	86.0	"	"	"	"
100	1.560	700	294.0	91.3	484.0	1569.0	11400	9831	86.1	"	"	"	"

See Red Efficiency Curve – Plate V.


100
90
80
70
60
50
40
30
20
10
0
% Efficiency
1
2
3
4
5
6
7
8
9
10
Output in KW
PLATEV
BM

disks and a circuit is closed once every revolution of the disk. These brushes are connected in series in a circuit containing a telephone receiver, a single phase winding of the armature and a portion of a rheostat; the terminals of the rheostat being connected to a storage battery (See Diagram No. IV).

In order to get accurate results, the E. M. F. in the armature winding at any instant was exactly balanced (as shown by no noise in telephone) against the storage batteries. The E. M. F. at that instant is then measured by a D. C. voltmeter. These values were found for every two degrees space on the armature and a curve was drawn with degrees as abscissa and values of E. M. F. as ordinates. This curve compares favorably with the sine curve which is plotted in red ink on same sheet (See Plate VI). It is to be noted that a complete electrical cycle is from 0 to 180 degrees and the curve was plotted for one complete relolution of the armature.

The sine curve was plotted from the equation $y = \sin x$, in which the average maximum height of the actual curve was used as unity, or $\sin \frac{\pi}{2}$.

The data of this experiment may be found on Page 31 .

Phase Characteristic.

A phase characteristic of a rotary corresponds to the regulation test of an alternator. It is a curve showing the relation between the armature current (A. C.) and the field current (D. C.), the test being carried out under constant conditions with respect to voltage, frequency and load.

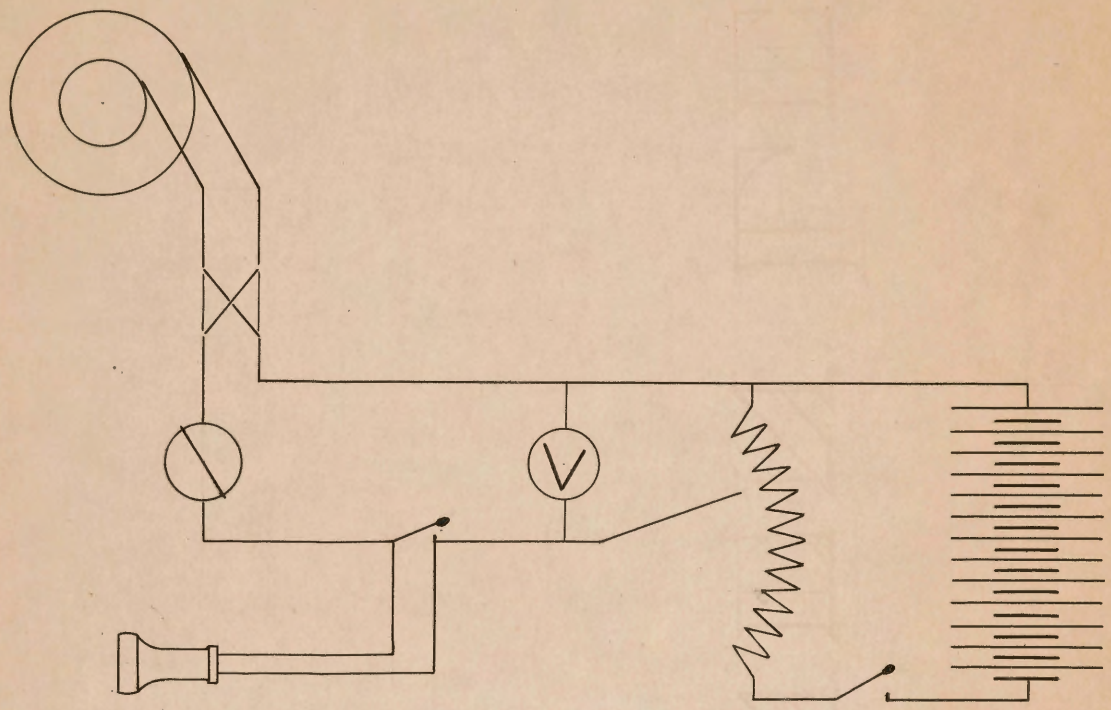
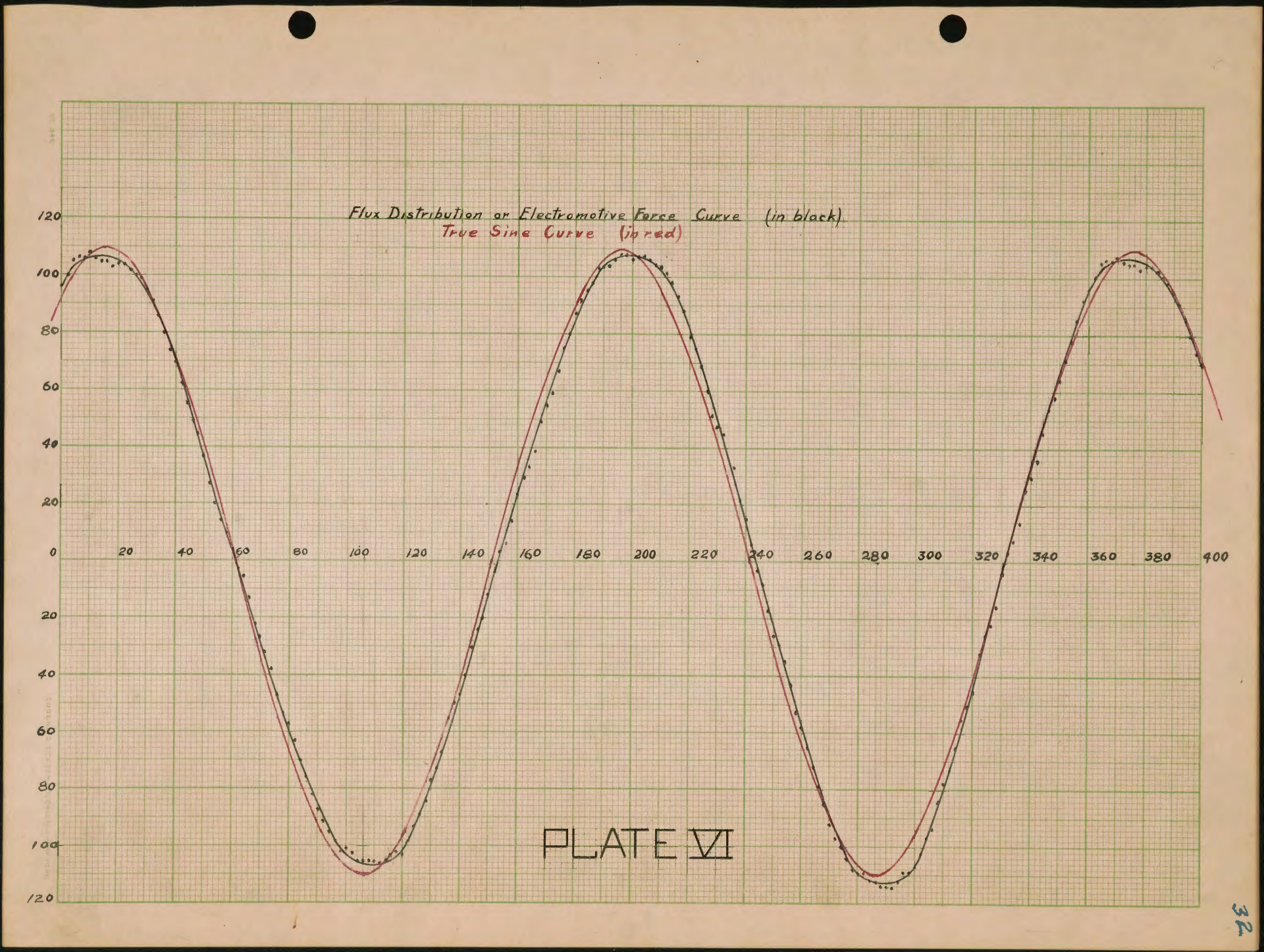


Diagram Nº IV

Flux Distribution or E.M.F Curve

Volts	Deg.	V	D	V	D	V	D	V	D	V	D	V	D
+96	0	27	52	105	104	+6	156	104	208	58	260	73	312
100	2	20	54	105	106	14	158	104	210	65	262	65	314
105	4	14	56	105	108	23	160	101	212	72	264	55	316
106	6	10	58	105	110	29	162	98	214	79	266	50	318
106	8	+4	60	106	112	33	164	93	216	85	268	45	320
108	10	−3	62	105	114	39	166	88	218	92	270	32	322
106	12	5	64	103	116	49	168	79	220	97	272	26	324
105	14	13	66	102	118	55	170	75	222	100	274	22	326
105	16	22	68	103	120	59	172	69	224	104	276	16	328
103	18	27	70	98	122	67	174	60	226	108	278	−4	330
104	20	32	72	93	124	75	176	51	228	109	280	+3	332
104	22	38	74	89	126	80	178	48	230	109	282	7	334
102	24	47	76	84	128	87	180	45	232	112	284	14	336
100	26	53	78	77	130	92	182	33	234	112	286	25	338
99	28	57	80	73	132	95	184	25	236	114	288	30	340
95	30	63	82	67	134	98	186	21	238	114	290	36	342
91	32	70	84	55	136	103	188	15	240	114	292	46	344
86	34	76	86	50	138	104	190	+4	242	112	294	54	346
80	36	82	88	47	140	104	192	−3	244	109	296	58	348
74	38	87	90	40	142	106	194	8	246	109	298	64	350
70	40	91	92	30	144	108	196	17	248	107	300	71	352
62	42	95	94	24	146	108	198	26	250	102	302	78	354
55	44	98	96	−20	148	106	200	29	252	97	304	85	356
49	46	102	98	−12	150	107	202	35	254	94	306	92	358
45	48	101	100	−4	152	107	204	43	256	84	308	96	360
37	50	102	102	+3	154	106	206	53	258	78	310	100	2

See Plate VI


Flux Distribution or Electromotive Force Curve (in black)
True Sine Curve (in red)
120
100
80
60
40
20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
20
40
60
80
100
120
PLATE VI

As a rotary, the machine runs at maximum efficiency when the $\overline{(RI)^2}$ losses of the armature are a minimum. This condition is realized when the machine runs at unity power-factor.

The phase characteristic enables the operator to adjust the field to give a minimum armature current or unity power-factor. The field may be adjusted here without changing the speed because the machine when running as a synchronous motor is controlled entirely by the speed of the generator driving it.

When the field is over-excited the rotary acts as a condenser and therefore the armature current is ahead of the voltage in phase. When the field is under-excited, the machine acts as an inductance in the circuit causing a lagging current in the armature.

The data of this test may be found on Page 35, the Characteristics on Plate VIII and the connections on Diagram No. V.

The characteristic curves show that the same field adjustment is good for all loads and therefore the power-factor does not change with change of load unless it is an inductive load. The field current alone under a non-inductive load controls the power-factor of the armature current or load in watts, when used as an A. C.—D. C. converter.

Voltage Relations.

The value of the alternating E. M. F. of a particular phase with reference to the D. C. voltage varies in practice because of the deviation of the E. M. F. curve from the sine curve, the voltage drop in the armature windings, the position

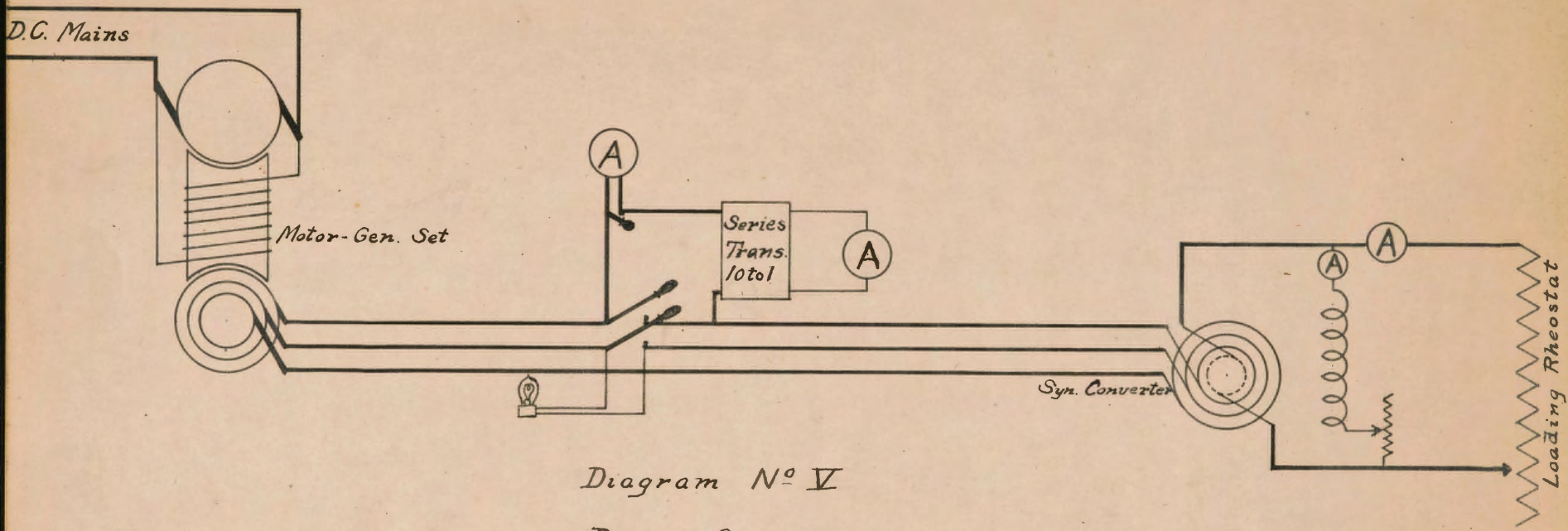


Diagram Nº V

Phase Characteristic

Phase Characteristic

Zero Load					Medium Load					Full Load				
Load	Ia	Cor.	If	Cor.	Load	Ia	Cor.	If	Cor.	Load	Ia	Cor.	If	Cor.
0	27.0	26.00	2.98	2.88	28.00	47.0	45.3	3.00	2.90	64.0	68.5	66.2	2.90	2.80
"	25.0	24.00	2.90	2.80	"	42.0	41.0	2.70	2.60	"	65.5	64.5	2.60	2.50
"	22.0	20.55	2.79	2.69	"	38.5	38.0	2.40	2.24	"	63.0	62.0	2.30	2.25
"	20.0	18.30	2.70	2.60	"	37.0	36.5	2.10	1.96	"	62.5	61.0	2.20	2.00
"	14.5	15.50	2.60	2.50	"	37.2	36.7	2.00	1.90	"	62.0	60.5	2.00	1.90
"	12.4	12.50	2.52	2.42	"	38.3	37.8	1.80	1.70	"	62.5	61.0	1.80	1.70
"	9.6	9.65	2.40	2.24	"	41.2	40.2	1.60	1.54	"	63.0	61.5	1.60	1.54
"	7.8	8.07	2.20	2.00	"	45.5	43.7	1.42	1.34	"	64.5	62.8	1.40	1.32
"	9.5	9.53	2.10	1.96	"	50.4	49.2	1.20	1.12	"	66.3	64.3	1.20	1.12
"	12.2	12.30	2.00	1.90	"	55.3	54.30	1.00	0.95	"	69.0	66.6	1.00	0.95
"	17.5	17.22	1.80	1.70	"	65.5	64.70	0.66	0.65	"	72.8	69.8	0.80	0.80
"	24.2	23.70	1.60	1.54						"	77.5	73.6	0.60	0.58
"	32.5	32.0	1.40	1.32										
"	38.6	38.1	1.20	1.12										
"	44.7	43.5	1.00	0.95										
"	51.5	50.5	0.80	0.80										
"	53.5	52.5	0.73	0.72										

See Plate VIII

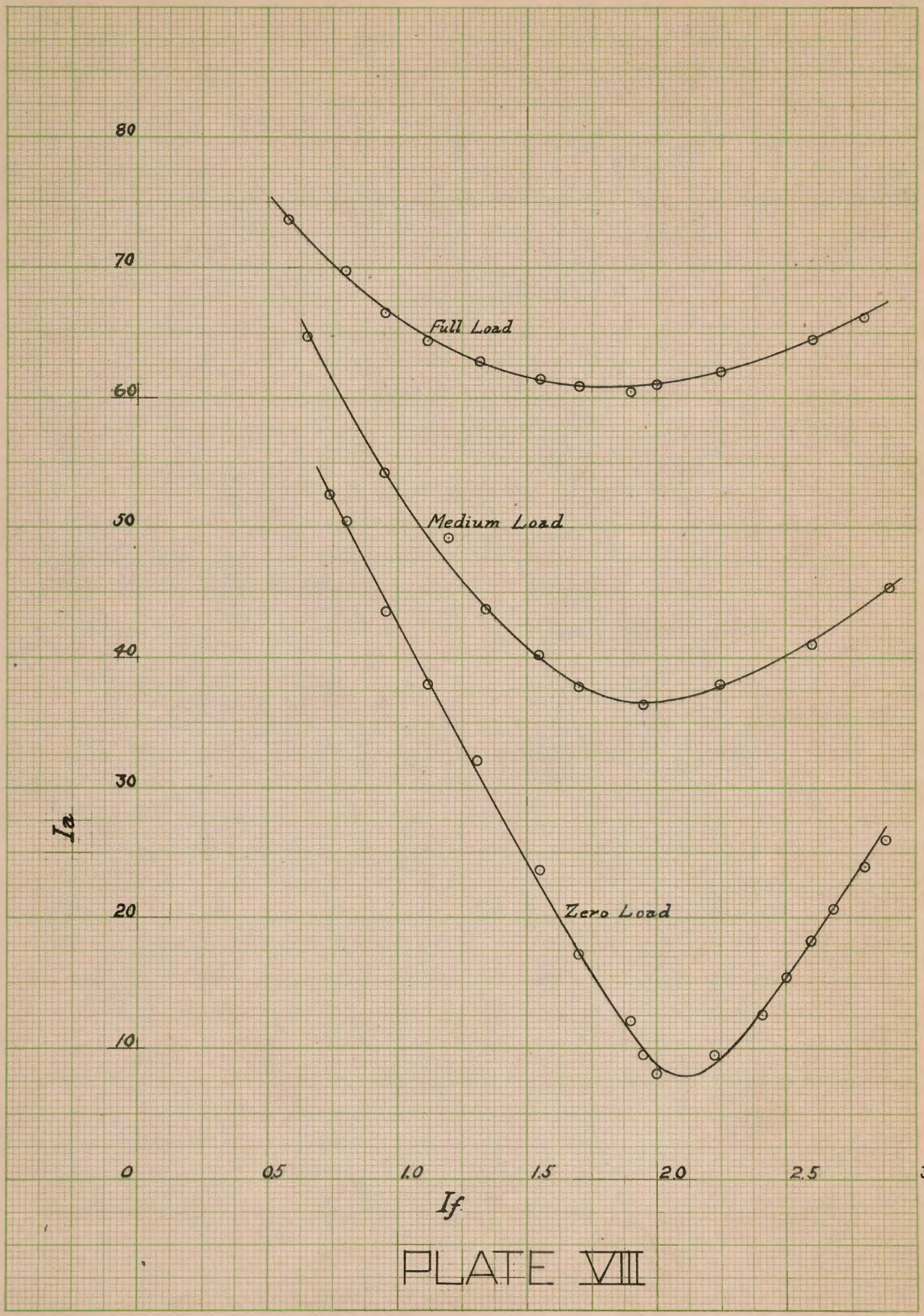

80
70
60
50
40
30
20
10
0
Ia
0.5
1.0
1.5
2.0
2.5
3.0
If
Full Load
Medium Load
Zero Load

PLATE VIII

of the D. C. brushes on the commutator and the degree of field excitation.

The voltage relations of the converter for the different phases were found D. C. to A. C. at rated speed and zero load.

The actual values found were about one to two percent greater than the theoretical values, which shows the effect of the nearly flat-topped E. M. F. curve, that the field is slightly over-excited and that the D. C. brushes are not set exactly right on the commutator. The over-excitation of the field is unavoidable because with the above running conditions the field controls the speed. The data of this experiment may be found on Page 38.

Phase Lag.

When a rotary converter is run as a synchronous-motor and loaded from the D. C. side, the armature drops behind ~~the~~ in phase according to the ammount of load it carries. As the machine runs in synchonism, the speed is exactly the same as the speed of the generator driving it, therefore the phase - lag occurs by the armature falling behind its original position with respect to the driving machine but it still runs at the same speed.

If the ammount that the shaft falls behind for different loads can be determined the phase-lag is just twice that ammount in electrical degrees, since the machine is four pole.

For this investigation, the normal conditions of running were chosen (i.e. 1800 R. P. M. and unity power-factor) and two contact makers (See Page 25) were used; one attached to

Voltage Relation D.C. to A.C.					
Phase	Volts A.C.	Correct	Theoretic	Volts D.C.	Speed
Single 0°-180°	79.00	78.50	77.77	110	1800
Three 0°-120°	68.50	68.20	67.32	"	"
Two 0°-90°	56.50	56.00	55.00	"	"
Six 0°-60°	41.50	41.00	38.94	"	"

$E_2 = .707\ E$
$E_3 = .612\ E$
$E_4 = .500\ E$
$E_6 = .354\ E$

the shaft of each machine (i. e. driving generator and converter). They were connected in series with a telephone receiver and a few storage cells, so that no current flowed in the circuit unless both made contact at precisely the same instant. At zero load the contact makers were set so that current flowed thru the circuit at each revolution. Now when a load was thrown on, the ammount that one of the contact makers was moved back to again allow the circuit to be closed every relolution was just one-half the phase lag of that current in electrical degrees.

In order to get the different loads and also to have conditions constant that were necessary, it was necessary to load the machine by feeding its D. C. current back into the line that was supplying the current to drive the motor-generator set (which was driving the rotary converter). This was done by adjusting the voltage of the converter (D. C.) to a value just a trifle greater than that of the main generator. This with the aid of two rheostats in the line enabled us to get any desired load with out overloading the main generator.

A curve was plotted with electrical degrees lag as ordinates and corresponding loads as abscissa (See Plate IX). The data of this test may be found on Page 42 . The connections are given in Diagram No. VI.

Heat Run.

The Heat Run may be made with the machine taking current through the collector rings or through the commutator. The following was made with the machine taking full rated load

(D. C. current) thru its commutator and delivering it to rheostats from the collector rings.

A three phase current was used and the rheostats delta-connected. The field, armature windage which is the air from revolving armature, and room temperatures were taken continously during the test at intervals of 30 minutes, and curves plotted (See Plate X). When the field had reached a constant temperature the machine was shut down and the other temperatures taken at once.

To reduce to standard room temperature (i.e. 25° C or 75° F) a correction of one-half percent is made for each degree above or below 75° F or 25° C. As the room was almost this temperature during test, no correction was made here.

The curves shown on Plate X show a drop about noon which was due to rain at that time. For data see Page 44 .

Inductance of armature, Saturation Curve and Short-Circuit Characteristic.

To get the inductance of the armature, a saturation curve was first obtained (See Page 48) and thus the relation between the field current and generated A. C. voltage at zero load.

After obtaining the saturation curve, the armature was short-circuited (3 Phase) thru an ammeter and the field adjusted until any desired current flowed. For each value of the current the short-circuit was opened and the voltage taken across terminals. A curve was then plotted with E. M. F. (A. C.) as ordinates and load current per phase for abscissa.

Knowing the field current for any load, the corresponding voltage is found from the saturation curve.

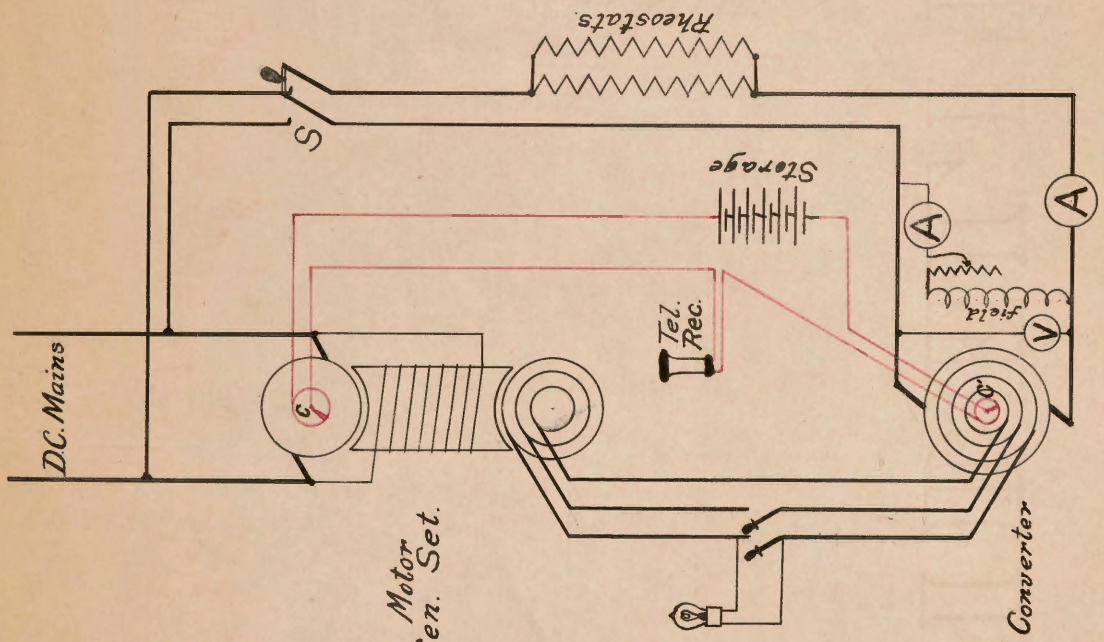


Diagram № VII

Phase Lag

Phase Lag						
If	Load	Correct	Readings	Voltage	Lag	Elec. Deg's.
1.94	0	0	132.50	114.0	0	0
"	18.0	19.0	129.75	"	2.75	5.50
"	30.0	28.0	127.50	"	5.00	10.00
"	41.0	36.0	125.00	"	7.50	15.00
"	53.5	47.5	121.00	"	11.50	23.00
"	67.0	64.5	116.00	"	16.50	33.00
Constant Speed & If				Unity Power Factor		

See Plate IX & Diagram No VI

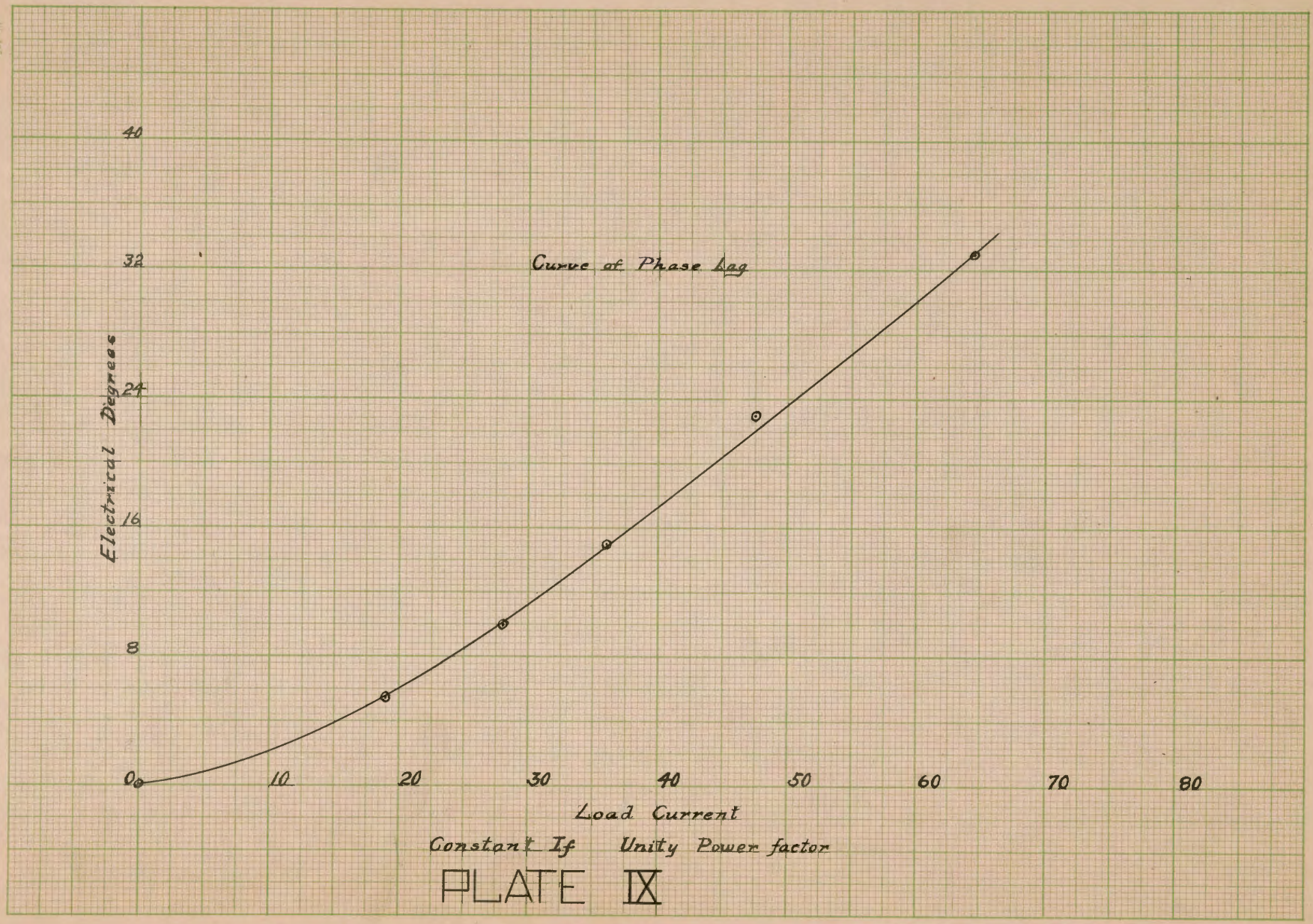

Curve of Phase Lag
Electrical Degrees
40
32
24
16
8
0
10
20
30
40
50
60
70
80
Load Current
Constant If Unity Power factor

PLATE IX

Heat Run.										
Time	Volts	Volts	Volts	I	I	I	Speed	Temperatures		
A.M.	D.C.	A.C.	Field	Field	D.C.	A.C.	R.P.M.	Room	Windage	Field
8.45	111	59.5	43.5	1.12	62.5	51.5	1800	71	71	71
9.00	110	59.5	44.0	"	68.0	57.6	"	72.5	77.5	74
9.30	110	58.8	44.5	"	"	55.4	"	73	81.3	77.2
10.00	110	59.5	45.0	"	"	56.5	"	73.3	83.3	83.1
10.30	110	58.5	45.5	"	"	56.2	"	74.1	85.5	87.0
11.00	110	59.0	46.0	"	"	56.0	"	75.0	86.5	88.0
11.30	110	59.0	47.5	"	"	56.5	"	74.5	87.3	89.2
12.00	110	59.0	47.0	"	"	56.0	"	73.0	86.0	90.0
12.30	110	57.5	45.0	"	"	55.0	"	74.5	87.8	90.4
1.00	110	59.0	45.0	"	"	56.0	"	75.0	87.8	90.4
A.C. = Current per Phase										
Armature Laminations							104°F			
Armature Coils							123°F			
Commutator							133°F			
Collector Rings							150°F			
Bearings							107°F			

See Plate X

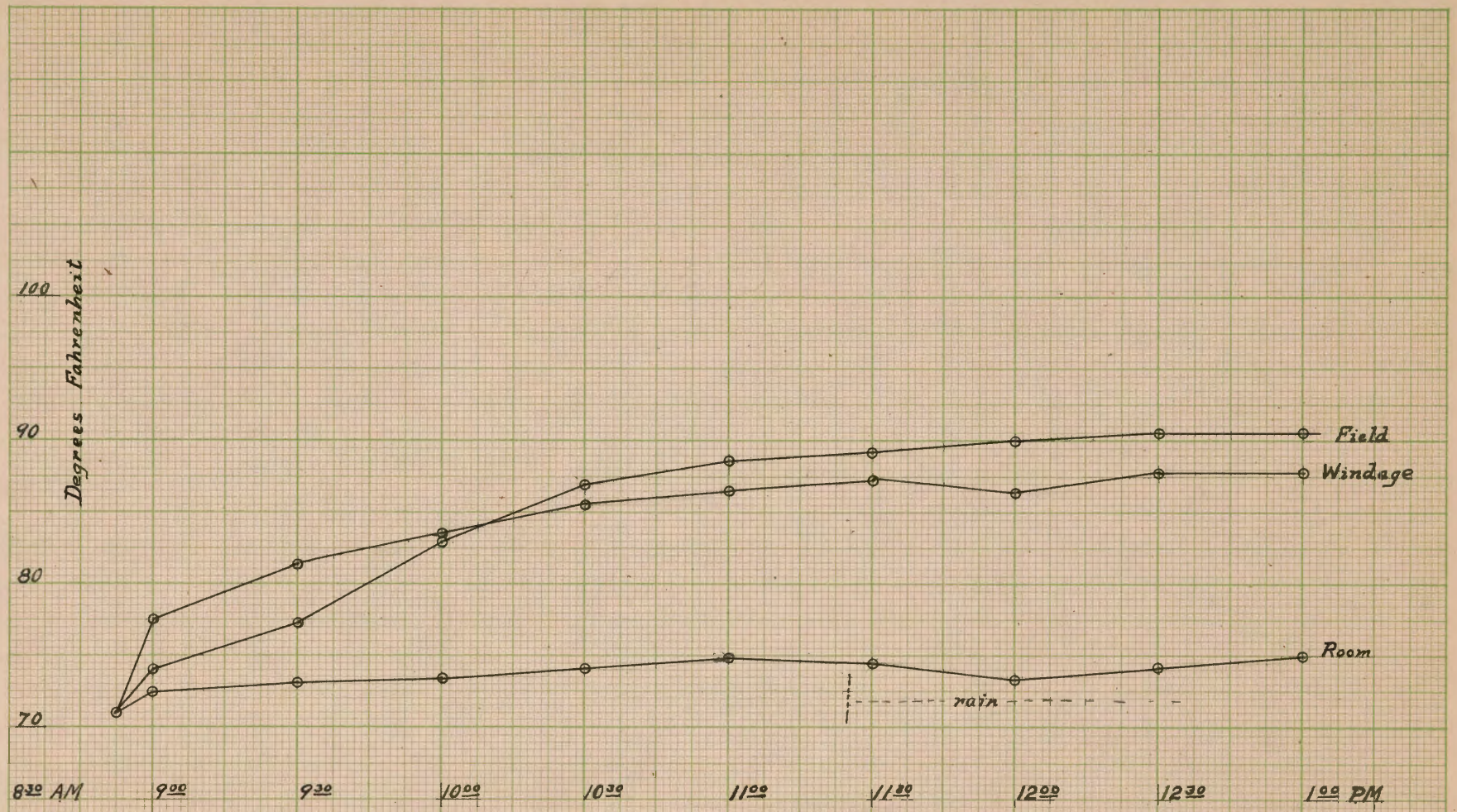

Degrees Fahrenheit
100
90
80
70
Field
Windage
Room
rain
8³⁰ AM
9⁰⁰
9³⁰
10⁰⁰
10³⁰
11⁰⁰
11³⁰
12⁰⁰
12³⁰
1⁰⁰ PM

PLATE X

Since there was no external load the entire voltage was used in forcing the current thru the $\underline{X}$ $\underline{I}$ and R $\underline{I}$ of the armature, therefore $\underline{X}$ is readily calculated from the right triangle $\left[\overline{E}^2 = (\overline{RI}^2 + \overline{XI}^2)\right]$

Since $\underline{X} = \omega$ L we can get the inductance L. In the above test, the machine was run as a generator by being belted to an induction motor. The data ~~is~~ are on Page 47 and the Saturation curve and Short-Circuit Characteristic are on Plate XI.

Inductance of Armature

Three Phase

Short-Circuit Characteristic & Saturation Curve Data

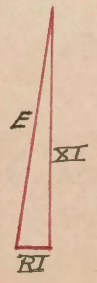
E. from Curve	I a.c.	Cor.	If	Cor.	R	E a.c.	Cor.	If	Cor.	Speed	XI	X
6.5	6.00	6.40	0	0	0048	95.0	94.4	2.70	2.60	1800	6.40	1.00?
38.0	44.00	42.50	0.60	0.58	"	94.0	93.4	2.60	2.50	"	37.97	0.89
50.0	60.30	59.30	0.82	0.81	"	92.5	91.9	2.49	2.39	"	49.96	0.83
54.5	66.80	64.80	0.94	0.90	"	91.5	90.9	2.40	2.24	"	54.10	0.84
62.0	79.00	75.00	1.15	1.07	"	90.0	89.4	2.30	2.11	"	61.82	0.82
64.0	82.00	77.00	1.20	1.12	"	88.0	87.4	2.14	1.97	"	63.80	0.83
					"	84.0	83.4	1.94	1.84	"	Aver = 0.842	
					"	82.5	81.9	1.82	1.72	"	L = 0.0022	
					"	80.5	79.9	1.72	1.63	"		
					"	77.0	76.6	1.54	1.49	"		
					"	71.5	71.3	1.35	1.25	"		
					"	64.0	63.5	1.12	1.05	"		
					"	59.0	58.5	1.00	0.95	"		
					"	54.0	53.6	0.88	0.86	"		
					"	51.0	50.9	0.82	0.81	"		
					"	39.0	39.0	0.67	0.66	"		
					"	36	36.0	0.60	0.58	"		
					"	?	?	0	0	"		

This is taken from saturation curve and then the value of XI is calculated from the triangle i.e. $E^2 = RI^2 + XI^2$

Average Inductance = L = 0.0022 Henry

Average value of X = 0.842

$X = \omega L \therefore L = \frac{X}{2\pi \times 60} =$ 0.0022.



See Plate XI

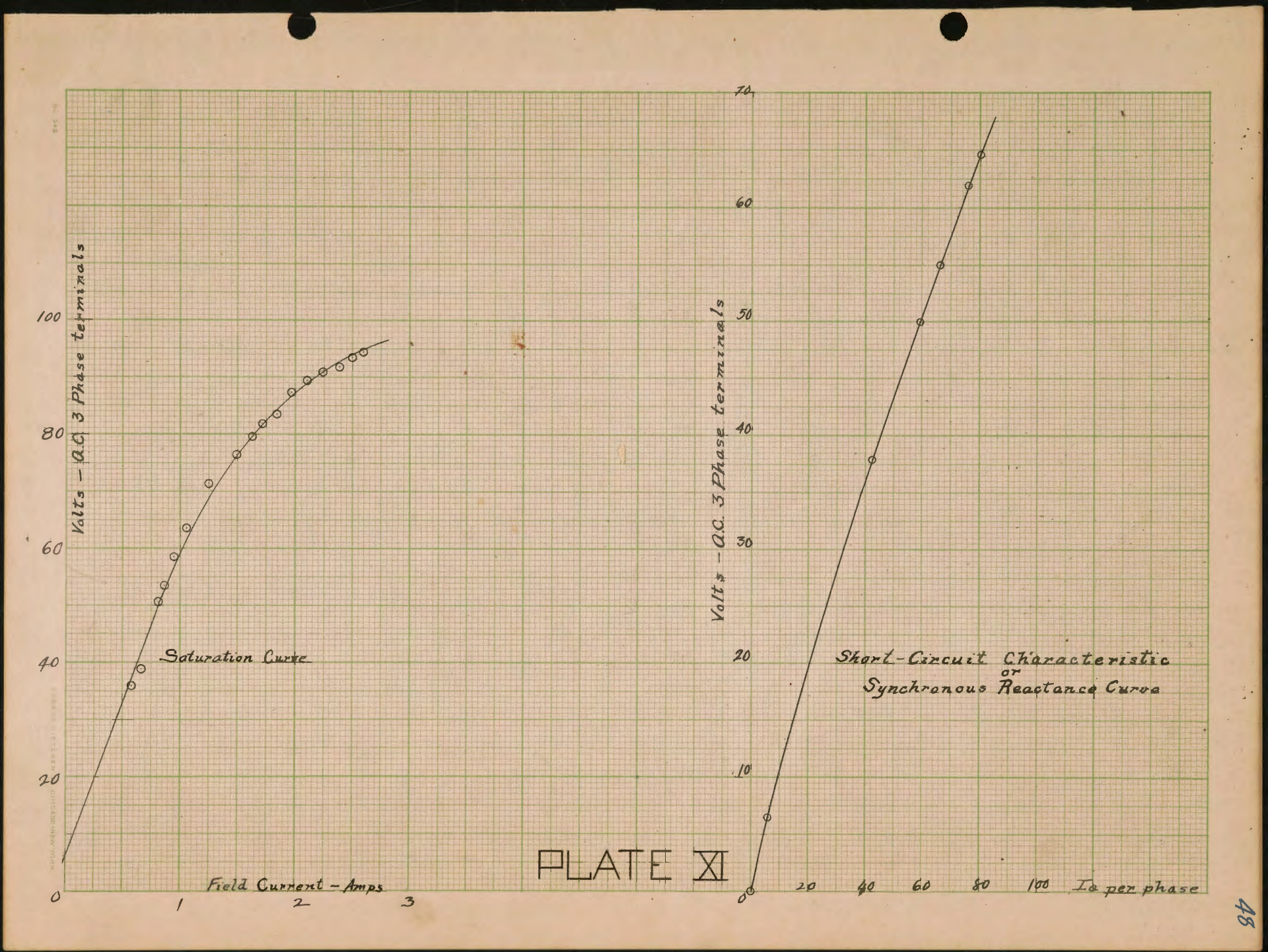

Volts – A.C. 3 Phase terminals
0
20
40
60
80
100
1
2
3
Field Current – Amps
Saturation Curve
Volts – A.C. 3 Phase terminals
0
10
20
30
40
50
60
70
20
40
60
80
100
Ia per phase
Short-Circuit Characteristic
or
Synchronous Reactance Curve

PLATE XI