T H E S I S

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TEST OF A 25K.W., THOMPSON-RYAN GENERATOR

By

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For the Degree of

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Under the direction of

Dr. Chas. A. Perkins.

1912

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It is the purpose of this paper to record the data and results of the necessary calculations for a series of tests made on a twenty-five kilowatt compound generator of the Thompson-Ryan interpole type directly connected to an American Ball thirty-five horse-power engine.

These tests are complete in themselves but others might have been added. It was impossible, however, to do certain things which might have been desirable on account of the lack of time and also on account of insufficient data of the construction of the machine.

THE CHARACTERISTIC CURVE:

The curve was found as follows:- The generator was driven at as nearly a constant speed as possible and the field excited so as to give some desired terminal voltage at no load. The resistance of the external circuit was then varied by suitable steps and the terminal electromotive force and the current in the external circuit were then read simultaneously for each step. This was continued from no load to full load for the machine. The characteristic was drawn from these readings with I_x as abscissas and E_x as ordinates, as shown on Plate I.

In obtaining data for this curve, the speed varied and thus an error was introduced. It was impracticable on account of the series field to correct this error perfectly but the trouble was alleviated to a great extent by correcting the voltage directly in proportion to the speed. The errors of the corrected readings are almost negligible. The readings were also corrected for instrument error.

The observed and corrected data are shown below.

DATA FOR THE CHARACTERISTIC CURVE:

E_x	I_x	R.P.M.	E_x (Corrected)	I_x (Corrected)	R.P.M. (Corrected
125.0	0	339	119.4	0	330
123.5	16.0	335	119.1	17.0	"
122.8	18.5	333	119.0	19.5	"
120.0	27.5	332	116.8	28.0	"
119.0	64.0	332	115.8	63.5	"
118.5	39.5	329	116.7	39.8	"
118.6	51.0	332	115.5	51.0	"
118.7	69.5	333	115.3	68.7	"
117.5	99.0	330	115.0	97.7	"
119.5	131.0	332	116.3	129.7	"
121.0	157.0	330	118.4	154.5	"
121.5	161.0	332	118.3	158.4	"
122.5	171.0	330	120.0	168.1	"
123.0	193.0	331	120.2	189.2	"

SATURATION CURVE:

The next test made was for obtaining data for the magnetization or saturation curve. This shows the relation between the shunt field current and the terminal voltage and is very important for this reason. It was determined as stated below.

The generator was operated at constant speed and on open circuit. The field current was varied by convenient steps from zero to a high enough value to excite the field so that the terminal voltage of the machine rose to some point above normal voltage. The field current was again varied until the elctromotive force dropped to zero. The field current and the terminal voltage of the generator were read simultaneously for each step as the excitation was being increased and while it was being decreased. The saturation curve was then drawn with I_f as abscissas and E_x as ordinates. The speed was maintained constant at 330 r.p.m., throughout the experiment. The curve is shown on Plate II.

The observed and corrected data are shown here.

DATA FOR THE SATURATION CURVE:

E_x	I_f	E_x, (Corrected)	I_f (Corrected)
5.2	0	3.2	0
6.0	.05	4.0	0.13
10.7	.27	9.1	0.34
17.9	.35	16.8	0.42
27.9	.72	28.0	0.78
40.0	1.12	40.3	1.17
62.8	2.05	62.9	2.07
95.0	3.30	92.9	3.29
103.8	3.95	102.1	3.92
107.8	4.30	105.8	4.27
115.4	4.85	113.4	4.80
119.8	5.23	117.2	5.18
123.4	5.50	120.9	5.44
125.8	5.95	123.8	5.88
129.5	6.54	127.5	6.46
131.5	6.76	129.4	6.78
129.6	6.44	127.6	6.36
127.7	6.04	125.5	5.97
124.6	5.60	122.2	5.54
118.5	4.95	115.9	4.90

112.5	4.27	111.0	4.24
98.7	3.38	96.7	3.37
50.0	1.43	50.2	1.47
20.6	0.43	19.6	0.50
9.4	0.08	7.7	0.16
10.0	0.11	8.3	0.16
9.3	0.05	7.6	0.13
6.0	0	4.0	0

If it were wished to obtain the saturation curve for any other speed, it could be found by multiplying the ordinates of the curve by the ratio of the speeds. This is evident when we consider that the flux ϕ has a definite value for each value of the field current so that the induced electromotive force, $\phi Z'n$, corresponding to any given field current, will be proportional to the speed.

It will be seen that this curve does not pass through the origin for the value of E_x is not zero when the field current is zero on account of residual magnetism. Therefore, E_x, when the field current is zero is the induced electromotive force due to this residual magnetism.

It will be noted also that the curve for decreasing values of the field current is slightly higher than that for increasing values.

ARMATURE CHARACTERISTIC:

The armature characteristic of a shunt generator is a curve showing the relation between the currents in the external circuits and the ampere-turns in the field or else the field currents when the machine is operated at constant speed and at constant electromotive force.

From this curve, the number of turns of wire required in the series field for flat-compounding can be determined but we are not concerned with that here.

Another use of the curve, which is self-evident, is that, if the generator be operated at constant speed as a shunt machine, the field current necessary to keep the terminal voltage constant for any output can be read directly from the curve. This is the use made of the curve in subsequent calculations. The curve is on Plate III.

The observed and corrected data are shown below.

DATA FOR THE ARMATURE CHARACTERISTIC:

E_x	I_x	I_f	R.P.M.	E_x (Corrected)	I_x (Corrected)	I_f (Corrected)
109.9	190.0	7.54	328	107.9	186.0	7.39
110.0	170.0	6.82	330	108.0	167.2	6.74
110.0	149.0	6.42	328	108.0	146.6	6.30
109.9	134.0	5.86	333	107.9	131.5	5.85
109.8	121.0	5.26	330	107.8	119.0	5.20
109.9	111.0	5.50	326	107.9	109.7	5.37
109.8	87.0	4.69	332	107.8	85.8	4.67
110.0	75.0	4.48	329	108.0	74.0	4.43
110.0	67.0	4.54	330	108.0	66.3	4.50
110.0	53.5	5.12	333	108.0	53.5	5.12
110.0	29.0	4.48	334	108.0	29.6	4.50
109.6	21.0	4.26	334	107.6	22.0	4.29
109.6	15.5	4.13	335	107.6	16.5	4.17
109.9	11.0	4.12	336	107.9	11.8	4.17
110.0	0.0	3.92	336	108.0	0	3.97

The readings were corrected to 330 R.P.M.

An important phase of this test was to determine the various losses in the generator and, by knowing these, to calculate the efficiencies for various loads.

The losses are as follows:-

(1) The copper loss in the armature.

(2) The copper loss in the series field.

(3) The copper loss in the shunt field.

(4) The brush loss.

(5) The stray power losses which include,

(a) Mechanical friction.

(b) Eddy current loss.

(c) Magnetic hysteresis in the armature.

The above losses were determined as follows:-

(1) Current was passed through the armature and the value of the current and the drop of voltage in the armature were read simultaneously and the resistance calculated by the formula $R = \frac{E}{I}$.

The loss is then RI^2 watts.

The measured and corrected data are as follows:

E_a	I_a	E_a (Corrected)	I_a (Corrected)	R Armature.
.0514	2.81	.0521	2.81	.01850
.0725	4.07	.0737	4.04	.01825
.0975	5.51	.0995	5.45	.01825
			Average R_a	.01830

(2) The copper loss in the series field was determined as for the copper loss in the armature and the data are shown here.

E_{sf}	I_{sf}	E_{sf} (Corrected)	I_{sf} (Corrected)	R
.0430	2.97	.0424	2.97	.01428
.0475	3.30	.0469	3.29	.01425
.0470	3.25	.0464	3.24	.01430
			Average R_{sf}	.01428

(3) The shunt field of this generator consisted of two separate sets of coils which were connected in series. The resistance of each ~~coil~~ set was found by means of a testing set and the two results thus found were added giving the total resistance.

The data are here shown:-

The resistance was found to have the following value:-

Resistance of the left hand coil is equal to 7.72

Resistance of the right hand coil " " 7.74

Resistance of the two coils in series " 15.46

(4) From a table in the Standard hand-book the voltage drop in the brushes was taken to be 1.6 volts. The loss is then equal to EI watts.

(5) In order to determine the stray power losses the generator was disconnected from the driving engine and operated as a separately excited shunt motor. The impressed electromotive, current input, field current, and the speed, were measured for approximately constant speed and different field excitations. The field current was varied from a high value by successive steps to as low a value as convenient. The readings were taken simultaneously.

The measured and corrected data are shown below.

DATA FOR STRAY POWER LOSSES. (Generator used as shunt motor.)

E_a	I_x	I_f	R.P.M.	E_a (Corrected)	I_a (Corrected)	I_f (Corrected).
130.5	13.0	6.20	330	128.5	13.9	6.13
125.0	13.0	5.38	330	122.6	13.9	5.33
121.0	13.0	5.00	328	119.0	13.9	4.95
119.5	11.4	4.75	329	117.2	12.2	4.70
118.5	12.0	4.45	330	115.9	12.9	4.41
112.0	11.8	4.17	330	110.4	12.6	4.14
107.5	11.0	3.88	330	105.6	11.6	3.85
104.0	12.5	3.58	331	101.9	13.4	3.56
94.0	14.1	3.15	330	92.0	13.8	3.14
85.0	15.3	2.76	330	83.4	15.0	2.76
77.0	16.5	2.28	329	76.8	16.2	2.29
70.0	15.1	2.02	328	70.5	14.9	2.04
56.0	16.4	1.50	330	56.0	17.4	1.53
48.0	27.5	1.13	330	48.2	28.0	1.18
42.2	34.0	0.75	330	42.4	34.4	0.81
37.0	25.0	0.72	329	37.3	25.4	0.78
38.0	29.8	0.72	329	38.3	30.4	0.78

The readings were corrected to 330 R.P.M.

DATA FOR STRAY POWER LOSS CURVE:

I_f	Input. (watts)	Brush Loss.	Armature Loss.	Stray Power Loss.
6.13	1786	22.2	3.54	1760
5.33	1703	22.2	3.54	1677
4.95	1655	22.2	3.54	1629
4.70	1430	19.5	2.73	1408
4.41	1495	20.6	3.05	1471
4.14	1392	20.2	2.91	1369
3.85	1225	18.6	2.47	1204
3.56	1365	21.4	3.29	1340

3.14	1273	22.2	3.51	1247
2.76	1251	24.0	4.12	1223
2.29	1247	26.0	4.84	1216
2.04	1050	23.7	4.05	1022
1.53	972	27.8	5.54	938
1.18	1348	44.8	14.40	1289
0.81	1460	55.1	21.70	1383
0.78	947	40.7	11.80	895
0.78	1164	48.7	16.90	1098

From these readings, the inputs, brush losses, and armature losses were determined for the different field excitations. Since the machine was separately excited, the shunt field loss did not enter into the calculations. The stray power loss for each set of readings was the input less the copper loss in the armature and brush loss corresponding to that set.

The stray power loss curve was then plotted with losses as ordinates and the field currents as abscissas. It was then possible to separate the iron losses from the friction losses for, if there were no field excitation there would be no iron loss and the loss shown by the curve for zero field excitation would, therefore, be friction loss. Since the machine was run at constant speed, the friction loss may be assumed to be constant. Therefore a straight line drawn parallel to the X-axis through the intersection of the stray power loss curve and the ordinate for zero field excitation will be the friction loss curve. These curves are on plate IV.

EFFICIENCY CURVE:

In order to obtain the efficiency curve, different values of external current and the voltage used in determining the armature characteristics were assumed and the losses calculated as follows:-

The shunt field current corresponding to the external current assumed was read from the armature characteristic. Knowing the resistance of the shunt field, the field loss was readily calculated. The field current found above was added to the assumed external current to get the armature current. Knowing this and the resistance of the armature, the copper loss of the armature was determined.

The brush loss was considered to be 1.6 volts.

Since the field current was known, the stray power loss was read directly from the curve.

The output is $E_x I_x$.

The actual power generated in the machine is equal to the output plus the total losses which occur in the machine.

The electrical efficiency of the generator is then equal to the output divided by the actual power generated. The efficiency was calculated for each value of assumed external current. The efficiency curve was then plotted on Plate IV.

DATA FOR EFFICIENCY CURVE: (Stray power method)

I_x (Assumed)	E_x	Output (Watts)	I_f	I_a	Armature Loss. (Watts).
25	110	3148	3.60	28.60	15.0
50	"	5950	4.05	54.05	53.5
75	"	8755	4.55	79.55	116.0
100	"	11580	5.13	105.13	203.0
125	"	14390	5.75	130.75	313.0
150	"	17200	6.37	156.37	448.0
175	"	20040	7.o5	182.05	608.0
200	"	22850	7.75	207.75	789.0

I_x (Assumed)	Brush Loss.	Field Loss.	Stray Power Loss.	Output plus Losses.	Efficiency. %
25	46	201	1308	4718	66.8
50	86.5	254	1385	7729	76.9
75	127	320	1480	10798	81.2
100	168	402	1600	13953	82.8
125	209	511	1728	17151	83.9
150	250	628	1860	20386	84.5
175	291	768	2020	23727	84.5
200	332	930	2190	27091	84.2

An interesting and instructive experiment which was performed was to determine the distribution of potential about the armature.

The principles involved are as follows:-

If a coil of wire be revolved uniformly between the two poles of a magnet, it will be found that no electromotive force will be induced in the coil when it is at right angles to the axis of the poles because, at this point, the coil is merely slipping through and not cutting the lines of flux. As the coil is revolved, the induced electromotive force will gradually increase until it reaches a maximum which will be when the coil is parallel to the axis of the poles for, when it is in this position, it is cutting the greatest possible number of lines of flux at the greatest rate possible when the coil is rotated at that speed. The induced electromotive force will then decrease until it reaches zero which will be when the coil is turned 180° from its original position. If the coil be wound on an iron core and be made to carry a current, the induced electromotive force will not be zero and will not reach a maximum at the point stated above but the action of the rotating current-carrying coil will be to distort the field of the magnet and consequently the zero and maximum points will be shifted so as to correspond with the new field as it did with the other field when the coil carried no current. The action of a coil wound on an iron core but which carries no current is so nearly like that of the one described where no iron core was used that they can be assumed to be the same.

The two methods of investigating the electromotive force of the armature coils are, (1) The electromotive force of any one coil in different positions of the armature, - (2) The way in which the electromotive force varies from one brush around the armature to a brush of similar polarity.

The former method was used in this test.

In order to obtain the necessary readings, an arrangement which consisted of two points fastened rigidly to a block of wood and held so they were the thickness of one commutator bar and one insulation apart was made. A strip of wood fibre was cut so as to just fit between two like brushes and to bend around the armature. This strip was notched between the brushes with as many notches as there were commutator bars. This fibre was placed in position and the points of the arrangement described above were connected to a voltmeter. With the machine running uniformly at normal speed, the two points were placed in different positions around the armature and the electromotive force, as shown by the voltmeter, and the positions of the points, as shown by the wood fibre, were recorded. This was continued until the entire distance from a ~~pole~~ brush to one of like polarity was traversed.

This operation was performed with the machine running at no load and repeated for full load. The curves are shown on Plate V. The observed and corrected data are shown here.

DISTRIBUTION OF POTENTIAL AROUND THE ARMATURE:

At no load.

Commutator Bar No.	E.M.F.	R.P.M.	E_x	E.M.F. (Corrected)
1	0	330	118	0
2	0	"	"	0
3	8.4	"	"	8.3
4	9.0	"	"	8.9
5	9.5	"	"	9.4
6	9.8	"	"	9.65
7	10.0	"	"	9.85
8	9.8	"	"	9.65
9	9.5	"	"	9.4
10	9.1	"	"	9.0
11	9.0	"	"	8.9
12	8.8	"	"	8.7
13	6.0	"	"	6.0
14	3.5	"	"	3.5
15	0	"	"	0
16	0	"	"	0
17	0	"	"	0
18	0	"	"	0
19	6.0	"	"	6.0
20	8.5	"	"	8.4
21	9.2	"	"	9.1
22	9.5	"	"	9.65
23	8.9	"	"	8.8

Commutator Bar No.	E.M.F.	R.P.M.	E_x	E.M.F. (Corrected)
24	8.8	330	118	8.7
25	7.9	"	"	7.85
26	8.0	"	"	7.95
27	7.9	"	"	7.85
28	7.2	"	"	7.2
29	6.2	"	"	6.2
30	2.2	"	"	2.2
31	0	"	"	0
32	0	"	"	0
33	0	"	"	0

At Full Load.

1	0	330	118	0
2	0	"	"	0
3	7.2	"	"	7.2
4	8.6	"	"	8.5
5	9.6	"	"	9.5
6	9.4	"	"	9.3
7	9.5	"	"	9.4
8	8.2	"	"	8.15
9	8.8	"	"	8.7
10	8.5	"	"	8.4
11	7.9	"	"	7.85
12	7.5	"	"	7.45
13	5.3	"	"	5.3
14	1.6	"	"	1.6
15	0	"	"	0
16	0	"	"	0

Commutator Bar No.	E.M.F.	R.P.M.	E_x	E.M.F. (Corrected)
17	0	330	118	0
18	0	"	"	0
19	8.2	"	"	8.15
20	8.6	"	"	8.5
21	8.9	"	"	8.8
22	8.4	"	"	8.3
23	7.9	"	"	7.85
24	7.5	"	"	7.45
25	7.2	"	"	7.15
26	7.6	"	"	7.55
27	7.5	"	"	7.45
28	7.0	"	"	6.95
29	5.6	"	"	5.6
30	1.6	"	"	1.6
31	0	"	"	0
32	0	"	"	0
33	0	"	"	0

The two curves were plotted from the two sets of readings with the positions as abscissas and the electromotive forces as ordinates.

By a comparison of the two curves, the distortion caused by the full load current may be seen. This is small and shows that the commutation secured by the inner poles of the generator is very good.

The current densities in the different conductors were calculated.

Upon examination of the armature, it was found to have a duplex wave winding. Since this is the case, there are four paths between the brushes and at full load there will be two hundred divided by four or fifty amperes in each conductor. The dimensions of the armature winding are 1/2" by 1/8" or 79500 circular mils. The current density is then 0.000629 amps. per circular mil. 1590 cir mil per amp.

The brush area is 13.75 square inches or 17,500,000 cir.mils. The current density is then 14.55 amperes per square inch or .0000001143 amperes per circular mil.

The shunt field current is 6 amperes. Area of the wire is 6,530 circular mils. The density is then 0.000919 amperes per circular mil. 1100 cir mil per amp -

The series field current is 200 amperes. The area of the conductor is 0.1953 square inches or 248,800 circular mils. The current density is then 0.000803 amperes per circular mil. 1245.

All the instruments used in obtaining data for this test were carefully calibrated by comparison with the laboratory standard with the exception of the Simplex ammeter which was calibrated by comparison with a milli-voltmeter and its shunt which were already calibrated. The laboratory standard voltmeter was calibrated by means of a potentiometer. The curves were plotted with the readings as abscissas and errors as ordinates. The errors shown by the curves, consequently, must be subtracted from the instrument readings in order to obtain the correct readings. These curves are shown on Plates VI and VII.

The following is a table of comparion of different determinations made on three generators of different manufacture taken from the theses of Messrs. Leach, McFee, and myself on an Edison shunt machine, a General Electric three-wire compound machine, and a Thompson-Ryan interpole compound machine respectively.

Part.	Edison.		Thompson-Ryan.		General Electric.	
	Flux Density	Current Density	Flux Density	Current Density	Flux Density	Current Density
Field Core.	83660	-	-	-	-	-
Yoke.	78000	-	-	-	-	-
Pole Face.	41640	-	-	-	124000	-
Armature Core.	49000	-	-	-	119000	-
Shunt Field.	-	*.000406(L) .000540(S)	-	.000919	-	.000111
Series Field.	-	-	-	.000803	-	.0000904
Armature Condr.	-	.00193	-	.000625	-	.00018
Output-K.W.	20		25		50	
Voltage	125		125		225/250	
Amperes	160		200		400/200	
Rated Speed	1500		325		290	
Field Poles	2		10		6	
Latest Patent	1882		1893		1902	

The flux density is in lines per square inch and current density in amperes per circular mil.

*The shunt field of the Edison generator was wound with two sizes of wire, large and small, marked (L) and (S).

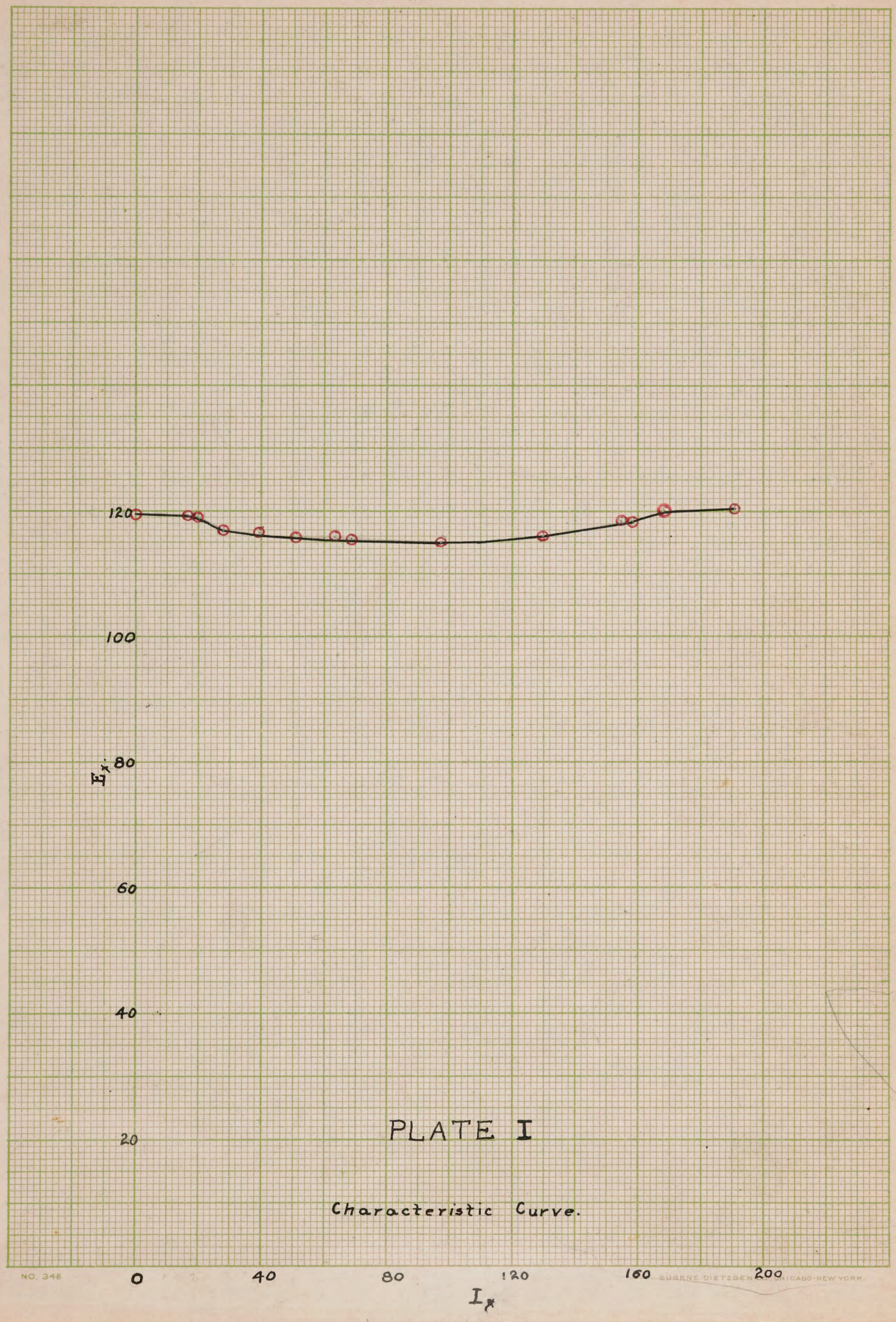


PLATE I

Characteristic Curve.

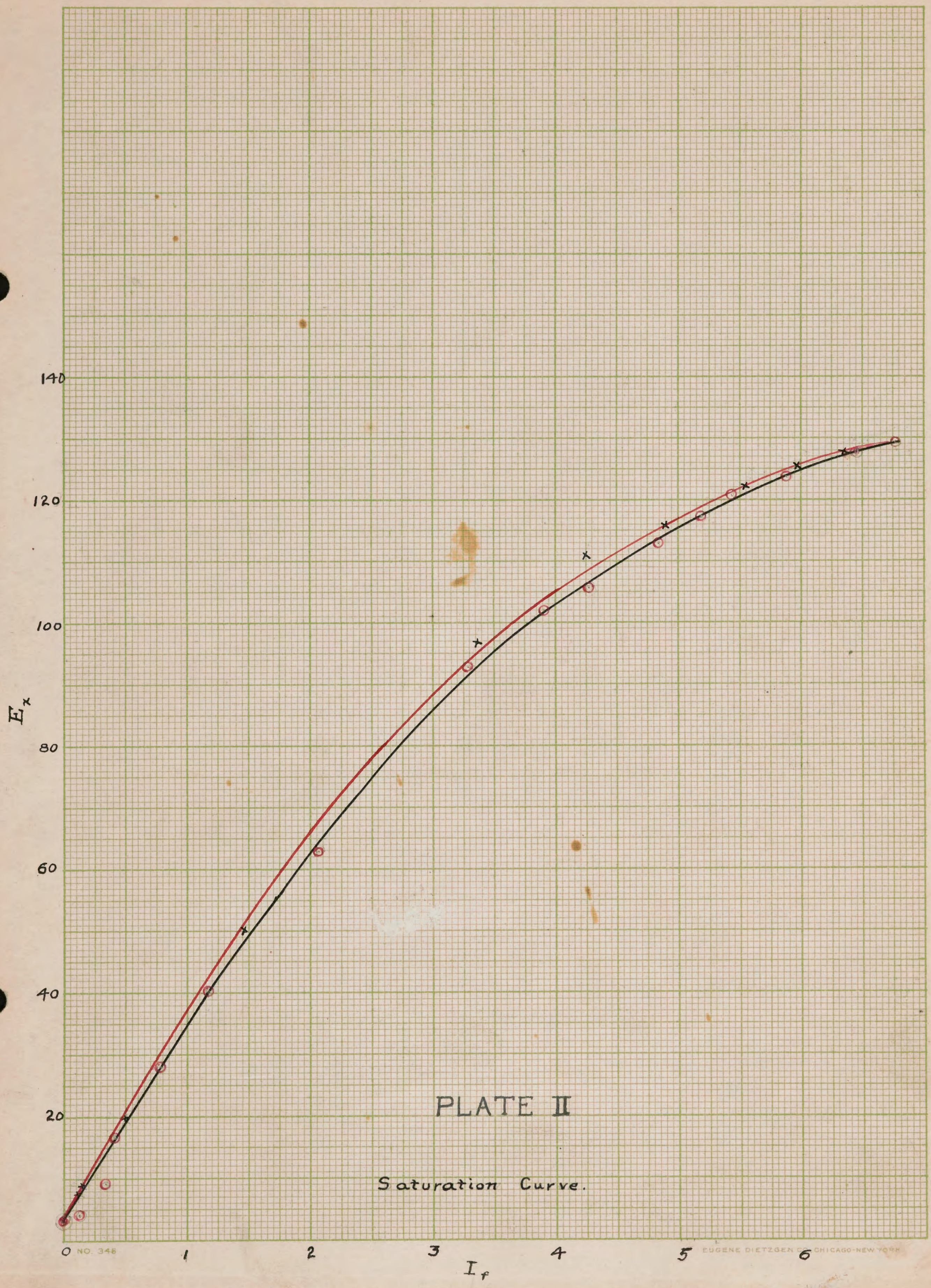


PLATE II
Saturation Curve.
E_x
I_f
0
1
2
3
4
5
6
20
40
60
80
100
120
140
NO. 348
EUGENE DIETZGEN CO. CHICAGO-NEW YORK

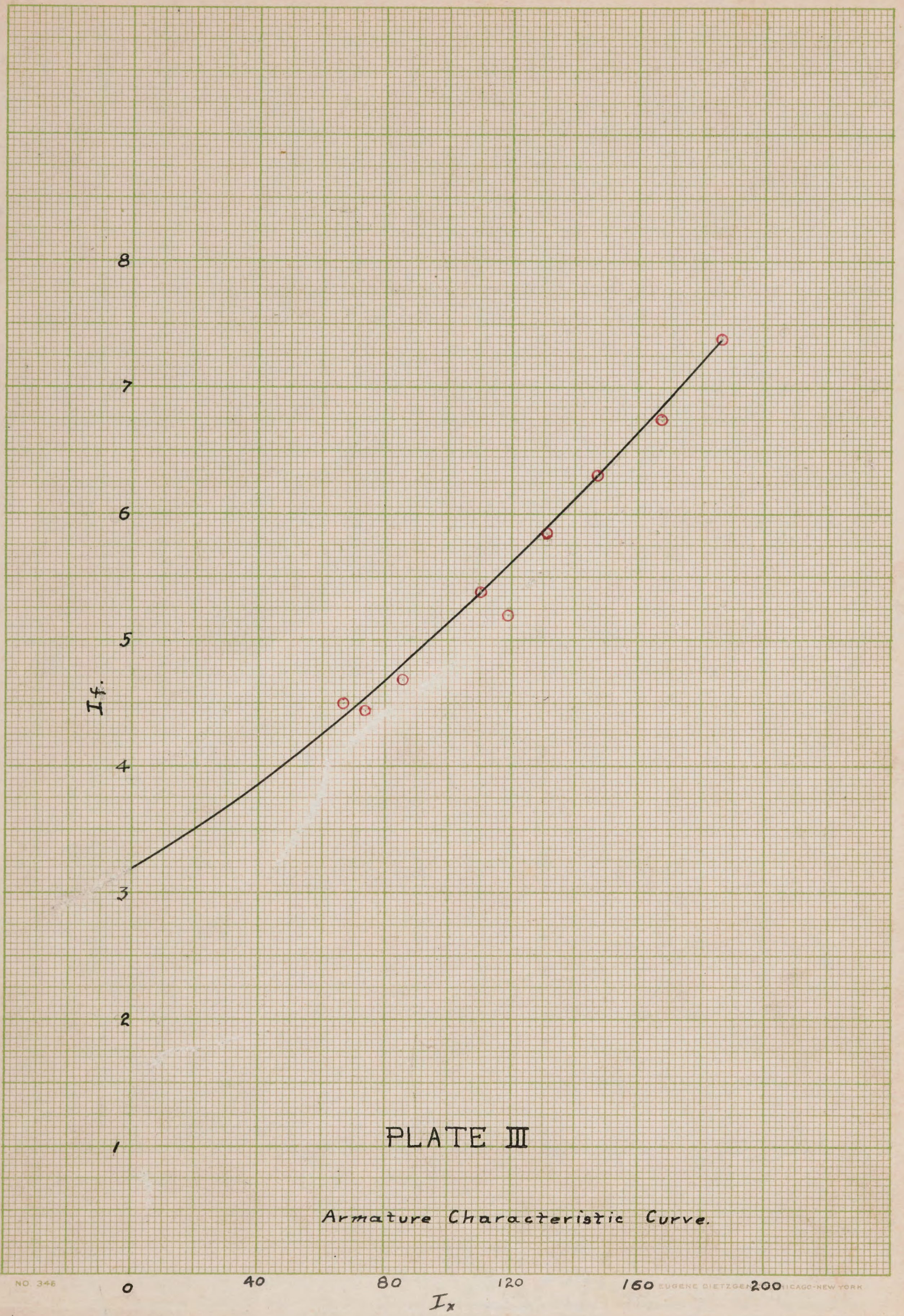


PLATE III

Armature Characteristic Curve.

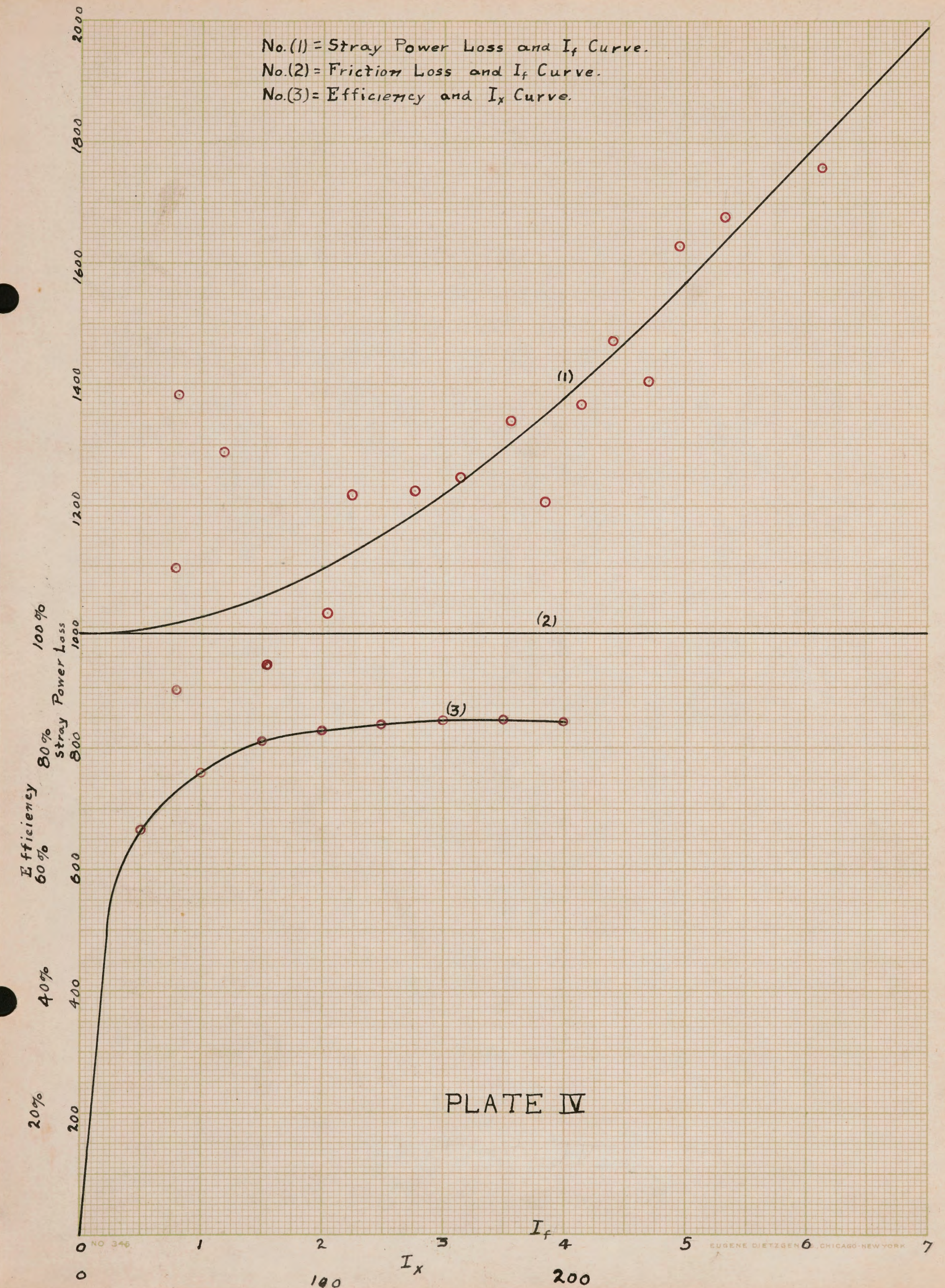
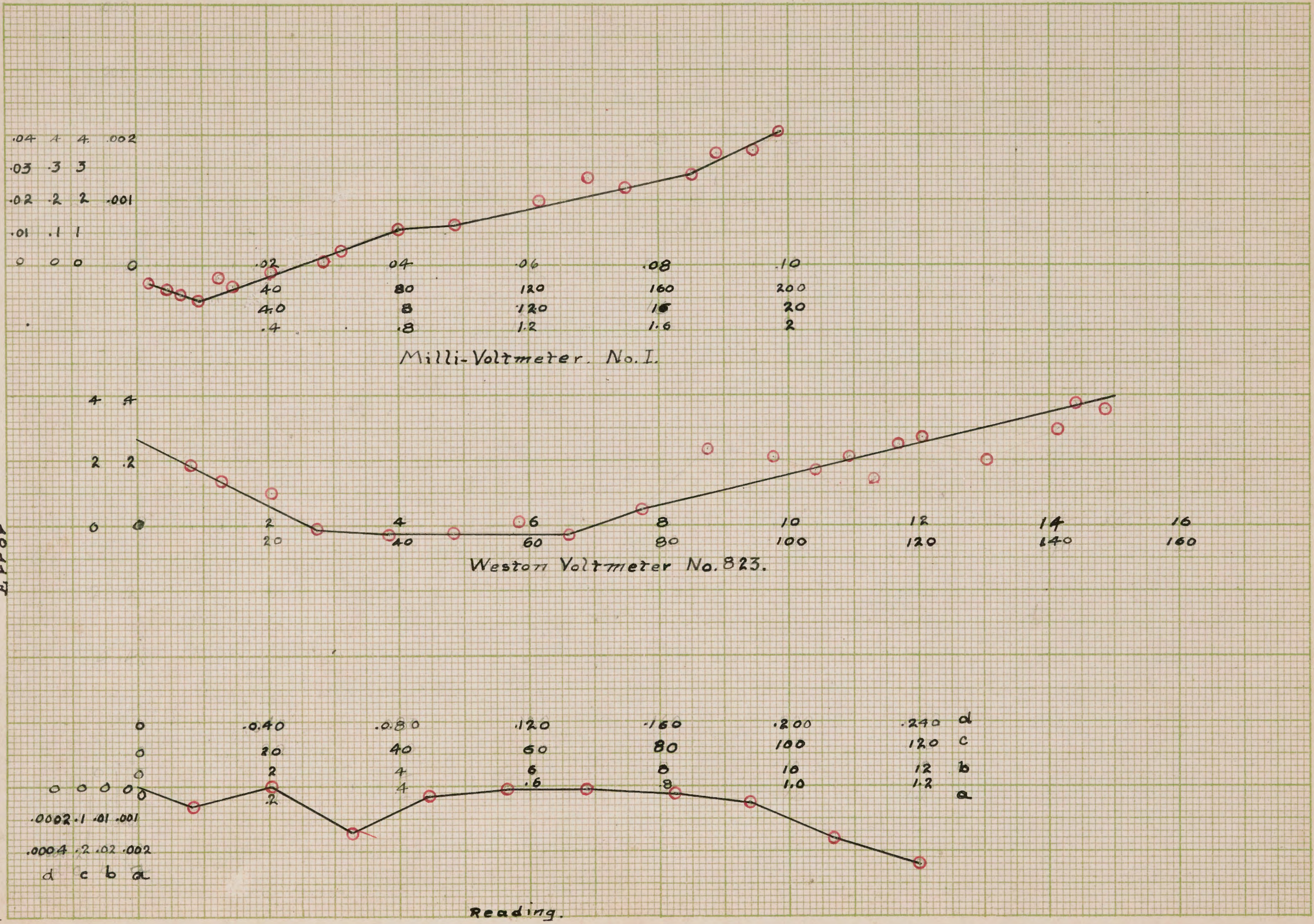

No.(1) = Stray Power Loss and I_f Curve.
No.(2) = Friction Loss and I_f Curve.
No.(3) = Efficiency and I_x Curve.
(1)
(2)
(3)
Stray Power Loss
Efficiency
100%
80%
60%
40%
20%
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
I_f
I_x
0
100
200
NO. 346
EUGENE DIETZGEN CO. CHICAGO-NEW YORK

PLATE IV

PLATE V

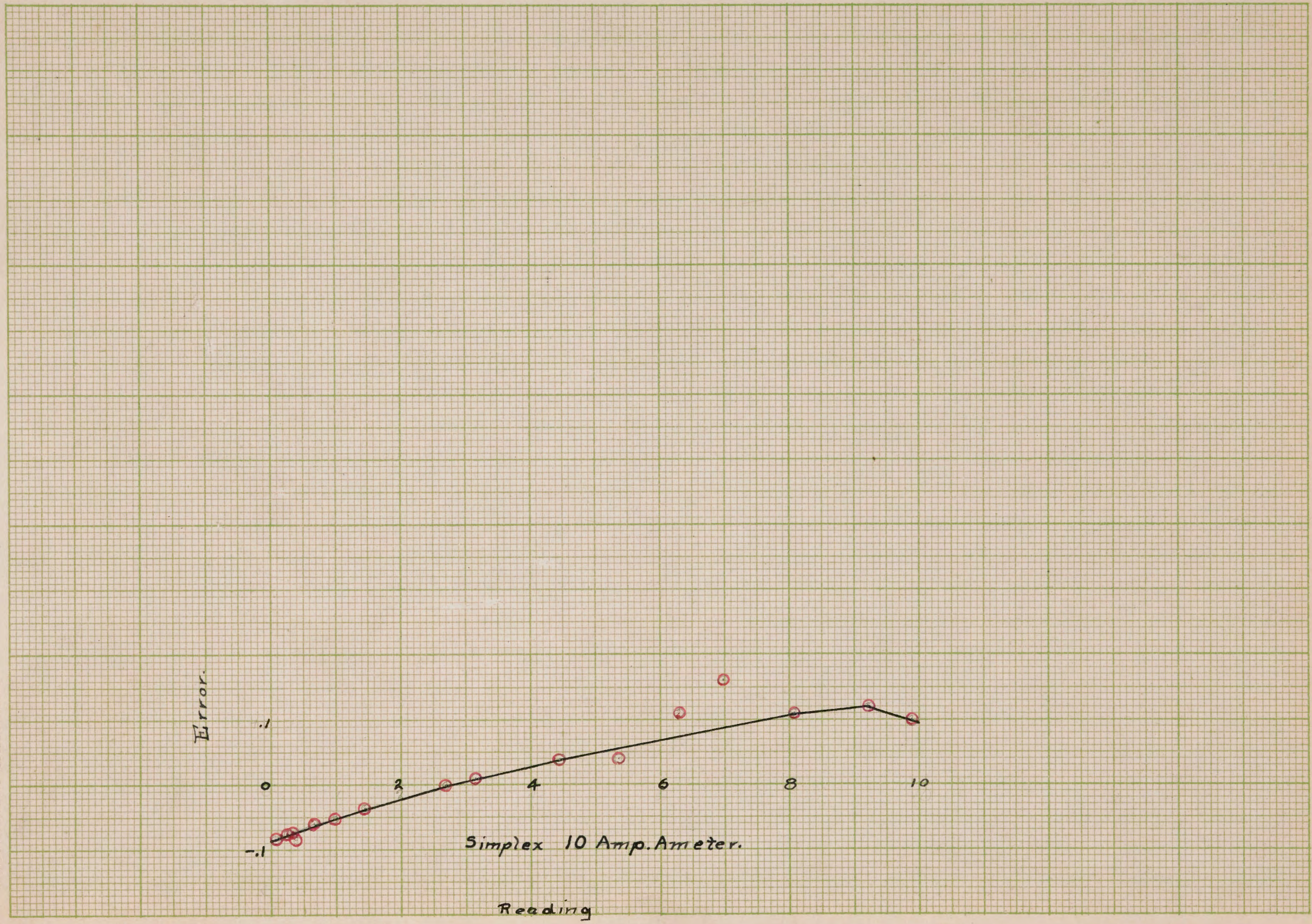
Distribution of Potential Around Armature.

PLATE VI



Calibration Curves.

PLATE VII



Calibration Curves.