T H E S I S

TEST OF GENERATOR OF JELLICO ELECTRIC LIGHT, HEAT, & POWER CO.,

At JELLICO, TENNESSEE.

For the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

By

E. BRYAN AND F. A. SMITH

Under

DR. CHAS. A. PERKINS.

1912

1912

T H E P L A N T.

This plant was euipped with two, one hundred and fifty,(150), horse power, boilers, built by the Springfield Boiler and Mfg., Co.; one Westinghouse, direct current, five kilowatt, one hundred and ten volt, (110), exciter; a belt driven, one hundred and twenty, (120), kilowatt, one hundred and twenty-five,(125), cycle, sixteen, (16), pole Westinghouse alternator, generating current at 2200 volts. There was also a two panel switch board, on which were mounted an ammeter, a voltmeter, a circuit breaker, an oil switch for main line and a switch for the exciter.

We ran a twelve hour test on the plant for the effeciency, the heat run, the energy of field excitation, and the variation of field current with armature current at constant generator voltage. The power and current output readings were taken every minute. Curves were plotted with time as abscissas and these readings as ordinates. The other readings for the twelve hour test were taken every fifteen minutes and are as follows: the indicator cards and revolutions per minute of engine; the voltage and revolutions per minute of generator; the current and voltage of exciter. The generator energy was taken by means of a watt-hour meter. The temperatures of the room, the field, and the armature were taken at the beginning and end of the test.

A separate test was run for the voltage regulation of the alternator. To obtain voltage regulation by calculation readings were taken for the saturation curve, the synchronous react-

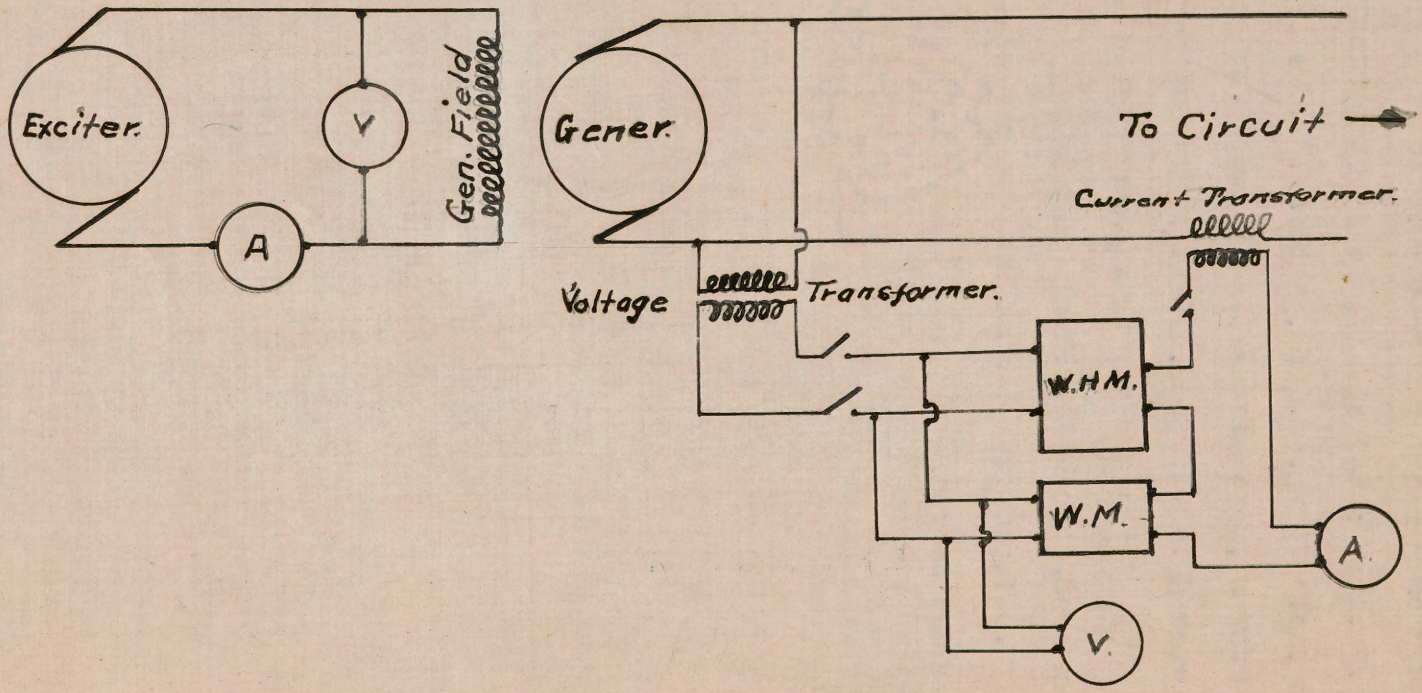
ance curve, and the resistance of field and armature, (hot and cold).

As this plant was used for lighting only, the test was run from 5:30 P.M., March 20th 1912 to 5:30 of the following morning.

The following instruments were used in this test; an A. C. ammeter, an A. C. voltmeter, a D. C. ammeter, a D. C. voltmeter, a voltage transformer, a current transformer, a wattmeter, a watt-hour meter, and a Roberts-Thompson indicator, all of which were calibrated by comparison with standards at the University of Tennessee. Correction curves were drawn for them and the corrected readings were used in the calculations of our results.

A diagram of connections for the twelve hour test is shown on the following page.

Connections of Instruments for 12 Hour Test.



E F F I C I E N C Y.

The combined efficiency of the generator and engine is the ratio of the output of the generator to the input of the engine. The output was obtained by means of a wattmeter and transferred to horse power by multiplying the watts by 0.00134, the data for which is found on page . The input was obtained from the indicated horse power, the data for which is found on page

The efficiency was calculated for four different loads varying from the minimum to maximum and the average of these also given on page .

The indicated horse power of the engine was calculated from the data by means of the equation I.H.P.= PLAN/33000, where P is the mean effective pressure which is gotten by integrating the indicator cards; L is the length of the stroke in feet; A is the area of the piston in square inches; and N is the number of revolutions per minute of the engine.

D A T A.

Time.	M.E.P.		Indicated Horse Power.		
	C. E.	H. E.	C. E.	H. E.	Total.
5:30 P.M.	40.0	42.0	60.5	64.9	125.4
45	50.0	43.0	77.2	67.9	145.1
6:00	50.0	42.0	75.7	64.9	140.6
15	49.0	50.0	74.6	77.7	152.3
30	52.0	53.0	79.7	83.1	162.8
45	50.0	51.0	76.8	80.0	156.8
7:00	49.0	49.0	74.4	76.0	150.4
15	53.0	46.0	81.9	72.6	154.5
30	51.0	46.0	77.8	71.9	149.7
45	50.0	47.0	75.6	72.6	148.2
8:00	47.0	45.0	71.3	69.8	141.1
15	50.0	47.0	75.6	72.6	148.2
30	45.0	43.0	68.0	66.5	134.5
45	45.0	44.0	68.5	68.5	137.0
9:00	47.0	41.0	72.1	64.3	136.4
15	44.0	40.0	66.5	61.8	128.3
30	39.0	28.0	58.8	43.2	102.0
45	34.0	28.0	51.4	43.2	94.6
10:00	36.0	27.0	55.0	42.2	97.2
15	37.0	25.0	57.2	39.5	96.7
30	39.0	26.0	60.5	41.2	101.7
45	33.0	24.0	50.8	37.7	88.5
11:00	31.0	23.0	47.5	34.7	82.2
15	34.0	24.0	47.5	38.2	91.1
30	31.0	25.0	48.1	39.6	87.7
45	36.0	27.0	56.0	42.9	98.9
12:00	34.0	24.0	52.7	38.0	90.7
15	33.0	23.0	50.8	36.2	87.0
30	31.0	20.0	48.4	31.9	80.3
45	30.0	24.0	45.7	37.3	83.0
1:00	30.0	22.0	45.7	34.1	79.8
15	30.0	21.0	45.9	32.8	78.7
30	29.0	24.0	44.1	37.4	81.5
45	30.0	23.0	46.2	36.2	82.4
2:00	34.0	21.0	52.5	33.3	85.8
15	32.0	23.0	49.2	36.2	85.4
30	31.0	24.0	47.7	37.8	85.0
45	30.0	22.0	46.4	34.7	81.1
3:00	28.0	24:0	42.4	37.2	79.6
15	32.0	22.0	48.7	34.3	83.0
30	34.0	23.0	52.6	36.4	89.0
45	32.0	24.0	48.6	37.2	85.8
4:00	36.0	24.0	55.2	37.6	92.8
15	34.0	24.0	51.7	37.4	89.1
30	34.0	26.0	52.8	41.3	94.1
45	33.0	23.0	50.6	36.0	80.6
5:00	28.0	26.0	42.8	40.7	83.5
15	36.0	26.0	55.3	40.7	96.0
30	39.0	28.0	59.5	43.7	103.2

Time	Gen. Speed R. P. M.	Gen. Voltage	Gen. Volts. (corrected)	Eng. Speed. R. P. M.
5:30 P.M.	1000	2350	2344	279
45	976	2300	2291	285
6:00	986	2300	2291	279
15	965	2330	2324	281
30	997	2358	2354	283
45	973	2360	2356	283
7:00	978	2320	2313	280
15	975	2326	2319	285
30	964	2300	2291	282
45	980	2300	2291	279
8:00	968	2360	2356	280
15	982	2326	2319	279
30	967	2320	2313	279
45	994	2336	2331	281
9:00	981	2340	2335	283
15	1008	2340	2335	279
30	1008	2340	2335	278
45	990	2240	2224	279
10:00	965	2310	2302	282
15	1033	2285	2274	285
30	1007	2310	2302	286
45	1013	2260	2246	284
11:00	1010	2300	2291	283
15	988	2300	2291	287
30	990	2295	2286	286
45	1009	2300	2291	287
12:00	1025	2280	2270	286
15 A.M.	1021	2300	2291	284
30	1020	2280	2269	288
45	1023	2265	2251	281
1:00	1009	2190	2169	281
15	1010	2186	2165	282
30	994	2276	2265	281
45	1013	2260	2247	284
2:00	1008	2220	2201	286
15	970	2280	2269	284
30	948	2260	2257	284
45	1002	2190	2169	285
3:00	975	2260	2247	280
15	1002	2290	2280	282
30	994	2300	2291	286
45	1005	2260	2247	280
4:00	1010	2268	2255	283
15	992	2320	2313	281
30	995	2370	2367	287
45	968	2270	2253	283
5:00	990	2320	2313	283
15	996	2280	2269	283
30	980	2308	2299	282

Time	Exciter Voltage. Observed.	Exciter Voltage. Corrected.	Field Current. Observed.	Field Current. Corrected.
5:30 P.M.	143.0	143.0	16.5	16.8
45	97.2	94.4	16.2	16.5
6:00	99.0	95.9	16.6	16.9
15	103.5	100.7	17.4	17.8
30	105.0	101.4	17.0	17.4
45	105.5	102.1	17.0	17.4
7:00	102.5	99.4	16.4	16.7
15	103.8	100.8	16.8	17.1
30	102.2	98.9	16.5	16.8
45	102.1	98.7	16.5	16.8
8:00	104.1	101.0	17.4	17.8
15	103.9	100.9	16.8	17.2
30	103.3	100.3	16.6	16.9
45	100.5	97.2	16.3	16.6
9:00	101.0	97.6	16.3	16.6
15	101.0	97.6	16.3	16.6
30	96.0	93.5	15.3	15.5
45	94.5	92.4	15.0	15.3
10:00	97.0	94.3	15.5	15.8
15	93.5	91.7	15.0	15.3
30	95.0	92.8	15.0	15.3
45	91.5	90.0	14.8	15.0
11:00	94.0	92.1	15.0	15.3
15	94.0	92.1	15.0	15.3
30	92.5	91.1	15.0	15.3
45	94.0	92.1	15.0	15.3
12:00 M.	92.0	90.5	14.5	14.7
15 A.M.	92.5	91.1	15.0	15.3
30	91.0	89.5	14.6	14.8
45	90.0	88.5	14.5	14.7
1:00	87.0	85.3	14.0	14.2
15	87.0	85.3	14.1	14.3
30	92.5	91.1	15.1	15.4
45	91.0	89.5	14.7	14.9
2:00	89.2	87.6	14.5	14.7
15	91.5	90.0	15.0	15.3
30	91.0	89.5	14.8	15.0
45	88.5	86.9	14.3	14.5
3:00	92.0	90.5	15.0	15.3
15	92.5	91.1	15.0	15.3
30	93.0	91.4	15.0	15.3
45	91.5	90.0	14.8	15.0
4:00	92.0	90.5	14.9	15.1
15	96.3	93.7	15.5	15.8
30	98.0	95.1	15.8	16.1
45	92.2	90.5	14.8	15.1
5:00	95.0	92.8	15.3	15.5
15.	94.0	92.1	15.2	15.5
30	95.5	93.1	15.4	15.7

R E S U L T S.

Time	Amperes Observed	Voltage Observed	Amperes Corrected	Voltage Corrected
1:00 A.M.	20.2	2190	22.2	2180
9:30 P.M.	29.0	2340	29.8	2335
6:15 P.M.	40.0	2330	40.0	2324
7:00 P.M.	43.5	2320	41.5	2313

Time	I. H. P.	I. K. W.	D. K. W.	Efficiency %
1:00.A.M.	79.8	106.9	48.4	45.3
9:30 P.M.	102.0	134.7	69.6	51.6
6:15 P.M.	152.3	204.1	92.9	45.5
7:00 P.M.	150.4	201.5	96.0	47.6

Average Efficiency is 47.5%

V O L T A G E R E G U L A T I O N.

The voltage regulation was calculated by both the electromotive force and the magnetomotive force methods.

Readings were taken for the saturation and the synchronous reactance curves.

The resistances of the field and the armature, both hot and cold, were also obtained.

The saturation curve is plotted between the field currents and the generator voltage, which readings were obtained by running the altermator at constant speed and observing the terminal voltage for different values of the field current.

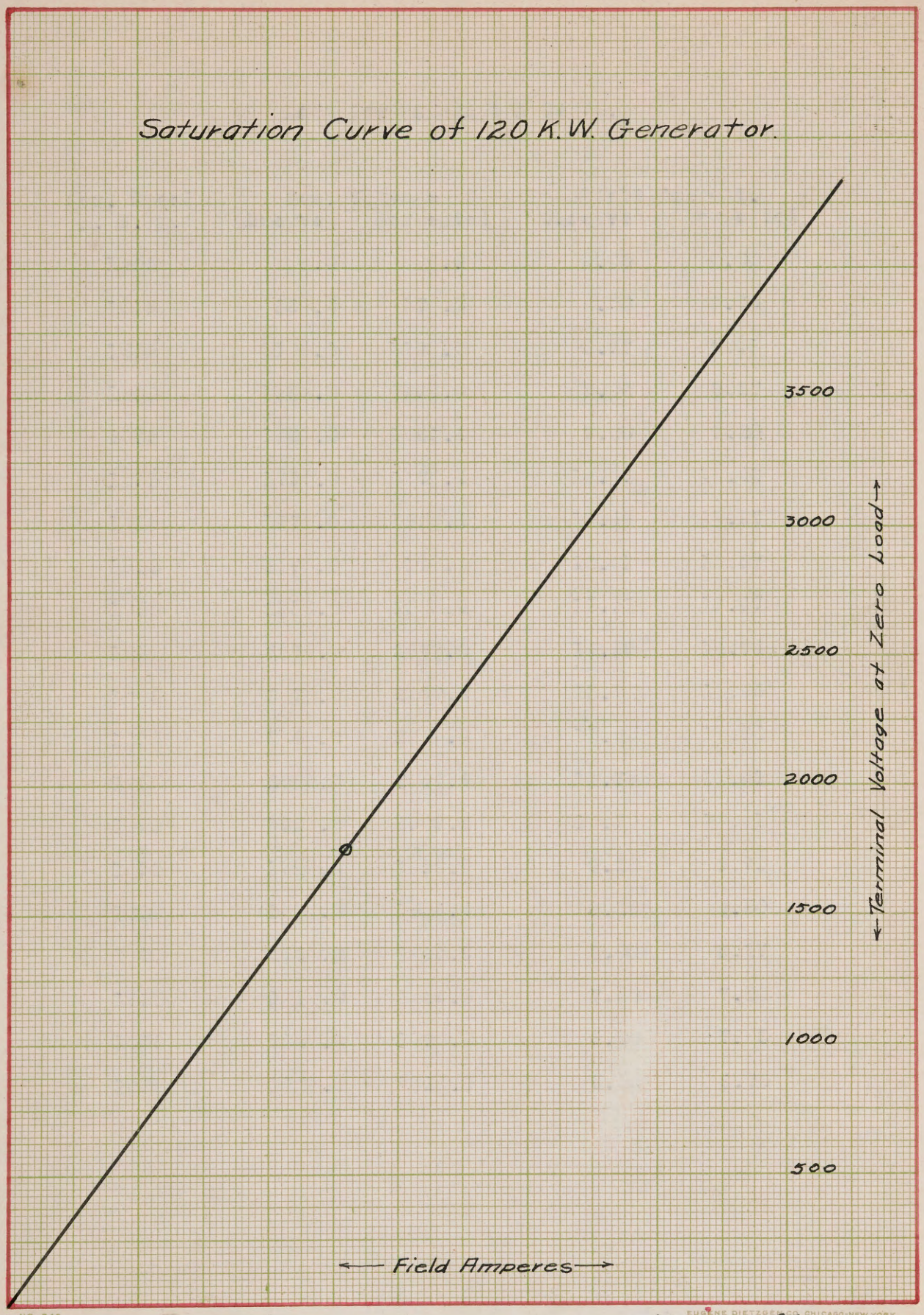
The synchronous reactance curve is plotted between the armature current and the terminal voltage with circuit open. To obtain these readings, the armature is short circuited through an ammeter, (the machine driven at normal speed), and the field is adjusted until the desired current flows through the ammeter and the ammeter reading is taken. The short circuit is then opened, and with unchanged speed and field excitation the terminal voltage is measured.

The resistances of the armature was obtained by passing a direct current through it while stationary.

The data, curves, and results are shown on the following pages.

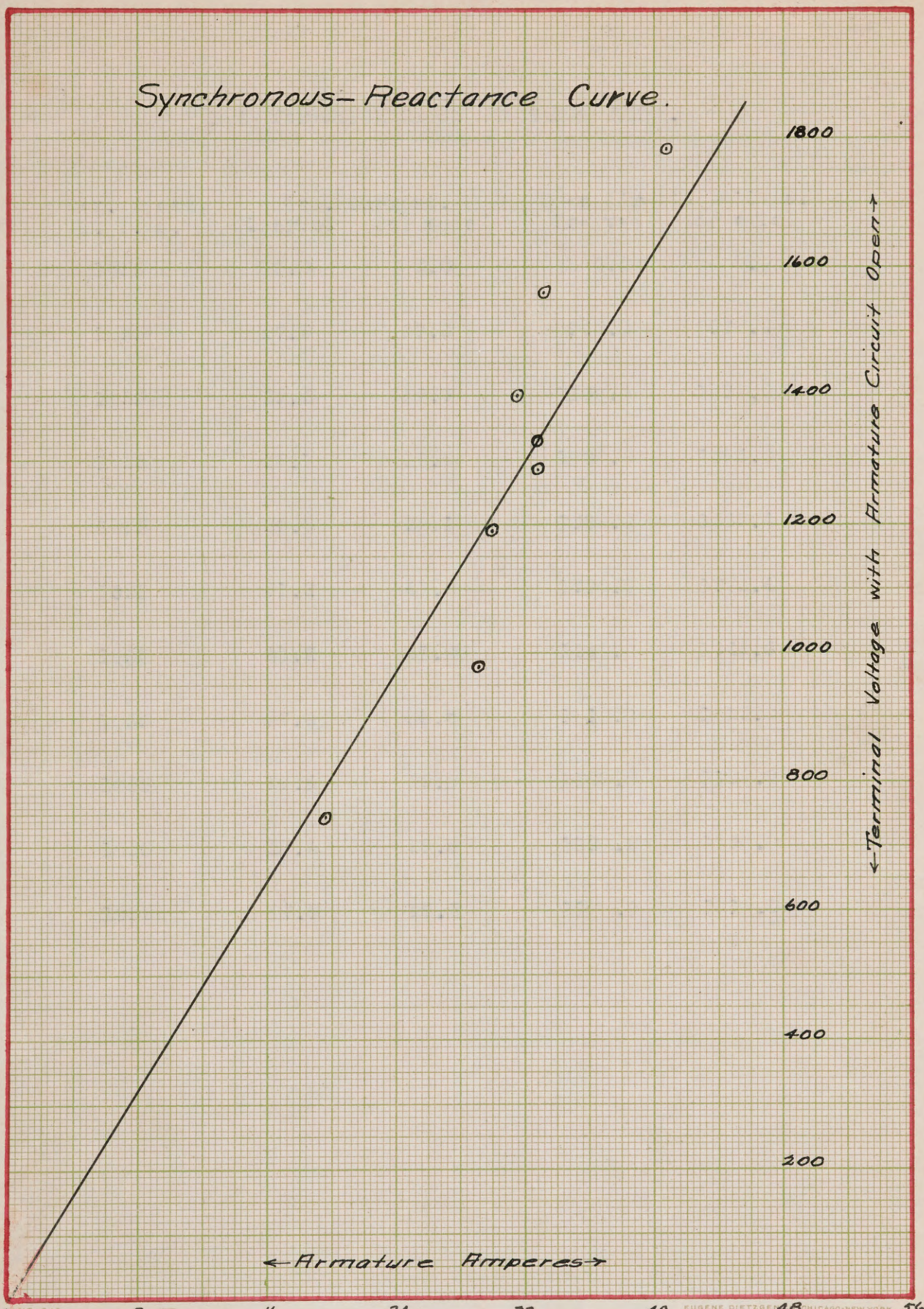
DATA for SATURATION CURVE.

Gen. Speed R. P. M.	Gen. Voltage Observed	Gen. Voltage Corrected	Field Current. Observed	Field Current. Corrected
1055	0.0	0.0	0.00	0.00
1055	560.0	970.0	5.50	5.76
1055	1180.0	1190.0	6.97	7.31
1055	1380.0	1396.0	8.00	8.27
1055	1580.0	1563.4	9.00	9.20
1055	1790.0	1772.4	10.25	10.48
1055	1970.0	1959.4	11.40	11.57
1055	2170.0	2148.6	12.51	12.67
1055	2330.0	2323.6	13.51	13.67
1055	2570.0	2478.0	14.50	14.74
1055	2370.0	2367.6	13.70	13.86
1055	2240.0	2223.6	12.80	12.96
1055	2080.0	2062.4	11.75	11.91
1055	1920.0	1908.8	10.70	10.91
1055	1710.0	1690.0	9.50	9.73
1055	1510.0	1504.4	8.25	8.50
1055	1440.0	1445.6	8.00	8.27
1055	1310.0	1325.0	7.50	7.80
1055	1180.0	1190.0	6.80	7.03
1055	1100.0	1110.0	6.50	6.70



DATA for SYNCHRONOUS REACTANCE CURVE.

Gen. Speed R. P. M.	Gen. Current. Observed	Gen. Current. Corrected	Open Circuit Voltage. Observed	Open Circuit Voltage. Corrected
1055	0.0	0.0	0.0	0.0
1055	27.5	29.3	960.0	970.0
1055	29.5	29.9	1180.0	1190.0
1055	34.1	31.6	1380.0	1386.0
1055	38.3	33.1	1580.0	1563.4
1055	41.2	41.0	1790.0	1772.4
1055	41.2	41.0	1440.0	1445.6
1055	37.8	38.0	1310.0	1325.0
1055	29.4	29.8	1180.0	1190.0
1055	29.4	29.8	1180.0	1190.0
1055	27.8	29.5	1100.0	1110.0



TEMPERATURE and RESISTANCE of ARMATURE and FIELD.

Resistance of Field (cold)

Observed. Amperes	Volts.	Corrected Amperes	Volts	Resistance. Ohms.
6.50	33.0	6.70	33.1	4.90
10.25	53.0	10.48	53.1	5.07
14.50	76.0	14.74	74.2	5.03
18.50	98.0	18.83	95.1	5.08
23.75	125.0	24.21	121.5	5.02

Resistance of Field (hot)

2.11	11.2	2.27	11.2	4.95
6.50	31.0	6.70	31.1	4.63
10.20	55.3	10.43	55.5	5.41
14.60	81.8	14.84	79.9	5.25

Resistance of Armature (cold)

9.75	5.95	9.99	5.9	0.594
17.60	10.80	17.99	10.8	0.600
19.75	12.00	20.03	12.0	0.599
22.50	13.80	22.99	13.8	0.600

Resistance of Armature (hot)

10.25	7.60	10.48	7.0	0.668
13.75	9.20	13.93	9.2	0.660
14.60	9.80	14.84	9.8	0.660
18.50	11.80	18.83	11.8	0.627

TEMPERATURE and RESISTANCE of ARMATURE and FIELD.

T E M P E R A T U R E S.

At beginning of Test.

ROOM	ARMATURE	FIELD
74.0° F	74.0° F	74.0° F

At end of Test.

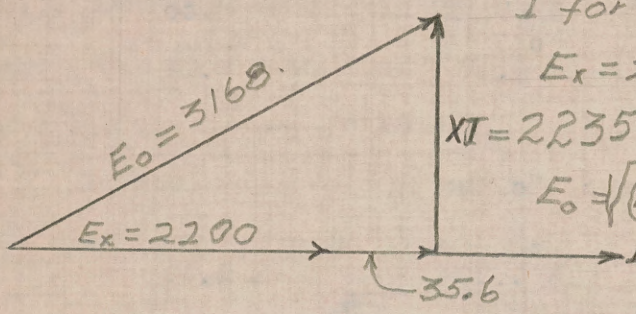
64.0° F	92.5° F	84.0° F

The above temperatures show that neither the armature nor field of the alternator or excessively heated for a twelve hour run.

RESULTS for VOLTAGE REGULATION.

By Electromotive Force Method.

The voltage regulation by the electromotive force method is zero load voltage minus the full load voltage divided by the full load voltage and expressed as a per cent.



I for full load = 54.4 Amp's.

$E_x = 2200$, Arm. Res. = 0.654.

$E_o = \sqrt{(E_x + RI)^2 + XI^2} = 3168$ Volts at no load.

From the synchronous reactance curve the voltage corresponding to an armature current of 54.4 amperes is 2235 volts which is XI.

$$Reg. = \frac{3168 - 2200}{2200} = 44\%$$

By Magnetomotive Force Method.

From the saturation curve the field currents corresponding to E_x + RI and XI were found to be 13.1 amperes in each case.

Therefore $I_o = \sqrt{13.1^2 + 13.1^2} = 18.5$ Amp's.

Now from the saturation curve the terminal voltage corresponding to this field current was found to be 3135 volts.

$$\text{The regulation} = \frac{3135 - 2200}{2200} = 42.5\%.$$

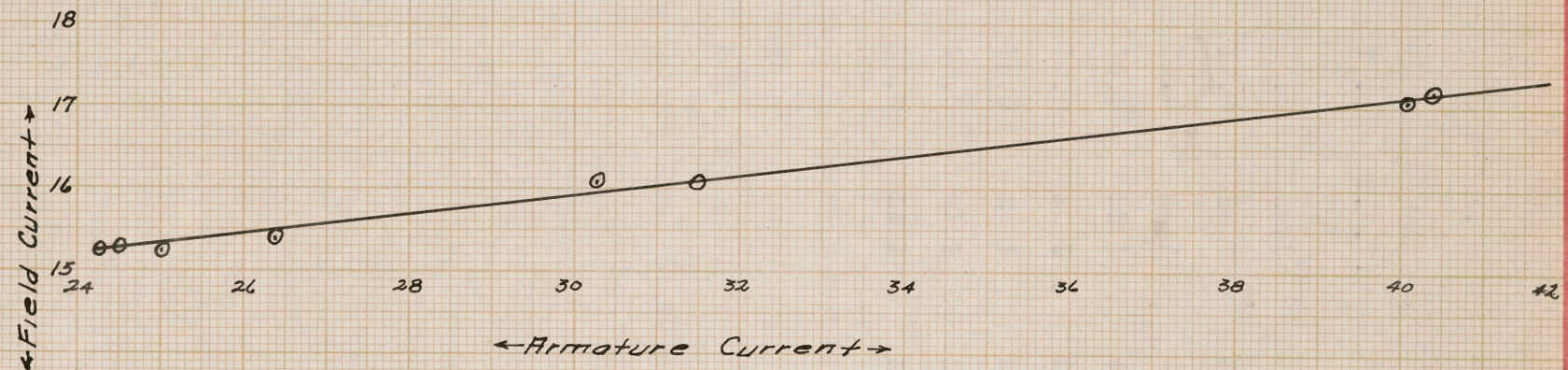
VARIATION of I_f with I_a for Constant E. M. F.

For this test the voltage was kept constant and for different values of field current the armature currents were noted. These readings were corrected for a constant speed and a curve was drawn using the armature currents as abscissas and the field currents as ordinates.

A tabulation of this data and the curve showing the relation between the two currents are given on the following pages.

D A T A.

Observed.			Corrected.		
E.M.F.	I_a.	I_f.	E.M.F.	I_a.	I_f.
2300	33.9	16.2	2291	31.5	16.5
2300	37.0	16.6	2291	36.2	16.9
2300	40.5	16.5	2291	40.1	16.8
2300	40.7	16.5	2291	40.2	16.8
2300	23.2	15.0	2291	26.4	15.3
2300	22.1	15.0	2291	24.4	15.3
2300	21.8	15.0	2291	24.4	15.3
2300	21.7	15.0	2291	24.2	15.3


Curve between If and Ia for Constant Eo.
18
17
16
15
←Field Current→
24
26
28
30
32
34
36
38
40
42
←Armature Current→

ENERGY of FIELD EXCITATION.

The readings were taken every fifteen minutes for twelve hours by means of an ammeter and a voltmeter which were placed in the exciter circuit.

The average of these readings was taken and the watts obtained by the formula W = EI.

D A T A.

This data may be found on page 7.

Average Field Current is 15.49 amperes.

Average Field Voltage is 96.52 Volts.

R E S U L T S.

Energy is obtained by means of the formula stated above.

Therefore the energy is EI which is 15.49 x 96.52 equal 1495.00 watts or 1.49 kilowatts.

CALIBRATION of A. C. VOLTMETER No. 6202.

This instrument was calibrated by comparison with Standard D. C. Voltmeter and Multicellular Voltmeter. The Standard D. C. Voltmeter and the Multicellular Voltmeter were connected in parallel and readings taken on the two between the points of 60 and 120 volts for every 10 volts, then the D. C. Voltmeter was taken out and the A. C. Voltmeter connected in its place and readings taken through the same range.

A curve was plotted between the Standard D. C. Voltmeter readings and the Multicellular readings.

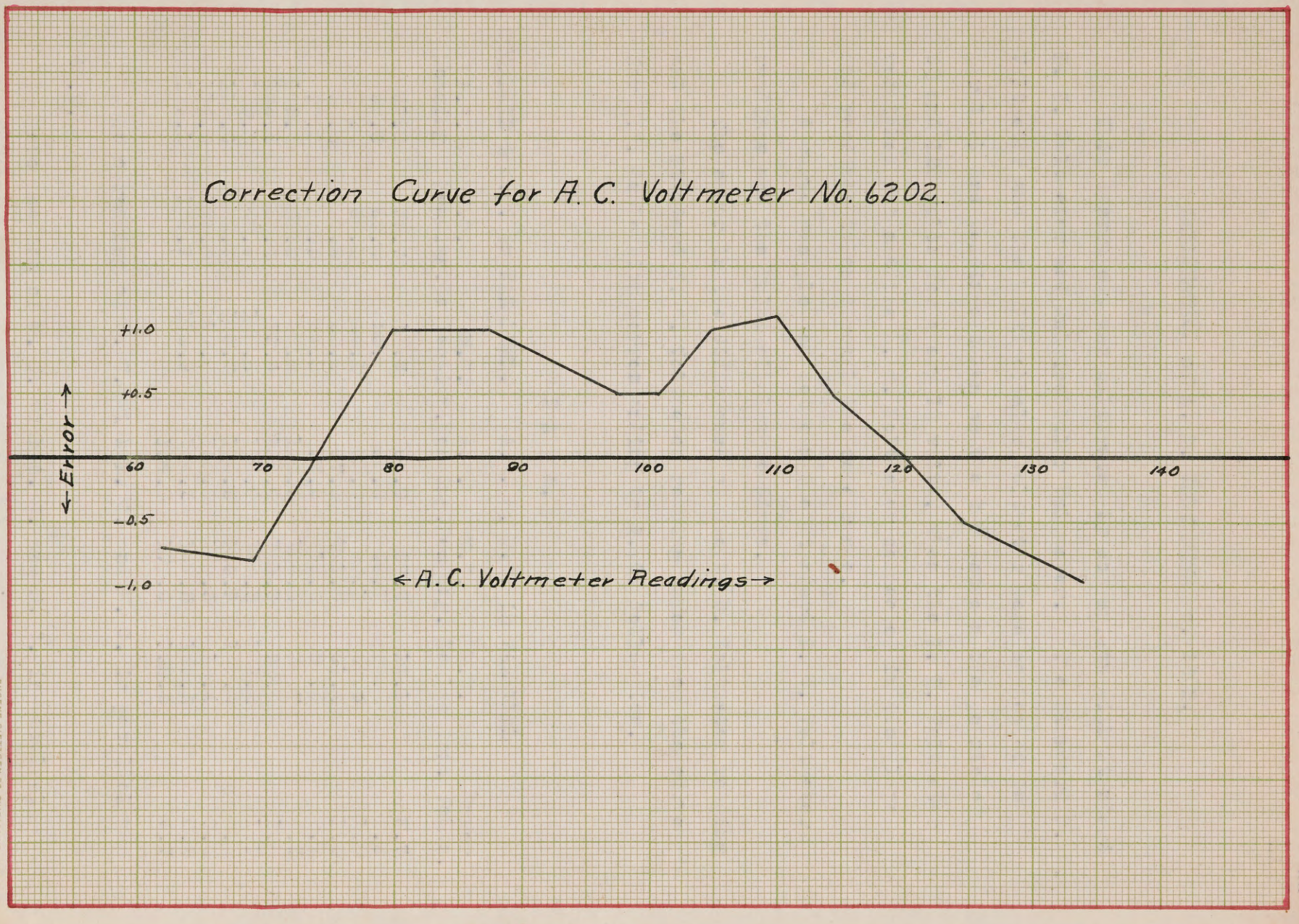
The error is the difference of the A. C. Voltmeter reading and the Standard D. C. Voltmeter reading taken from the curve for M.C. deflection corresponding to A. C. deflection.

D A T A.

STANDARD & M.C. in PARALLEL.			A.C. &. M.C. in PARALLEL			
D.C. Reading	M.C. Reading.	M.C. Deflection.	A.C. Reading.	M.C. Reading.	M.C. Deflection?	Error Volts.
61.0	55.7	15.7	62.0	57.2	17.1	-0.7
69.8	66.2	26.2	69.0	66.1	26.0	-0.8
78.0	84.1	44.1	80.0	86.1	46.0	+1.0
88.2	103.8	63.8	87.5	101.5	61.4	+1.0
98.3	122.5	82.5	97.5	119.6	80.5	+0.5
102.4	129.8	89.8	100.5	124.8	85.7	+0.5
104.4	133.4	93.4	105.0	131.9	92.8	+1.0
108.5	140.6	100.6	110.0	140.3	101.2	+1.1
110.6	143.7	103.7	114.5	148.9	109.8	+0.5
115.2	152.0	112.0	120.0	159.5	118.4	0.0
119.1	156.9	116.9	124.5	164.3	125.2	-0.5
			134.0	177.6	138.5	-0.7

Zero reading of M. C. with D. C. and M. C. in parallel was 40.0.

Zero reading of M. C. with A. C. and M. C. in parallel was was 40.1



CALIBRATION of WESTON A. C. AMMETER No. 113.

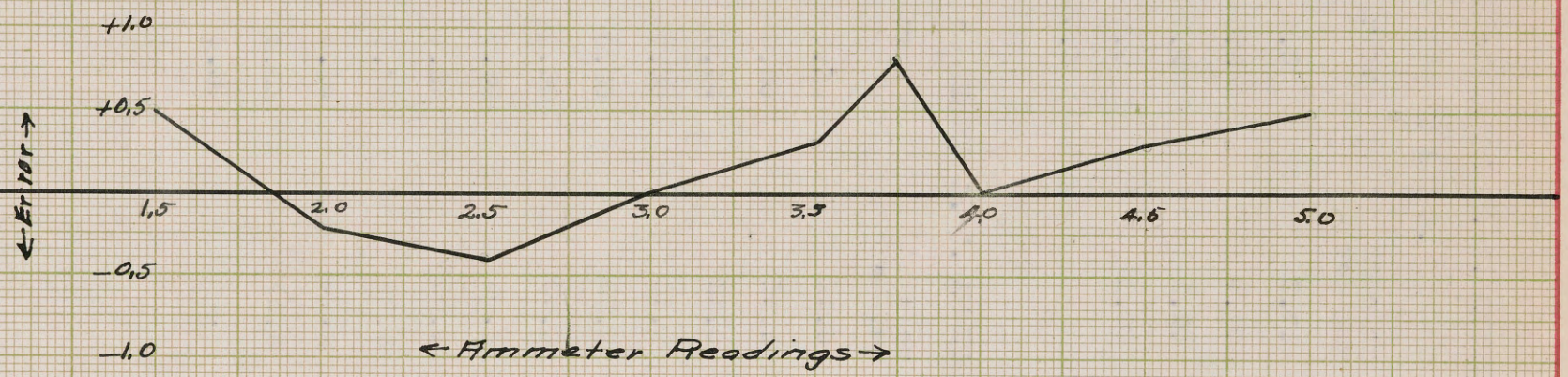
D A T A.

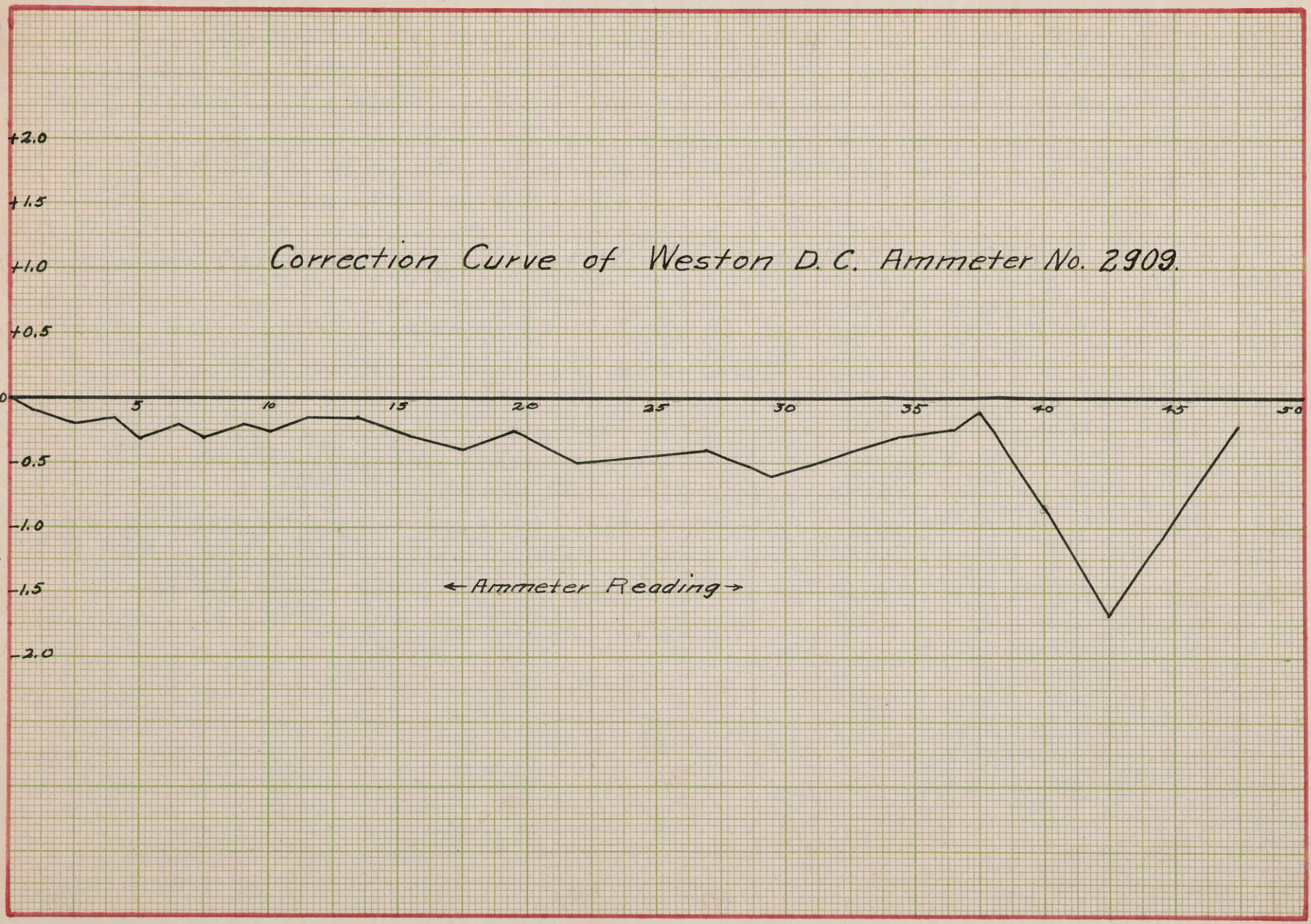
Ammeter reading	Error	Ammeter reading	Error
1.50	+0.5	3.75	+0.8
2.00	−0.2	4.00	0.0
2.50	−0.4	4.50	+0.3
3.00	0.0	5.00	+0.5
3.50	+0.3		

CALIBRATION of WESTON D. C. AMMETER No. 2909.

Ammeter reading	Error	Ammeter reading	Error
1.0	−0.10	17.5	−0.38
2.5	−0.20	19.5	−0.25
4.0	−0.14	22.0	−0.50
5.0	−0.30	25.0	−0.44
6.5	−0.20	27.0	−0.40
7.5	−0.30	29.5	−0.60
9.0	−0.20	34.5	−0.30
10.0	−0.25	36.5	−0.25
11.5	−0.15	37.5	−0.10
13.5	−0.16	40.0	−0.87
14.5	−0.23	42.5	−1.67
15.5	−0.30	47.5	−0.21

Correction Curve for Weston A. C. Ammeter No. 113.





CALIBRATION of WESTON D. C. VOLTMETER No. 823.

D A T A.

Number.	Standard Voltmeter reading	D. C. Voltmeter reading	Error in volts
1	27.20	27.30	+0.10
2	37.25	37.00	−0.25
3	47.40	47.50	+0.10
4	53.25	53.10	−0.15
5	63.25	62.80	−*0.45
6	71.40	73.20	+1.80
7	79.60	81.50	+1.90
8	90.05	92.50	+1.45
9	92.40	94.50	+2.10
10	94.25	97.00	+2.75
11	96.30	99.40	+3.10
12	98.40	101.90	+3.50
13	100.50	103.10	+2.60
14	101.40	105.00	+3.60
15	103.30	106.40	+3.10
16	105.25	108.20	+2.95
17	107.20	110.00	+2.80
18	109.80	112.80	+3.00

Correction Curve for Weston D. C. Voltmeter

No. 823.