TEST OF A $37\frac{1}{2}$ K. V. A. A.C. GENERATOR

by

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THESIS SUBMITTED FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

University of Tennessee

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P R E F A C E

This test was run on a Westinghouse 37.5 K.V.A. A.C. turbine generator. The machin can best be described by giving the specifications on the name plate.

37.5	K.V.A.	60	Cycles
2300	Volts	1200	R.P.M.
9.5	Amps.	9.5	Exciting Amps.
80%	P.F.	125	Volts.
3 phase			

S.O. 93097

Serial 2411992

The Exciter is directly connected to the alternator.

E X C I T E R

Shunt wound	$1\frac{1}{2}$ K.W.
125 Volts	12 Amps.
	1200 R.P.M.

Style 73A985

Serial 2730638

The alternator is driven by a Westinghouse Steam Turbine having a rated speed of 7200 R.P.M. The turbine is connected to the alternator through a gear box having a ratio 6 to 1, here the speed is reduced from 7200 R.P.M. to 1200 R.P.M.

This machinery is located on the boiler room floor of the University power house. It is used primarily to carry the night load after the lights at various dormitories are cut off. It usually operates about eight hours per day from 11 P.M. to 7 A.M. This night load consists of the lamps used for lighting the Campus, fire escapes at the dormitories, etc. The machine is also operated on Sundays, but for other week days it is too small to carry the load and the 500 K.W. machine is operated.

The tests that were made are not original but apply to this specific generator.

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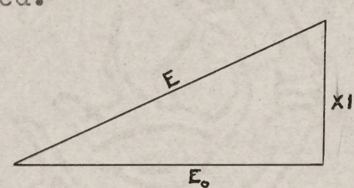
THE SATURATION CURVE

The saturation curve is a curve plotted between field current as abscissa and terminal volts as ordinate. This curve is used in calculating the regulation of the machine by the indirect tests. A voltage transformer having a ratio of 20 to 1 was connected between two terminals of the machine. An A.C. voltmeter connected to the secondary of the transformer measured the generated voltage. A. D.C. ammeter was connected in series with the field to measure the exciting current. The voltage on the field was also measured with a D.C. voltmeter. A rheostat in the field circuit was used to vary the exciting current. Then with the machine running at normal speed with no load the terminal voltage was increased step by step and readings for field current and voltage and terminal voltage were taken for each step. This was continued until more than rated voltage was passed and then the readings were taken for a decreasing field current. To verify the points on the low voltage part of the curve, a high reading voltmeter (0-300) was connected directly across the terminals and readings were taken. The generated voltage present with nofield excitation is caused by the residual magnetism in the iron. The recorded data represent the corrected values and not the actual instrument readings.

After the no load saturation curve was plotted, the full load saturation curve for 0% power factor was drawn parallel to the first curve, beginning at the point corresponding to a field excitation of 4.01 amperes. This point was found in the impedance test (described later) and it is the field excitation required to send full load current through the armature under short circuit.

The saturation curve for full load current and unity power factor was calculated from the previous curves. For an assumed generated voltage the reactance drop which is the vertical distance between the no load and full load 0% P.F. curve was read. The resistance drop in the armature was neglected in calculating the terminal voltage. For different voltages the corresponding terminal voltage was calculated and the curve plotted.



E = induced on generated voltage

Eo = terminal voltage.

DATA FOR SATURATION CURVES.

A.C. Voltmeter Reading	Terminal Volts	Field Current	Field Voltage
140;0	140	0.00	0.0
15.5	310	0.32	2.9
21.5	430	0.55	4.7
32.0	640	0.93	8.0
44.3	886	1.45	12.5
56.0	1120	1.95	17.0
67.0	1340	2.36	20.0
77.2	1544	2.90	23.5
86.6	1782	3.30	27.0
96.2	1924	3.80	31.0
106.0	2120	4.57	36.3
112.0	2240	4.72	38.2
118.0	2360	5.26	42.0
128.0	2560	6.20	49.0
134.5	2690	6.80	53.6
140.0	2800	7.40	59.0
132.0	2640	6.65	52.9
123.0	2460	5.65	45.5
115.6	2312	4.95	41.0
102.0	2040	4.10	34.0
90.0	1800	3.40	28.3
71.6	1432	2.52	21.0
60.1	1202	2.05	18.0
52.0	1040	1.75	15.0

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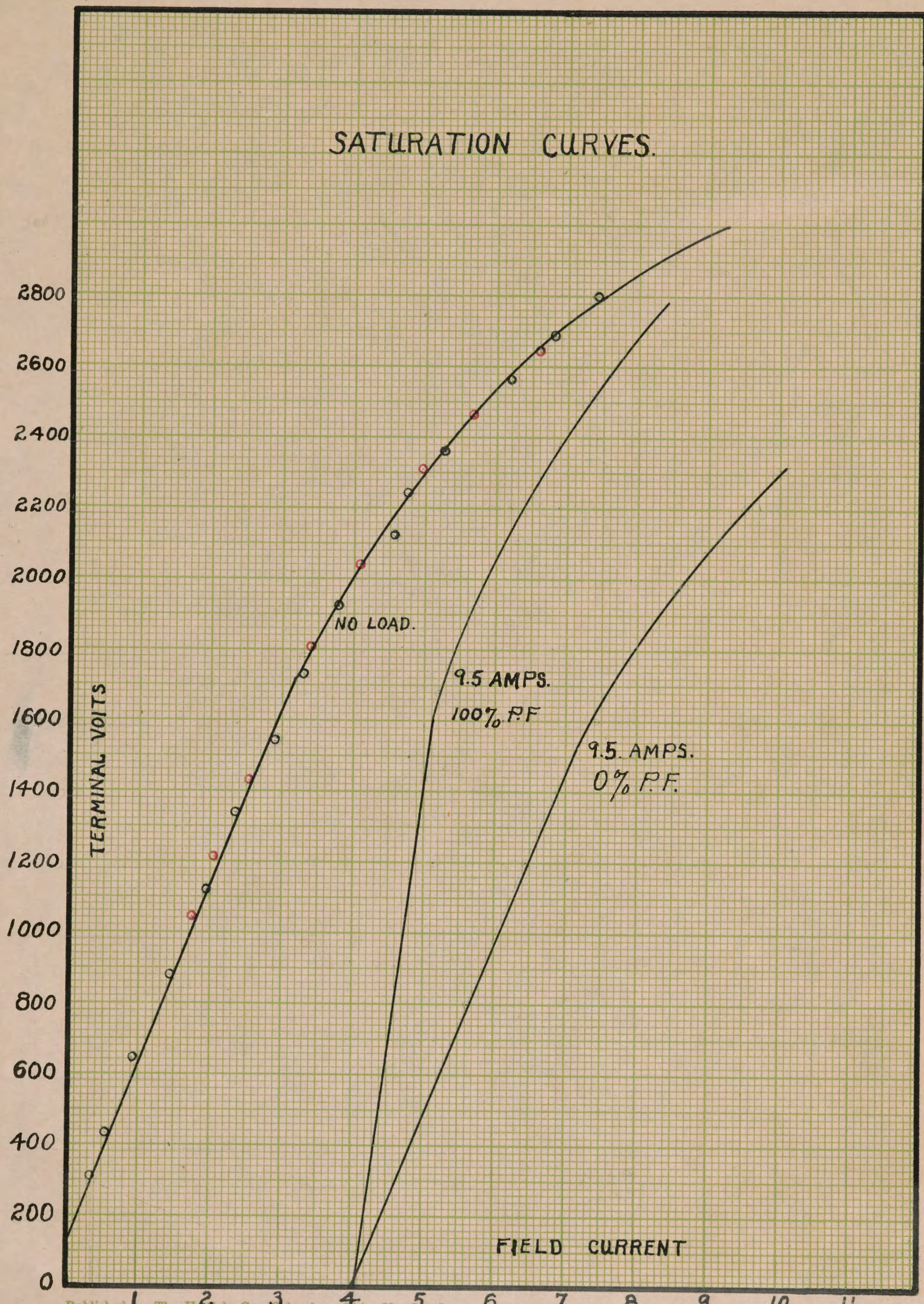
DATA FOR FULL LOAD SATURATION CURVE

Generated voltage	XI Drop	Terminal Voltage	Field I
2005	2005	0	4.01
2300	1800	1430	5.00
2400	1710	1680	5.40
2500	1600	1940	5.80
2600	1540	2110	6.10
2700	1310	2380	6.90
2800	1230	2520	7.40



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SYNCHRONOUS IMPEDANCE

The synchronous impedance is a fictitious quantity which serves as a measure of the effect of armature winding in changing terminal voltage as load is varied. It lumps together the armature resistance drop, the reactance drop and the effect of armature reaction. By the use of this the alternator behavior can be predicted.

The following procedure was used: a D. C. ammeter and voltmeter were connected in the field circuit as before. The armature of the machine was short circuited through two current transformers (Y connected). The current in the third phase was measured by connecting an ammeter between the two secondaries of the transformer which were in series. This ammeter measured the sum of the two currentsin the transformers which was the current in the third phase. Then with the machine running at normal speed the field current increased by small amounts, and readings of exciting and armature currents were taken. This was continued until the short circuited current was more than one and one quarter full load current - care was taken to prevent overheating of the armature. From this a curve was plotted between field current as abscissa and armature current as ordinate.

The synchronous impedance is defined as the voltage which will cause full load current to flow in the short circuited armature. From the above curve the field current necessary to produce full load current was read, then from the saturation curve the voltage corresponding to do this field excitation was determined. The full load synchronous impedance voltage per phase is the above voltage divided by the square root of three.

DATA FOR IMPEDANCE CURVE

AMMETER CURRENTS
Phase

1-2	1-3	2-3	Average I	I x 5	Field I	Field E
1.04	1.04	1.06	1.05	5.25	2.08	17.5
1.12	1.11	1.15	1.13	5.65	2.29	20.0
1.28	1.30	1.32	1.30	6.50	2.70	23.0
1.51	1.51	1.51	1.51	7.55	3.30	26.0
1.66	1.66	1.66	1.66	8.30	3.45	29.0
1.69	1.71	1.71	1.70	8.50	3.50	29.5
1.76	1.80	1.79	1.78	8.90	3.70	30.5
1.96	1.97	1.96	1.96	9.80	4.10	34.0
2.04	2.05	2.05	2.05	10.25	4.24	35.0
2.15	2.15	2.15	2.15	10.75	4.53	38.0
2.04	2.04	2.04	2.04	10.20	4.21	35.0

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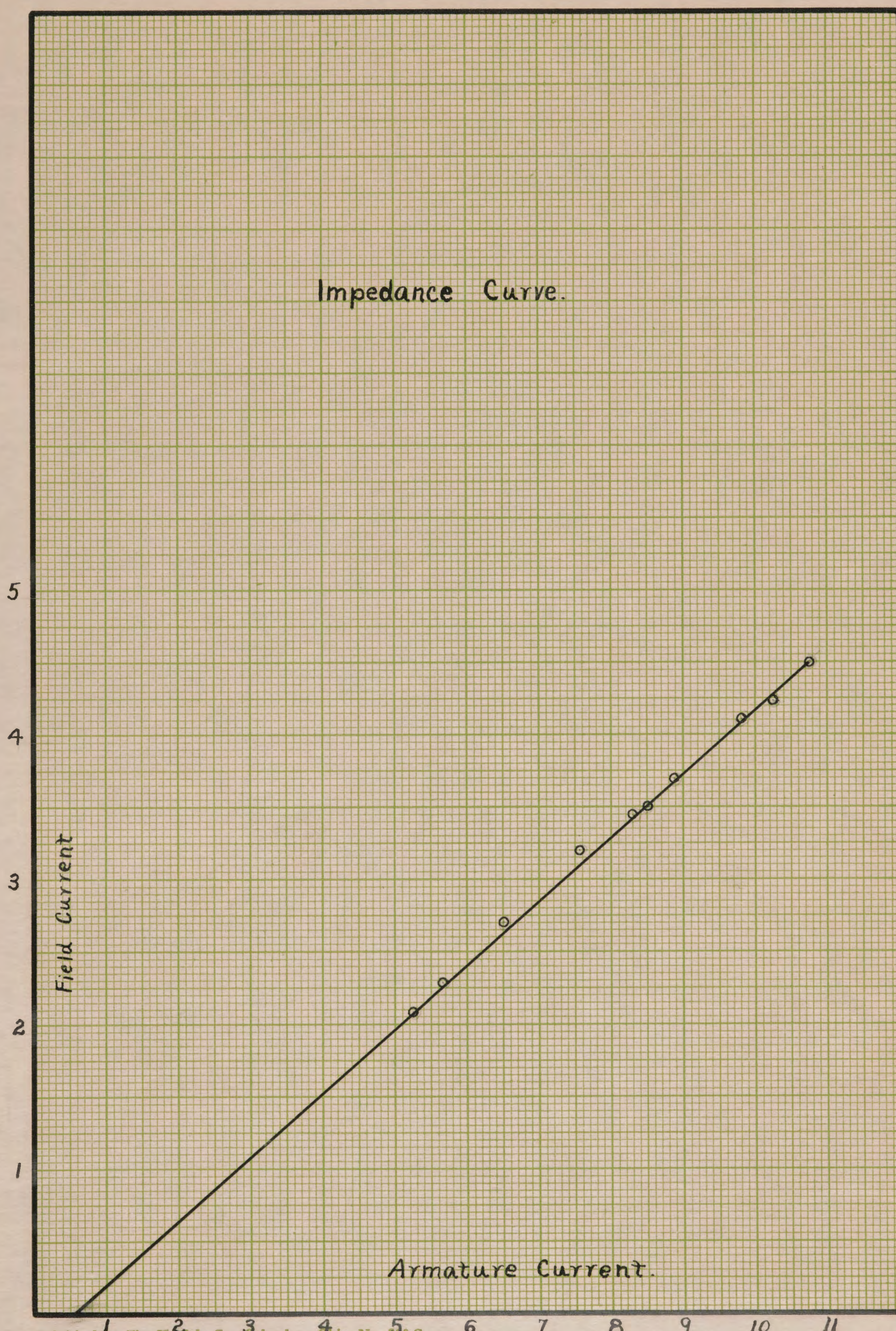

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R E S I S T A N C E

The resistance of the armature and field was found by passing a continuous current through the circuits. A milli-voltmeter with shunt was connected in series with the line to measure the current; a voltmeter measured the difference in potential between the two terminals. The resistance was calculated, according to Ohm's Law

$$R = \frac{E}{I}$$

The resistance of the field includes the voltage drop through the brushes. The resistance of the armature was measured just after the impedance test and is therefore the hot resistance.

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RESISTANCE OF ARMATURE

	E	I	R
Terminals 1-2	13.20	1.38	9.56
	10.60	1.11	9.55
	6.75	0.71	9.56
Terminals 1-3	13.30	1.38	9.64
	10.70	1.11	9.64
	6.85	0.71	9.65
Terminals 2-3	13.37	1.39	9.62
	10.70	1.12	9.57
	6.72	0.71	9.59

AVERAGE RESISTANCE BETWEEN TERMINALS = 9.60 Ohms.

RESISTANCE OF FIELD

E	I	R
13.30	1.63	8.17
10.65	1.30	8.18
6.80	0.83	8.19

Average Resistance - - - - - - - - - - - - - - 8.18 Ohms.

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REGULATION

There are three reasons for the difference between no load and full load voltage:

(1) The armature resistance drop which is equal to RI.

(2) The reactance drop. (3) Armature reaction which is caused by a distortion of the field flux by the armature current. By the regulation of an alternator is meant the percent increase in voltage from full load to no load.

$$\text{REGULATION} = \frac{Eo - Et}{Et} \times 100$$

From impedance curve for full load current of 9.5 amps, 4.05 amps are required for the field. From saturation curve this corresponds to a terminal voltage of 2005 volts. But the current readings were taken for Y connected ammeters therefore the corresponding voltage per phase is equal to this divided by the square root of three which is 1155 volts. Average Resistance is 9.60 ohms between terminals.

For convenience use equivalent single phase values in calculating the regulation.

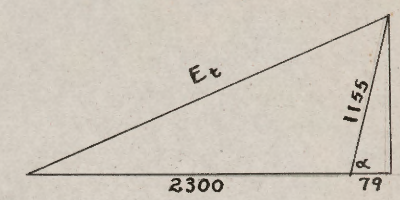
Equivalent single phase current is equal to the line current time the square root of three -

$$I = 9.5 \times \sqrt{3} = 16.4$$

Equivalent single phase current is equal to the resistance between terminals divided by 2

$$R = 9.6 \div 2 = 4.8 \text{ ohms.}$$

FOR UNITY POWER FACTOR



$$RI = 4.8 \times 16.4 = 79.0$$

$$\text{Cos}\,\alpha = 78.7 \div 1155 = 0.0681$$

$$\alpha = 86.1^{\circ} \qquad \sin\alpha = .9977$$

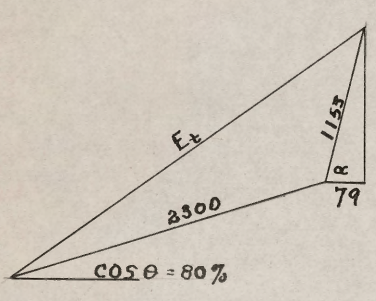
Horizontal component $= 2300 + 78.7 = 2379$

Vertical component $= 1155 \times .9977 = 1152$

$$Et = \sqrt{\overline{2379}^2 + \overline{1152}^2} = \sqrt{6,986,745} = 2643 \text{ volts}$$

$$\text{Req.} = \frac{2643 - 2300}{2300} = \frac{343}{2300} \times 100 = 14.9\ \%$$

FOR 80% POWER FACTOR



$$R\,I = 4.8 \times 16.4 = 79 \qquad \text{Cos}\,\alpha = 78.7 \div 1155 = .0681$$

$$\alpha = 86.1 \qquad \sin\alpha = 0.977$$

Horizontal Component =

2300 x .80	=	1840.0
79 x 1.	=	79.0
total		1919.0

Vertical component =

2300 x .6	=	1380
1155 x .9977	=	1152
total - - -		2532

$$Et = \sqrt{\overline{1919}^2 + \overline{2532}^2} = \sqrt{10,092,000} = 3177$$

$$\text{Req} = \frac{3177 - 2300}{2300} = \frac{877}{2300} = 38.1\ \%$$

From the heat test it was found that the alternator operates at a power factor of 97% therefore the regulation was calculated for this value.

$\cos\theta = .9700 \qquad \sin\theta = .2436$

Horizontal component =

$$2300 \times .9700 = 2231$$
$$79 \times 1.0 = \underline{\quad 79}$$
$$2310$$

Vertical component

$$2300 \times .2436 = 560$$
$$1155 \times .9977 = \underline{1152}$$
$$1712$$

$$Et = \sqrt{2310^2 + 1712^2} = \sqrt{8{,}266{,}100} = 2875$$

$$Reg. = \frac{2875 - 2300}{2300} = \frac{575}{2300} = 25.0\%$$

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LOSSES AND EFFICIENCY

The losses of an alternator are as follows

a. Bearing friction
b. Windage
c. Armature copper loss
d. Core loss
e. Field excitation loss

Bearing friction loss $= 0.81\ d\ l\ \left(\frac{V}{100}\right)^{3/2}$ in watts

d = Diameter bearing in inches.

l = length of bearing in inches

V = rubbing velocity in ft. per minute.

The generator has two bearings 7 inches in length and 3 in. in diameter.

$$V = \pi d \times R.P.M. = 3/12 \times 3.1416 \times 1200 = 942 \text{ ft. per in.}$$

$$\text{Loss} = .81\ d\ l\ \left(\frac{V}{100}\right)^{3/2} = .81 \times 3 \times 2 \times 7 \left(\frac{942}{100}\right)^{3/2}$$

$$= 0.81 \times 3 \times 2 \times 7 \times 28.94 = 984 \text{ watts}$$

The windage loss was ignored in calculating the efficiency of the machine.

The armature copper loss for a three phase machine is $3/2\ I^2 R$. Where R is the resistance between the terminals

Armature copper loss $= 3/2 \times 9.5^2 \times 9.60$

$= 3/2 \times 90 \times 9.60 = 1296$ watts

The core losses were read directly from a curve furnished by the makers. Core losses for 2300 volts = 1050 watts. This loss does not change with the load.

The field excitation required for normal voltage and full load current was read direct from the full load saturation cure.

Field loss $= I^2R = 6.22^2 \times 8.18 = 322$ watts.

The efficiency of an alternator is the ratio of the power output to the power input or

$$\text{Efficiency in per cent} = \frac{\text{output}}{\text{output + losses}} \times 100$$

For different loads the losses and efficiency for the alternator were calculated, the core, and friction losses remaining constant.

Load	Friction Loss	Core Loss	Field Loss	Copper Loss	Input	Output	Eff.
Full	0.98	1.05	0.32	1.29	41.14	37.50	91.2%
3/4	0.98	1.05	0.28	0.73	31.14	28.10	90.4%
1/2	0.98	1.05	0.24	0.26	21.28	18.75	88.0%
1/4	0.98	1.05	0.20	0.08	11.69	9.38	80.3%

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HEAT RUN

A heat test consists of determining the rise in temperature of the various parts of the machine under load. In this test the machine was operated under its normal load and not full load. Two thermometers were fastened on the armature with putty, another was fastened on the frame. The temperature surrounding the alternator was taken just before the machine started operation. For the first hour thermometer readings were taken every fifteen minutes; after than they were taken every thirty minutes. The rise in temperature became constant after one and a half hours. Also the reading of the field current, field voltage, generated voltage, power factor, and load were taken for each of the temperature readings. The power factor and load in K.W. was read from the instruments on the switch board; the other readings were taken from calibrated laboratory instruments. The current was so low it could not be read, but it was calculated knowing the load, voltage and power factor.

Time	K.W.	Volts	Field E	Field I	Armature Temperature T_1	T_2	Mean	Frame	Calculated I
11:15	15	2286	59.0	6.8	108	111	109.5	103	4.1
11:30	15	2180	52.6	6.1	110	114	112	105	4.1
11:45	15	2168	52.0	6.0	110	114	112	106	4.1
12:00	14	2144	51.8	5.9	111	114	112	106.5	3.9
12:30	14	2144	51.0	5.9	111	114	112.5	106	3.9
1:00	14	2144	51.0	5.9	110	113	111.5	105	3.9
1:30	13	2144	51.0	5.9	110	113	111.5	105	3.6
2:00	13	2174	51.0	5.9	109	112	110.5	105	3.5
2:30	13	2166	51.0	5.9	108	112	110	104	3.6
3:00	13	2160	51.0	5.9	108	112	110.5	103	3.6
3:30	13	2160	51.0	5.9	108	112	110	103	3.6
4:00	13	2124	51.0	5.9	108	112	110	103	3.6
4:30	13	2172	51.0	5.9	108	112	110	103	3.6
5:00	13	2150	51.0	5.9	108	112	110	103	3.6
5:30	13	2070	50.2	6.8	107	111	109	103	3.7
6:00	13	2084	49.3	5.6	107	111	109	103	3.7
6:30	20	2124	57.5	6.7	110	112	108	104	5.5
7:00	13	1164	34.0	3.7	114	116	115	104	6.7

Started 11:00 P.M. Temperature 96° F Temperature of Poles 102°

Stopped 7:00 A.M. " 92° F " " Rings 100°

POWER FACTOR = 0.97

The corresponding rise in temperature for full load was calculated from the above readings by assuming that the rise in temperature was proportional to the losses. If this assumption is not absolutely true it is a very close approximation. The friction losses were ignored in calculating the rise in temperature because it was thought that the bearings were far enough away from the armature not affect its temparature.

From the preceding section the losses at full load (ignoring friction) are as follows:

Armature copper loss	=	1.29	K.W.
Core loss	=	1.05	"
Field loss	=	.32	"
		2.66	K.W.

For a load of 14.5 K.W. and 4.0 amps, the losses are as follows:

Copper loss	=	0.230	K.W.
Core loss	=	1.050	"
Field loss	=	0.250	"
		1.530	K.W.

Therefore the rise in temperature will be in the ratio of $\frac{2.66}{1.53} = 1.74$

Time in Minutes	Load in K.W.	I	Arm. Temp. Rise F°	Arm. Temp Rise C°	Frame Temp. Rise F°	Frame Temp. Rise C°	Temp. Rise for Full Load Armature.	Temp. Rise for Full Load Frame
15	15	4.1	13.5	7.5	6.0	3.3	13.1	5.7
30	15	4.1	16.0	9.0	9.5	5.3	15.7	9.2
45	15	4.1	16.0	9.0	10.0	5.5	15.7	9.6
60	14	3.9	16.5	9.2	10.5	5.8	16.0	10.0
90	14	3.9	16.5	9.2	10.0	5.5	16.0	9.6

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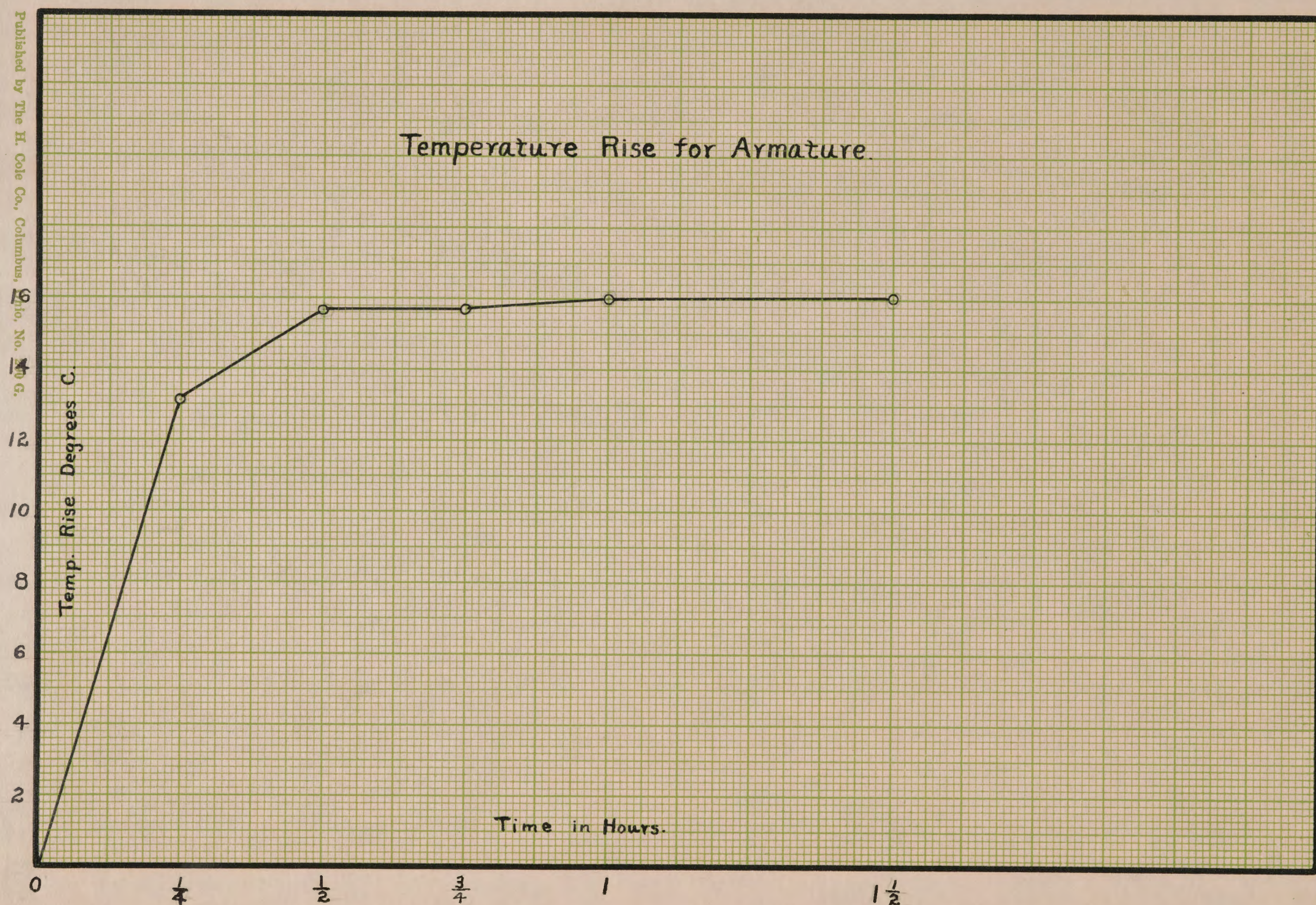
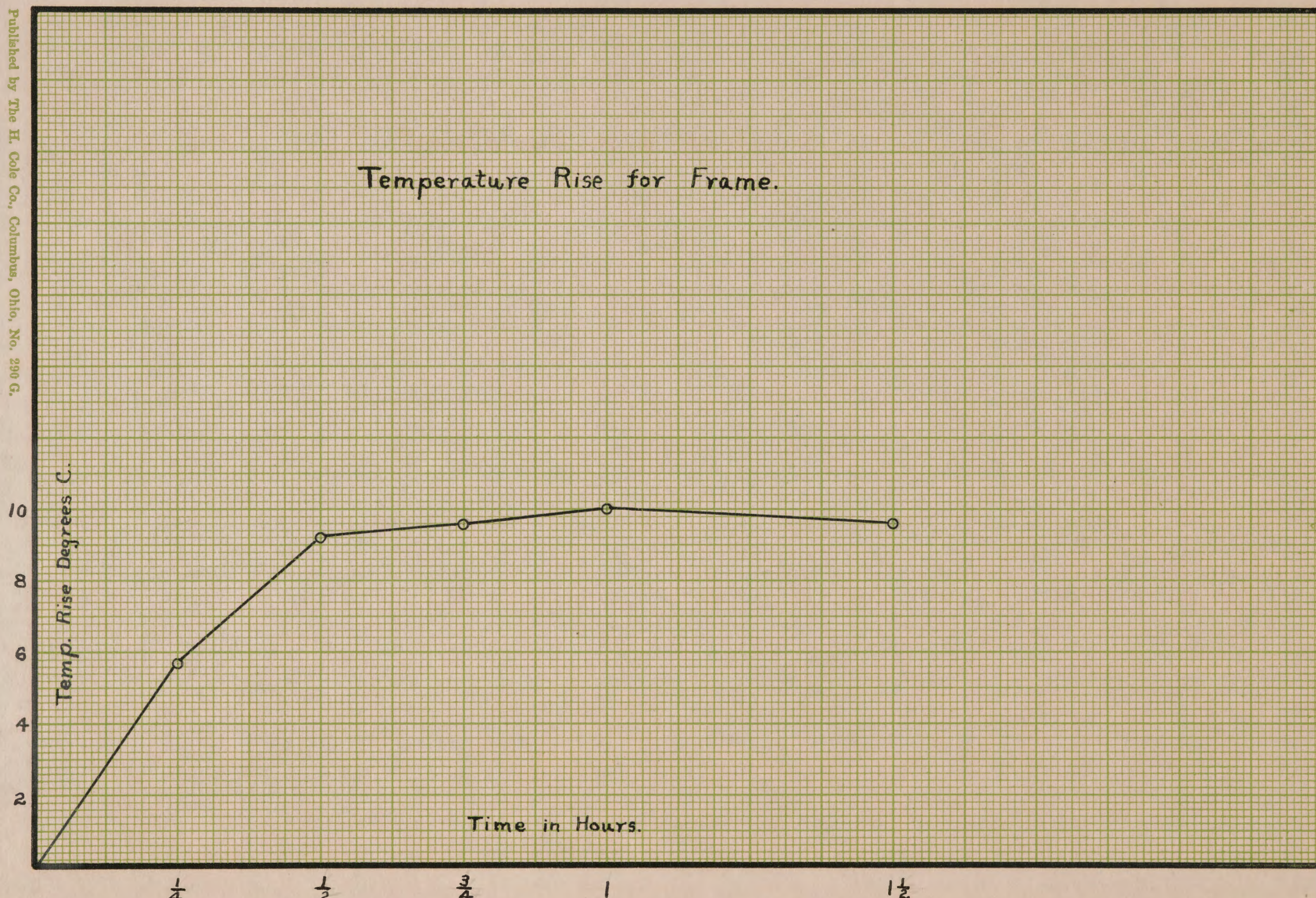

Temperature Rise for Armature.
Temp. Rise Degrees C.
Time in Hours.
16
14
12
10
8
6
4
2
0
1/4
1/2
3/4
1
1 1/2


Temperature Rise for Frame.
Temp. Rise Degrees C.
10
8
6
4
2
Time in Hours.
1/4
1/2
3/4
1
1 1/2

B I B L I O G R A P H Y

1. "Alternating Currents", Magnusson.
2. "Elements of Electrical Engineering" - Cook.
3. "Electrical Circuits and Machinery" - Morecroft & Hebre.
4. "A. C. Phenomena" - Steinmetz.
5. "Tests of Electro Magnetic Machinery" - Swenson & Frankenfield.
6. "Experimental Electrical Engineering" - Karapetoff.

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APPENDIX

This includes the calibration curves for the instruments used, and also the set of curves furnished by the makers of the machine.

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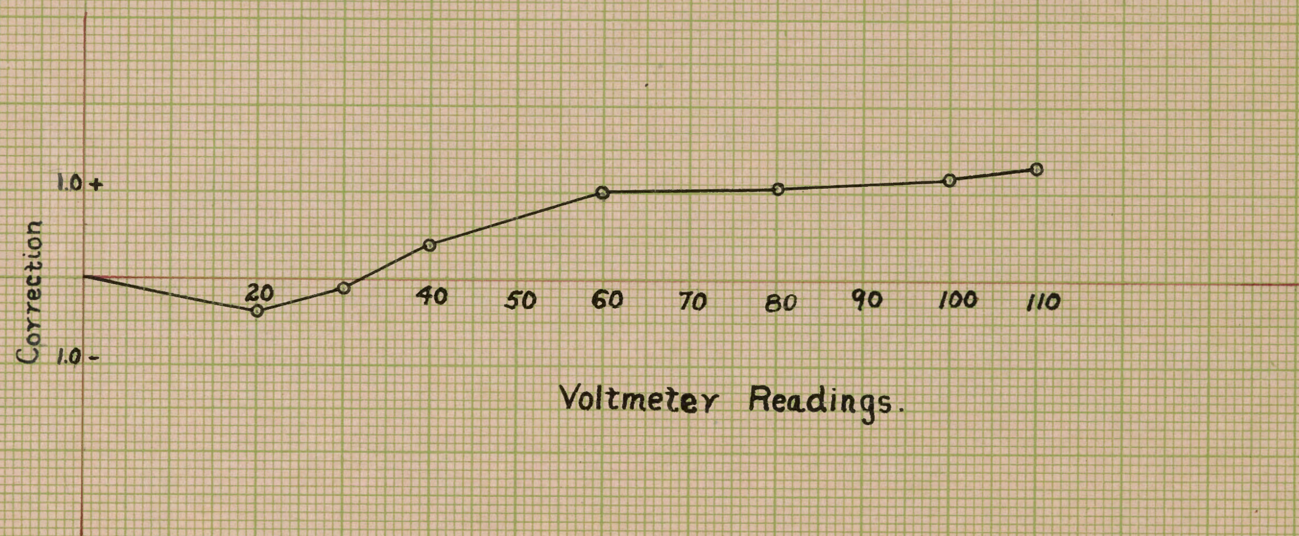
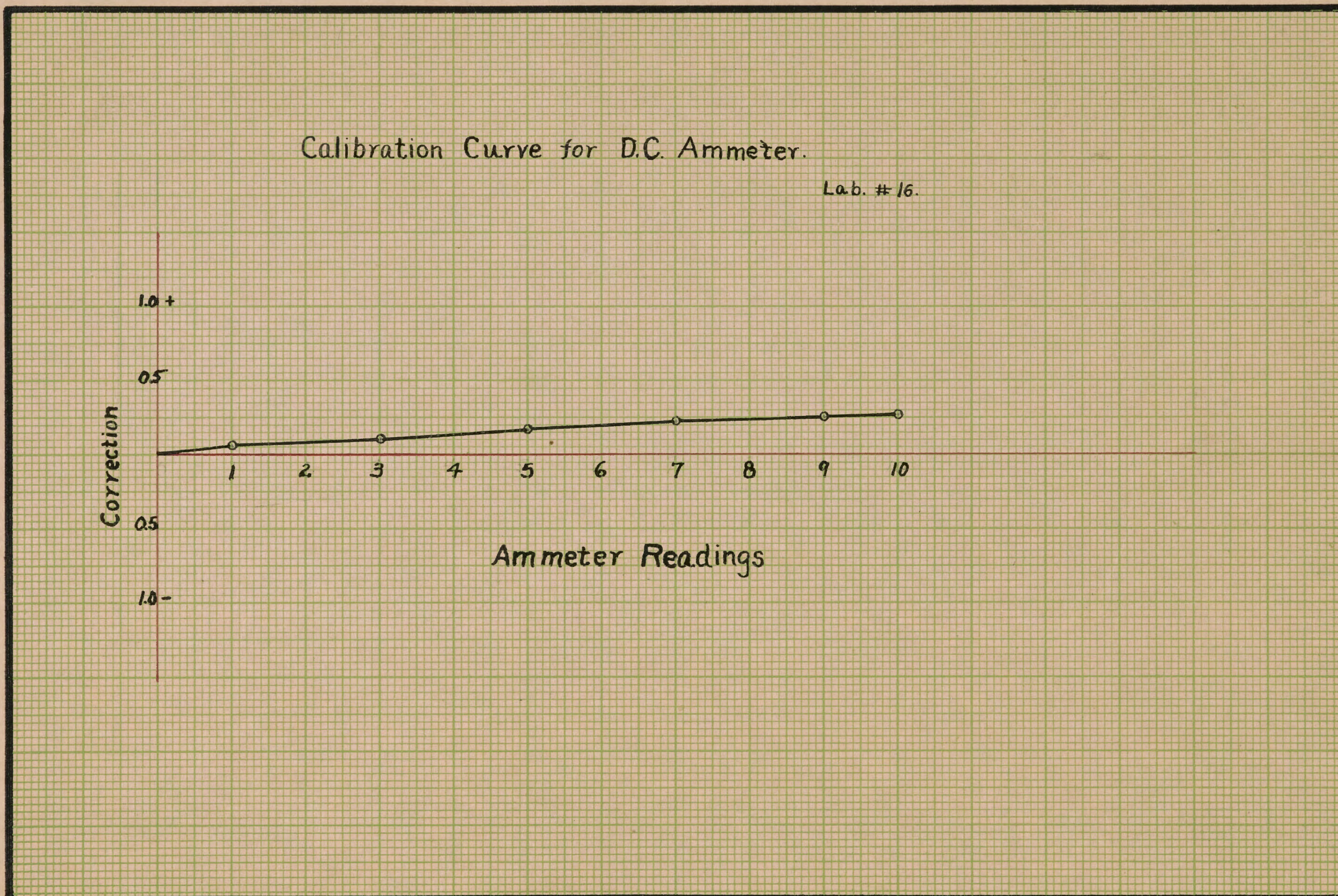
Calibration Curve for D.C. Voltmeter

#516,906





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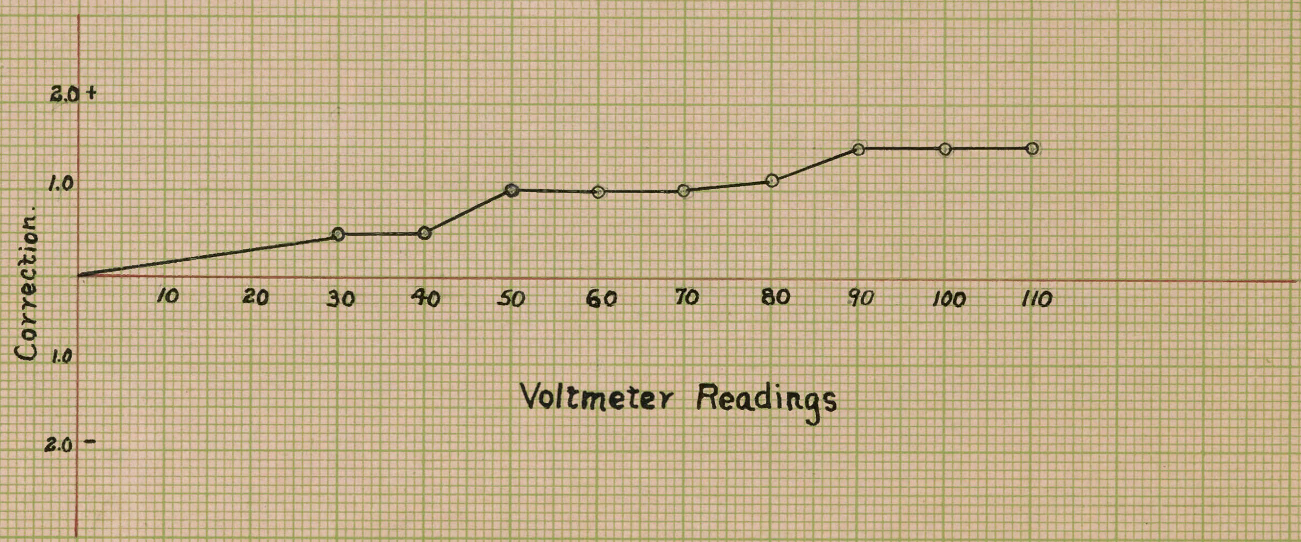
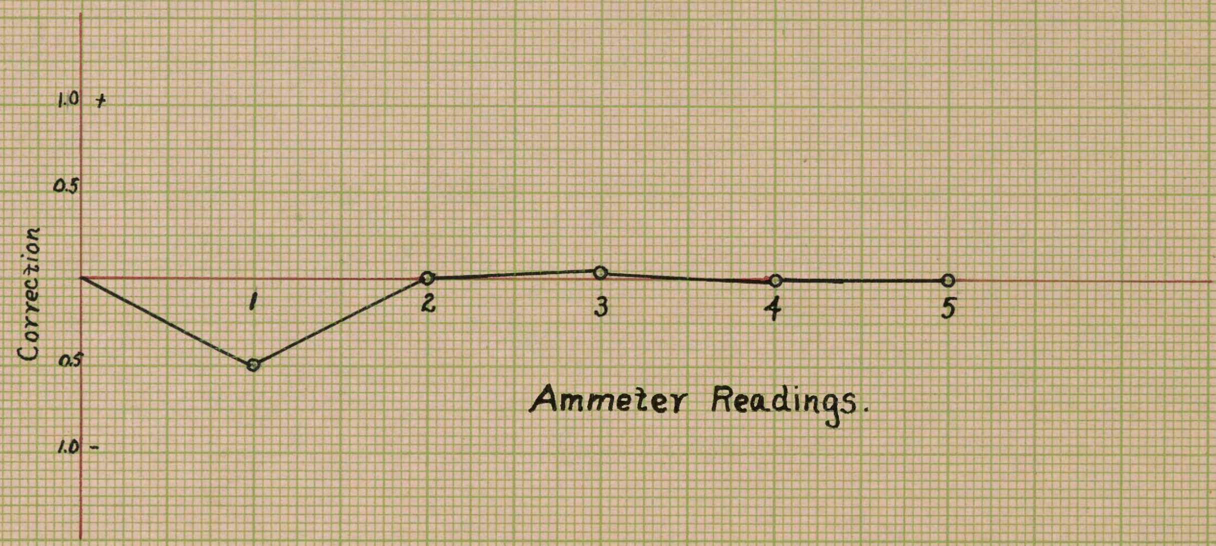
Calibration Curve for A.C. Voltmeter.

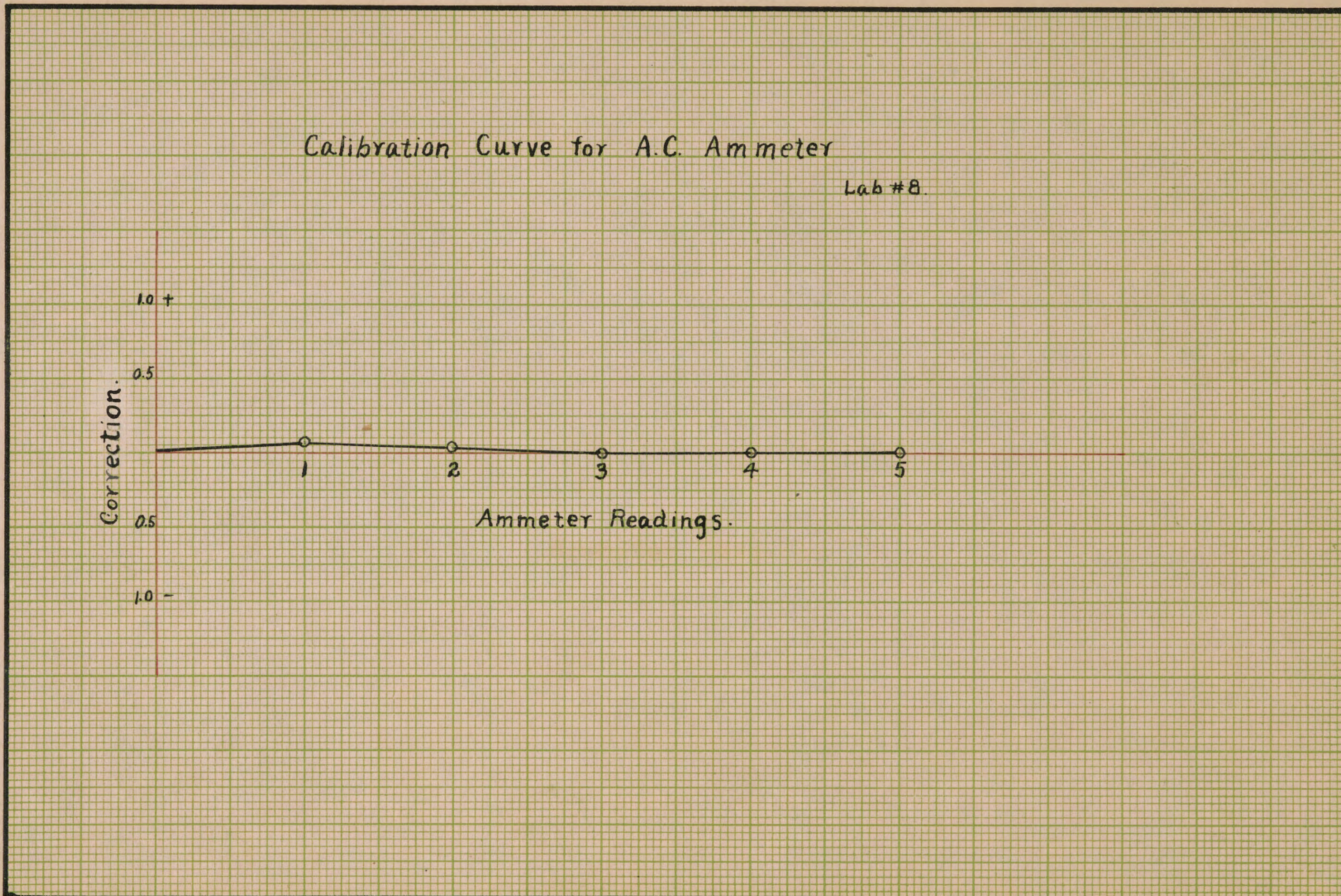
Lab. # 11.



Calibration Curve for A.C. Ammeter.

#37316.





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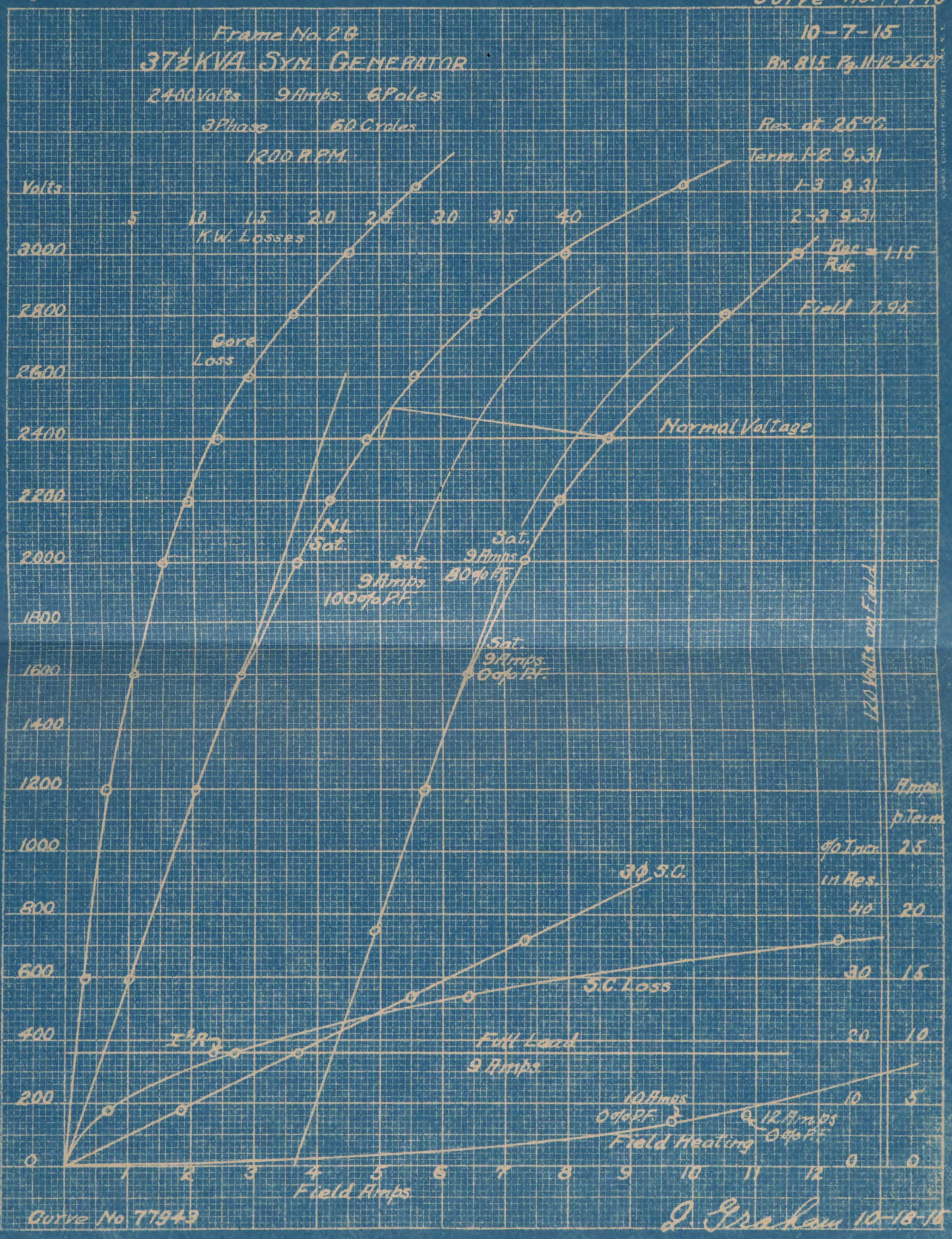
Curve No. 77943



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