ALTERNATING CURRENT AND DIRECT CURRENT RESISTANCE AS IT AFFECTS REGULATION OF ALTERNATORS AND TRANSFORMERS.

by

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TABLE OF CONTENTS

INTRODUCTION

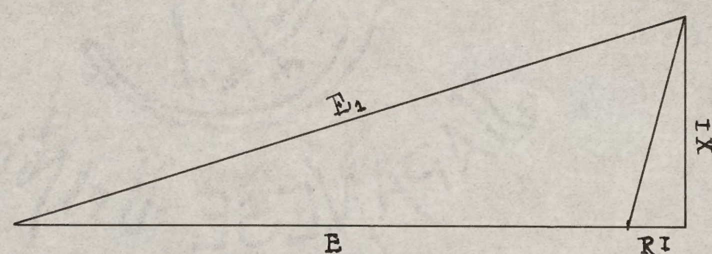
It is well understood that the R component of the impedence is much more than the ohmic R, but in calculating regulation, R equals E/I seems to be always used.

The object of this thesis is to study the effects of the different values of the resistance on the regulation and find if there is a definite reason for using this value.

GENERAL THEORY

In the majority of regulation tests the d.c. resistance is used in all calculations. The a.c. resistance in addition to containing the d.c. resistance also contains that resistance due to core losses. This resistance varies inversely as the square of the current and is found by dividing the power absorbed on open circuit (core loss) by thesquare of the different values of the current. Curves showing these variations are given in the Appendix.

The manner in which the regulation was figured is as follows:



Referring to thediagram, E, the load voltage of the machine is laid off horizontally (unity power factor). The RI drop is then laid off in phase with this E. This is the R being investigated and on which the conclusions are based. XI is than laid off at 90° with E and E_1 drawn. The regulation is then equal to $\frac{E_1 - E}{E}$-----at unity power factor. The regulation is much more dependent on R than it is on X as RI is in phase with E while XI is 90° out of phase.

The method of determining the regulation as just described was chosen because of its simplicity and if values of the resistance could be found that would make it check, this would be a comparatively short way of finding the regulation.

METHOD

The work may be classed into thee following divisions as the tests were made in their order.

1. Regulation of trahsformer.
    a. Using d.c. resistance.
    b. Using a.c. resistance.
    c. Actual regulation measured.
2. Regulation of alternator.
    a. Using d.c. resistance.
    b. Using a.c. resistance.
    c. Actual regulation measured.

Regulation of transformer using d.c. resistance.

The d.c. resistances of the primary and secondary were found using voltmeter and ammeter. The equivalent resistance of the whole transformer was found by adding the resistance of the primary to the resistance of the secondary and multiplying by the square of the ratio of transformation. This value was used in RI where I varied from 0 to $1\frac{1}{4}$ full load.

The voltage, current and power were next read with the secondary short circuited. From these readings the R and X were found. Both of these values remained fairly constant as there is practically no core loss an shortcircuit to affect R. This value of X was then used with the d.c. resistance in figuring regulation. See page 8.

Regulation using a.c. resistance.

The core loss was next found by reading the power absorbed on open circuit. This divided by I^2 gave the R due to core loss. This value was added to the R found on shortcircuit and using the corresponding X, the regulation was found. See page 9.

Actual regulation.

This was found by supplying 1100 volts furnished by another transformer to the primary of the tested transformer and loading the secondary with resistance. As the load was thrown on and off the impressed voltages were read. The ratio of the difference of the voltages divided by the load voltage gave the regulation. All these values were at unity power factor because of the non-inductive load. See page 10.

Regulation of alternator using d.c. resistance.

The resistance of the armature was found with voltmeter and ammeter. The reactance of armature was found by passing an alternating current thru it and reading the voltage, current and power. This was done at no excitation altho applying field current didn't change values. Using this R and X the regulation was figured. See page 12.

Regulation using a.c. resistance.

Using the values of voltage, current and power just found the R and X were figured. Using these the regulation was determined. See page 12.

Actual Regulation.

By throwing a load made up of resistance on and off of the machine, the two values of E necessary for calculations were determined. The voltage with the load on was brought up to about 110 volts at each load with the field reastat. The speed of the alternator was kept constant with the reastat on the motor field. See page 12.

CALCULATIONS

Instrument readings given below have been corrected by use of curves in Appendix.

To find the d.c. resistance of transformer:

E	I	R = E/I
9.2/30	12.6	0.0243
16/30	21.8	0.0245
6/30	8.0	0.025

$$3 \,\underline{)0.0730}$$
.0246 resistance of secondary.

E	I	R
11.13	5.2	2.16
12.97	6.0	2.13
14.70	7.0	2.13

$$3 \,\underline{)6.43}$$
2.14 resistance of primary.

$$0.0246 \times \left(\frac{1100}{110}\right)^2 = 2.46$$

2.46 + 2.14 = 4.60 equivalent resistance of whole transformer.

Reducing $R = 4.60$ at 80° to standard temperature (77°).

$$R_0 = \frac{R}{1 + .00242t} \qquad t = 80^\circ$$

$$= \frac{4.60}{1 + .00242 \times 80} = 3.85$$ resistance at 0° F.

$R = 3.85(1 + .00242 \times 77) = 4.56$ resistance at 77° F.

To find the reactance.

Readings taken on short circuit. Secondary shorted.

E	I	P	Z	EI	cosθ	R	X
15.8	2.32	15.0	6.81	36.6	0.41	2.97	6.21
18.1	2.76	24.0	6.55	50.0	0.48	3.15	5.75
20.4	3.13	35.5	6.52	63.8	0.56	3.62	5.42
22.1	3.52	47.5	6.18	77.8	0.61	3.84	4.96
24.7	3.89	57.5	6.35	96.1	0.60	3.80	5.08
27.7	4.23	69.5	6.55	117.1	0.59	3.88	5.28
29.5	4.42	76.5	6.66	130.2	0.59	3.92	5.38
31.0	4.64	87.0	6.68	144.0	0.61	4.04	5.32
31.7	4.75	91.5	6.68	150.8	0.61	4.05	5.32
32.6	4.87	97.5	6.69	158.8	0.61	4.11	5.28
34.8	5.11	111.0	6.70	180.6	0.62	4.12	5.29
39.4	5.31	118.5	7.41	209.3	0.57	4.20	6.11
33.6	5.00	104.0	6.73	168.1	0.62	4.16	5.28
31.0	4.62	86.5	6.70	143.2	0.60	4.05	5.35
27.0	4.11	65.0	6.56	111.0	0.59	3.85	5.32
23.7	3.70	53.0	6.40	87.5	0.60	3.87	5.10
20.5	3.00	36.0	6.84	61.5	0.58	3.99	5.55

See Curve Sheet # 1.

Regulation using d.c. resistance

I	RI	X	XI	Regulation %
1.5	6.68	5.35	8.02	0.618
2.0	8.91	"	10.70	0.810
2.5	11.15	"	13.38	1.013
3.0	13.39	"	16.05	1.216
3.5	15.60	"	18.73	1.418
4.0	17.82	"	21.40	1.620
4.5	20.09	"	24.10	1.828
5.0	22.29	"	26.75	2.025

See Curve Sheet # 2

Regulation using a.c. resistance.

The total resistance is given by Curve D on Curve Sheet # 1. Curve D found by adding curves A & C. Curve C found as follows:

Core loss measured = 42 watts.

I	$R = P/I^2$
1.5	18.6
2.0	10.24
2.5	6.72
3.0	4.67
3.5	3.42
4.0	2.52
4.5	2.07
5.0	1.68

I	Total R	RI	X	XI	Regulation %
1.5	22.4	33.6	5.35	8.02	3.05
2.0	14.0	28.0	"	10.70	2.54
2.5	10.5	26.2	"	13.38	2.38
3.0	8.5	25.5	"	16.05	2.32
3.5	7.2	25.2	"	18.73	2.29
4.0	6.4	25.6	"	21.40	2.325
4.5	5.8	26.1	"	24.10	2.37
5.0	5.5	27.5	"	26.75	2.50

See Curve Sheet # 2

Regulation by actual test.

I	E_1	E_2	E_2 corrected	Regulation %
1.74	105.45	1040	1085	1.382
2.52	101.85	1006	1088	1.194
3.56	98.50	961.5	1073	2.515
4.40	94.25	922.5	1077	2.140
5.11	91.75	889.5	1065	3.280
5.82	87.80	850.0	1063	3.480
0.0	109.2	108.9	1098	0.183
4.84	94.25	918.0	1071	2.708
1.4	105.2	1040	1088	1.103
2.2	101.5	1005	1088	1.103
3.3	98.0	960	1077	2.135
4.2	93.6	920	1080	2.325
5.01	91.0	886.0	1071	2.708
5.8	87.0	845	1068	2.995
0.0	109.1	109	1099	0.091
4.7	93.6	915	1075	2.310

See Curve Sheet # 2

Conclusions on transformer tests.

Referring to curve sheet # 2 the three regulation curves are given. It is seen that the curve where d.c. resistance was used lies below the actual regulation curve. The average difference between the curves is 0.5 % regulation. The d.c. seems to check better for higher values. The a.c. curve is widely different from the actual for low currents but for currents around full load the curves almost coincide. These curves would naturally lead to the conclusion that for small loads the d.c. resistance should be used but for larger loads the a.c. resistance would give more accurate results.

CALCULATIONS ON ALTERNATOR

Resistance of armature.

E	I	R
55/30	9.3	0.197
44/30	7.45	0.197

$t = 88^\circ$ F.

$$R_o = \frac{R}{1 + .00242\ t} = \frac{0.197}{1 + .00242 \times 88} = 0.1625$$ resistance at 0° F.

$R = 0.1625(1 + .00242 \times 77) = 0.1925$ resistance at 77° F.

Reactance of armature

E	I	P	$\cos\theta$	R	X
17.8	13.8	39.5	0.041	0.21	1.23
23.3	17.3	67.0	0.099	0.233	1.28
28.1	20.2	95.0	0.115	0.245	1.37
30.4	22.1	120.0	0.142	0.25	1.35
35.4	24.3	145.0	0.142	0.248	1.439
39.5	26.7	194.0	0.170	0.276	1.454
40.3	27.4	214.0	0.183	0.292	1.445
42.1	28.6	233.0	0.187	0.292	1.444
39.2	30.9	279.0	0.226	0.293	1.236
47.1	33.3	333.0	0.200	0.299	1.463
51.6	34.7	365.0	0.204	0.330	1.413
53.5	35.9	395.0	0.206	0.326	1.453
51.1	34.2	365.0	0.209	0.320	1.460
49.1	32.9	328.0	0.203	0.303	1.460
45.9	30.8	275.0	0.194	0.289	1.461
42.4	28.6	225.0	0.186	0.275	1.457
39.7	26.6	180.0	0.171	0.254	1.470
36.0	24.3	140.0	0.160	0.237	1.462

See curve sheet # 3.

Regulation using d.c. resistance

I	RI (R=.1925)	XI	E_1	Regulation %
16.0	3.08	20.8	115.0	4.55
18.0	3.46	23.9	116.0	5.45
20.0	3.85	27.1	117.0	6.37
22.0	4.24	30.4	118.0	7.28
24.0	4.59	33.8	119.5	8.64
26.0	5.02	37.1	121.0	9.10
28.0	5.39	40.5	122.8	11.63
30.0	5.78	43.8	123.7	12.53
32.0	6.16	47.2	125.2	13.82
34.0	6.55	50.5	127.0	15.46
36.0	6.93	52.8	128.2	16.54

See curve sheet # 4.

Regulation using a.c. resistance.

I	RI	XI	E_1	Regulation %.
16.0	3.62	20.8	115.4	4.91
18.0	4.18	23.9	116.8	6.27
20.0	4.76	27.1	118.0	7.27
22.0	5.36	30.4	119.3	8.45
24.0	6.04	33.8	121.0	10.00
26.0	6.76	37.1	122.2	11.09
28.0	7.70	40.5	124.3	13.00
30.0	8.42	43.8	126.1	14.62
32.0	9.47	47.2	128.4	16.73
34.0	10.75	50.5	130.8	18.90
36.0	12.24	52.8	133.2	21.10

See curve sheet # 4.

Regulation by actual measurement.(loading with resistahce).

I	E	E_1	E_1-E	Regulation %.
13.8	110.4	119.3	8.9	8.05
16.6	109.9	119.8	9.9	9.00
18.4	111.5	123.4	11.9	10.66
20.0	109.5	121.8	12.3	11.13
22.6	111.9	127.3	15.4	13.77
24.2	111.4	128.8	17.4	15.61
26.2	112.4	130.3	17.9	15.91
27.4	108.9	128.8	19.9	18.28
29.9	109.4	130.8	21.4	19.55
31.8	110.9	137.3	26.4	23.80
33.6	111.4	138.8	27.4	24.60
35.2	109.9	137.8	27.9	25.40

I	E	E_1	$E_1 - E$	Regulation %
38.5	112.4	142.8	30.4	27.00
30.3	113.1	136.8	23.7	20.92
31.2	108.9	144.3	25.4	23.32
27.6	112.9	133.8	20.9	18.51

In taking these readings, when theload was thrown off the machine would speed up. To remedy this, the speed was lowered by changing the resistahce in the field of the motor. The frequency was kept at 60 cycles.

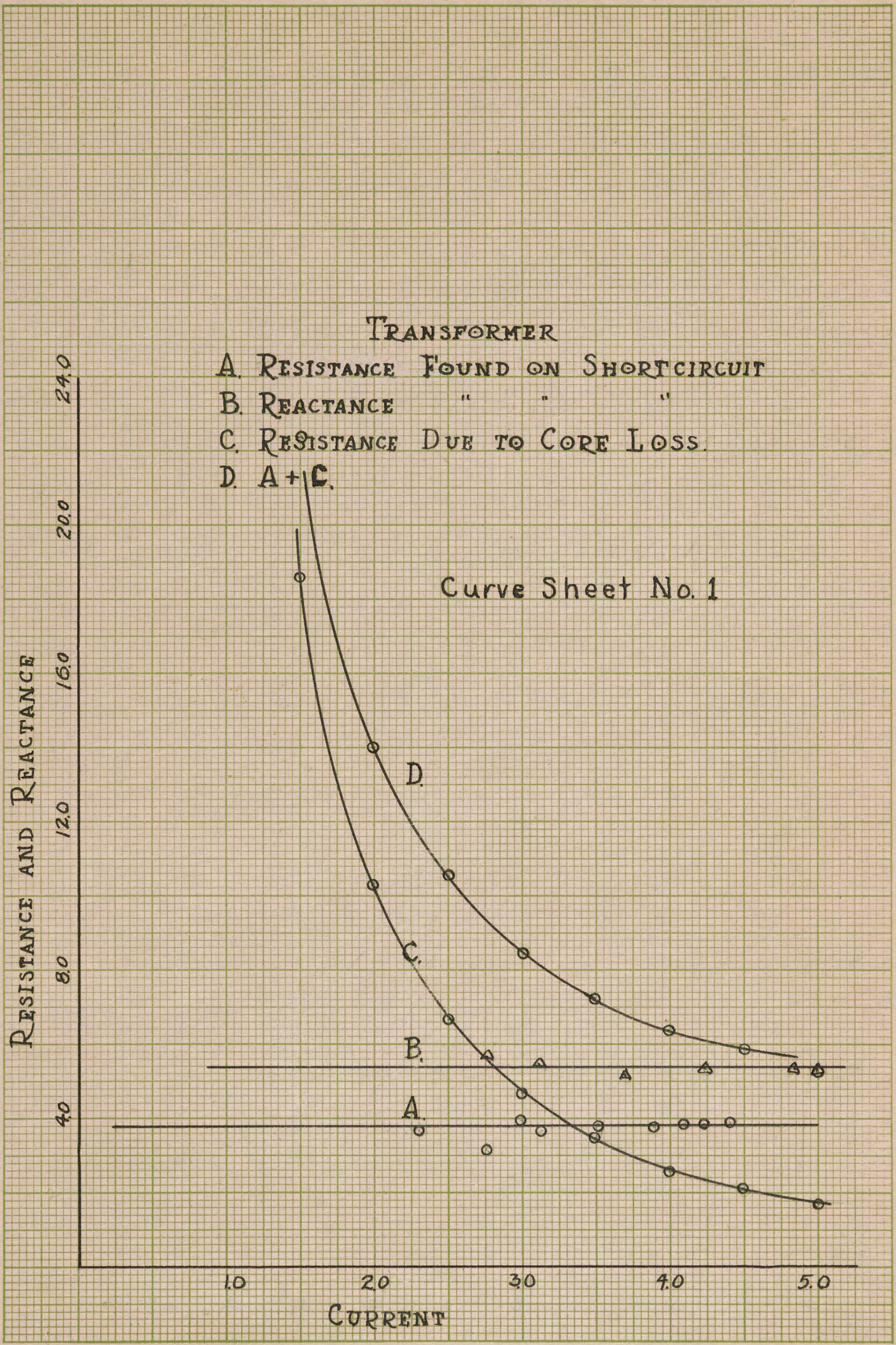
Conclusions on alternator tests.

Regulation curvesare found on curve sheet # 4.

The regulation figured with d.c. resistance is quite considerably smaller than the actual regulation. The a.c. resistance runs the regulation higher but it is still lower than the actual. By assuming different constants and multiplying the a.c. resistance by these and refiguring the regulation, various values were found. The constant that came the most nearly to making theresults check was 1.77. This gave the regulation indicated by curve D. It checks very closely with the actual but not close enough to make an assumption on.

So far as these experiments show there seems to be no good reason for saying that by using a certain value of resistance the correct value of therregulation may be found.

FormE-5



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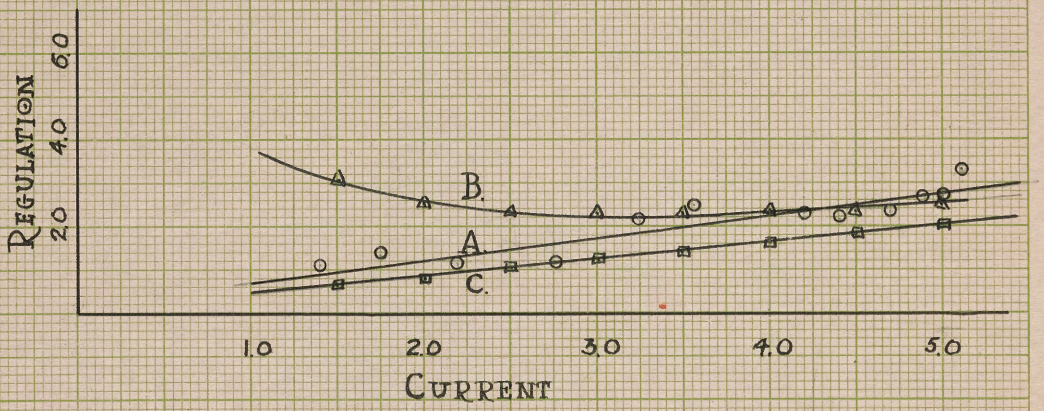
TRANSFORMER

A. ACTUAL REGULATION.

B. REGULATION FIGURED USING A.C. RESISTANCE.

C. " " " D.C. " .

Curve Sheet No. 2.



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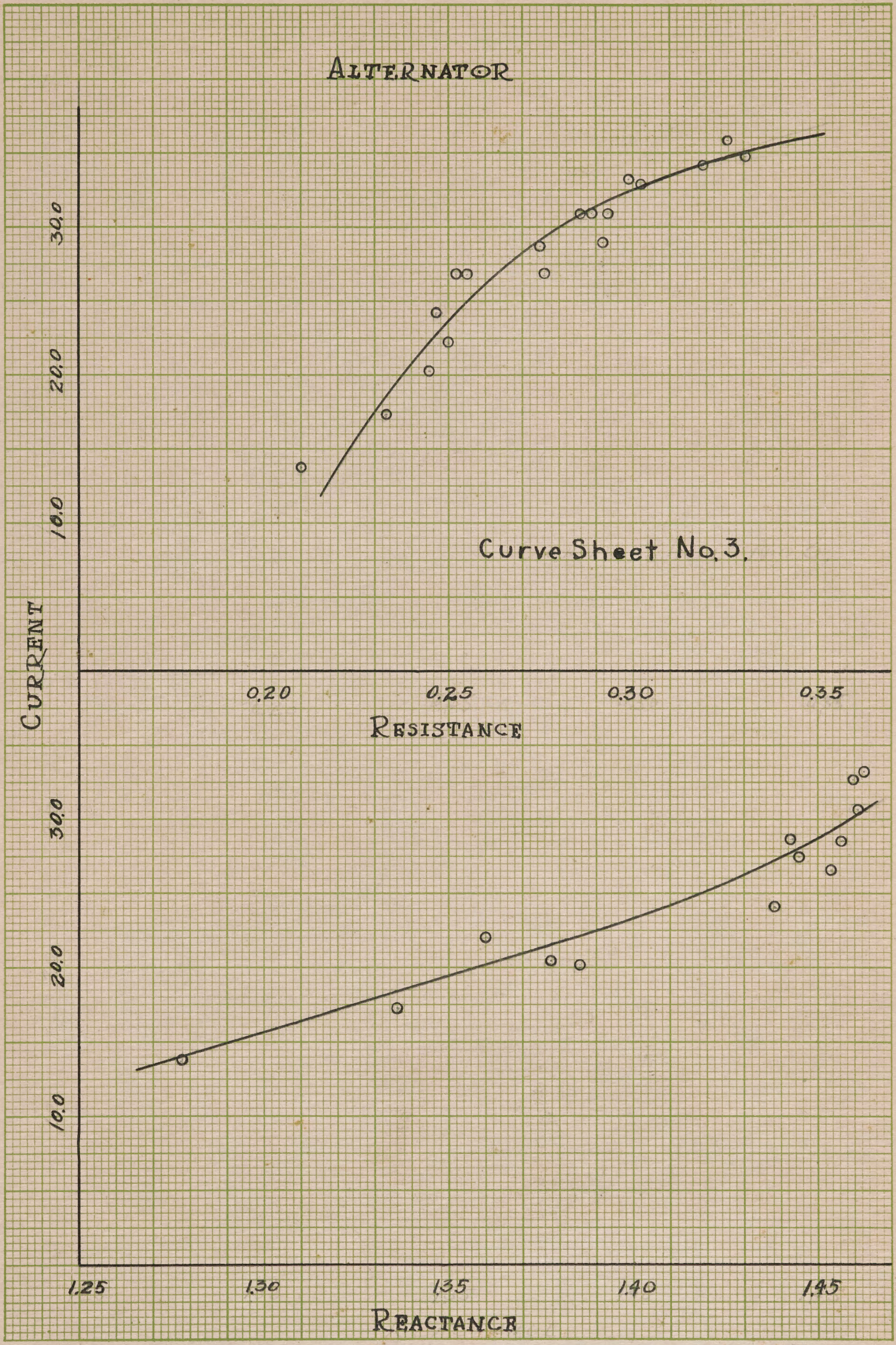

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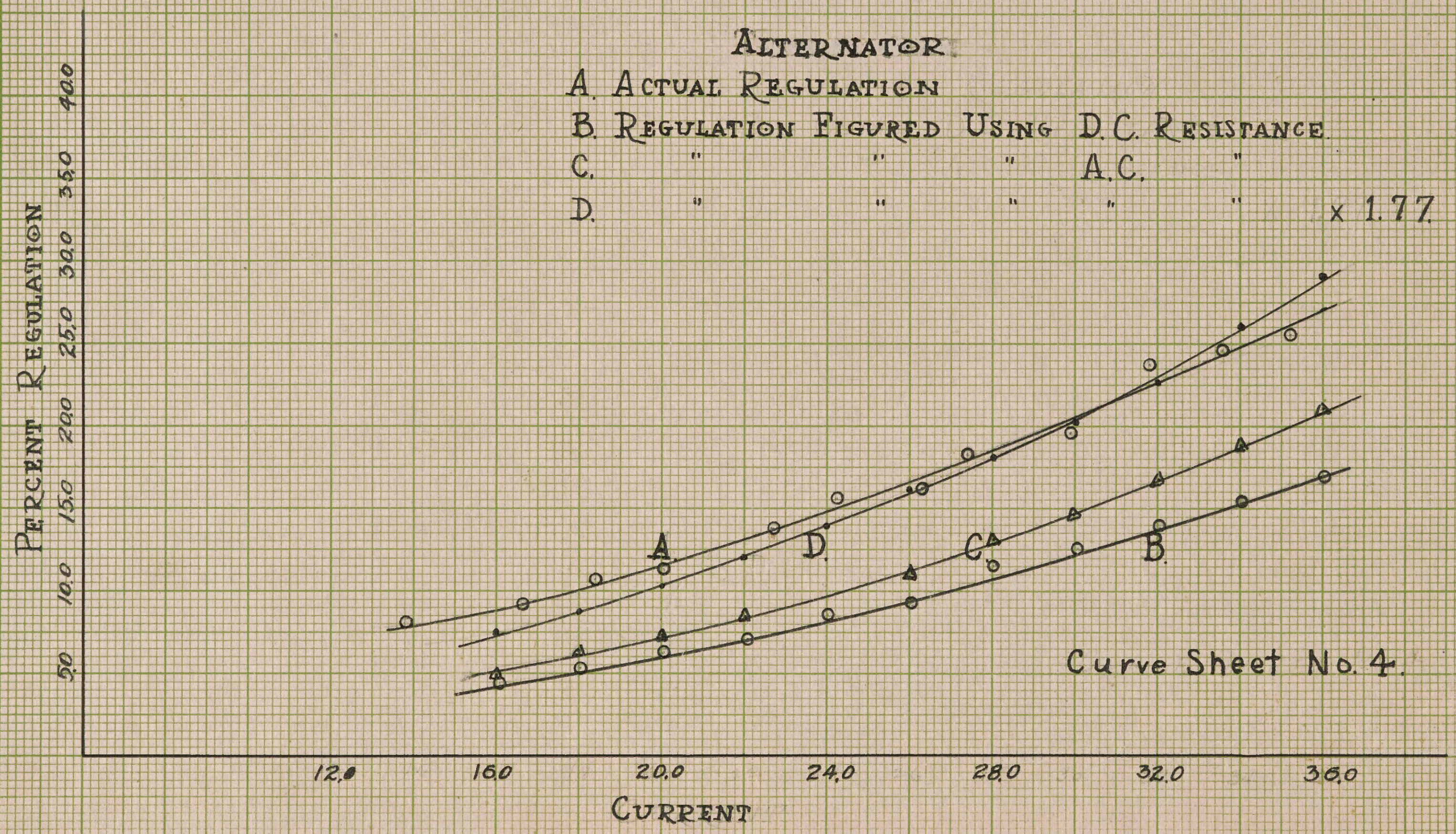

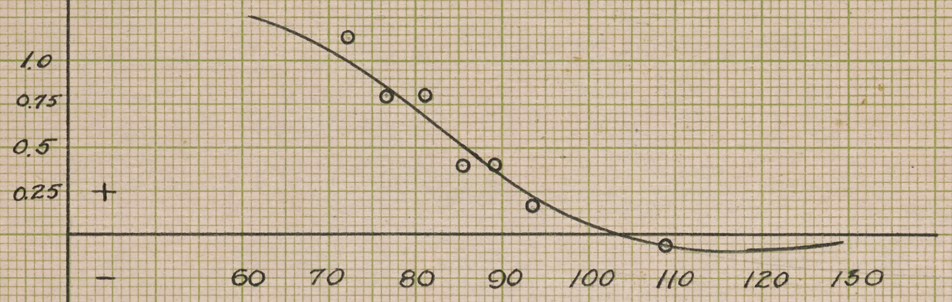

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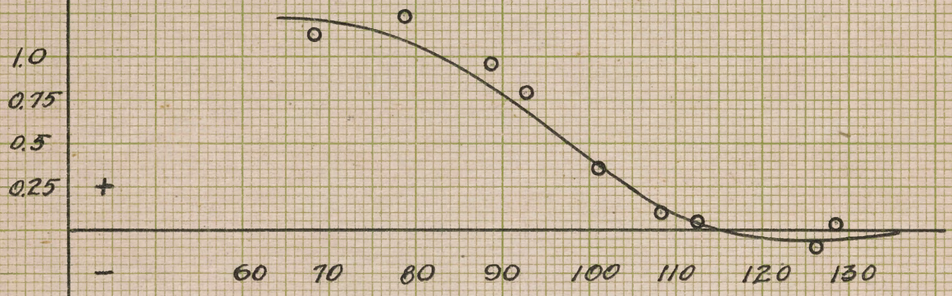

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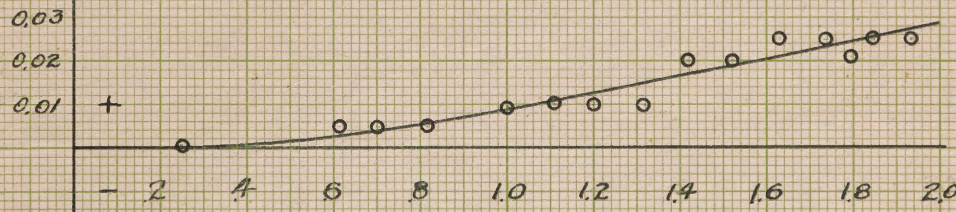

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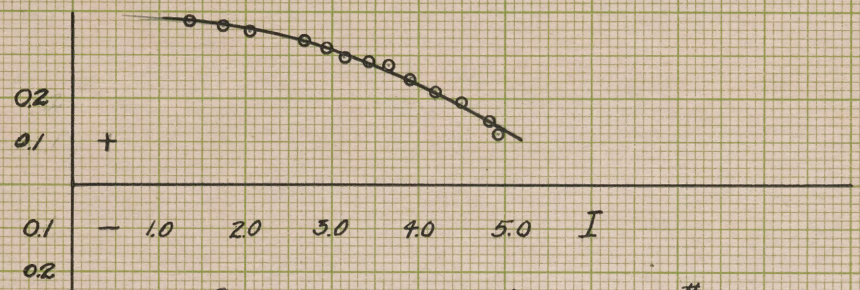

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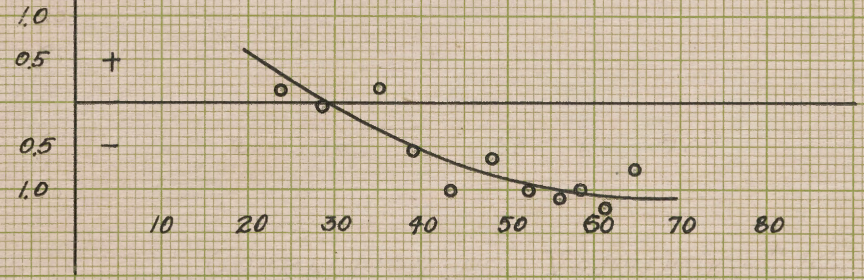

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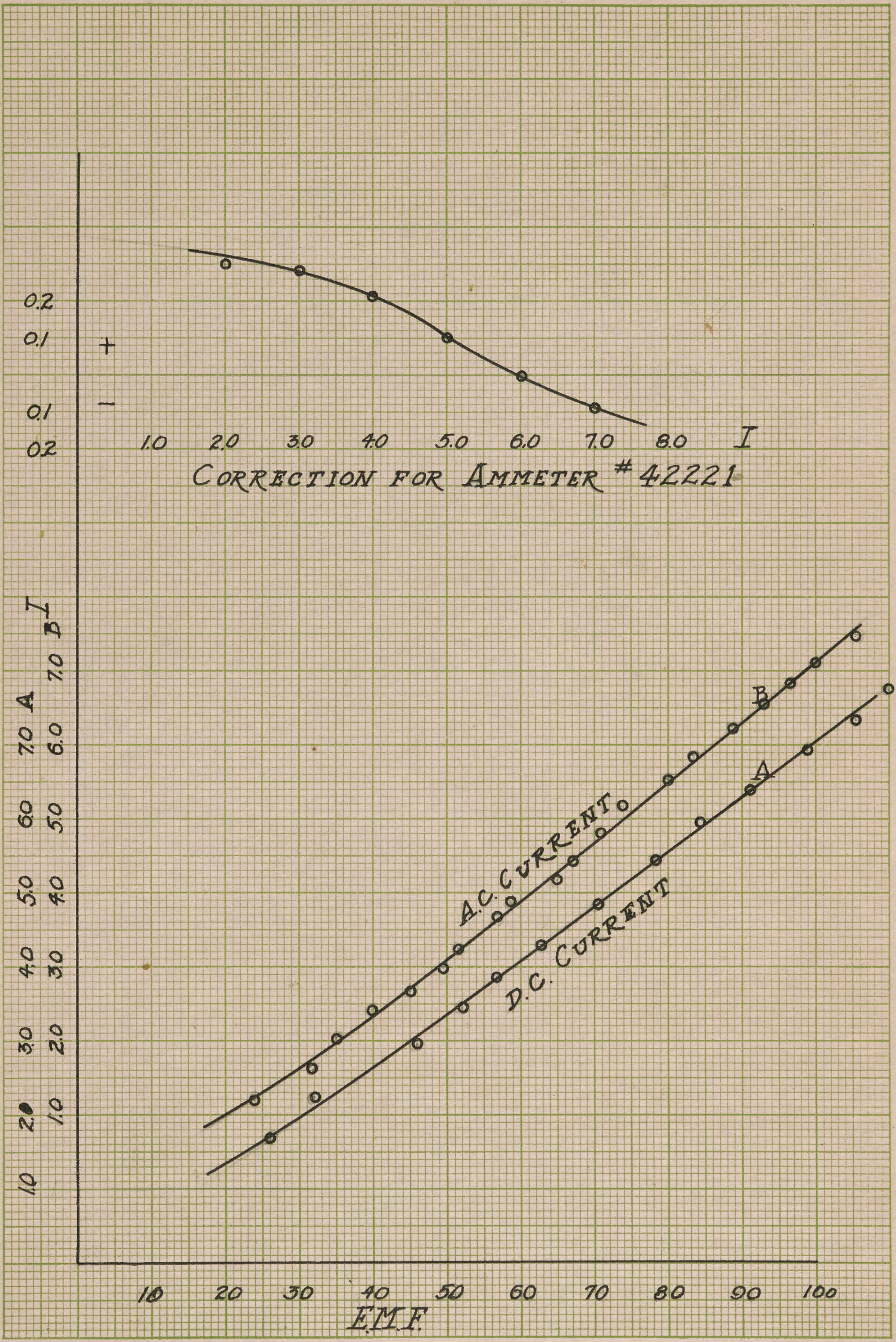

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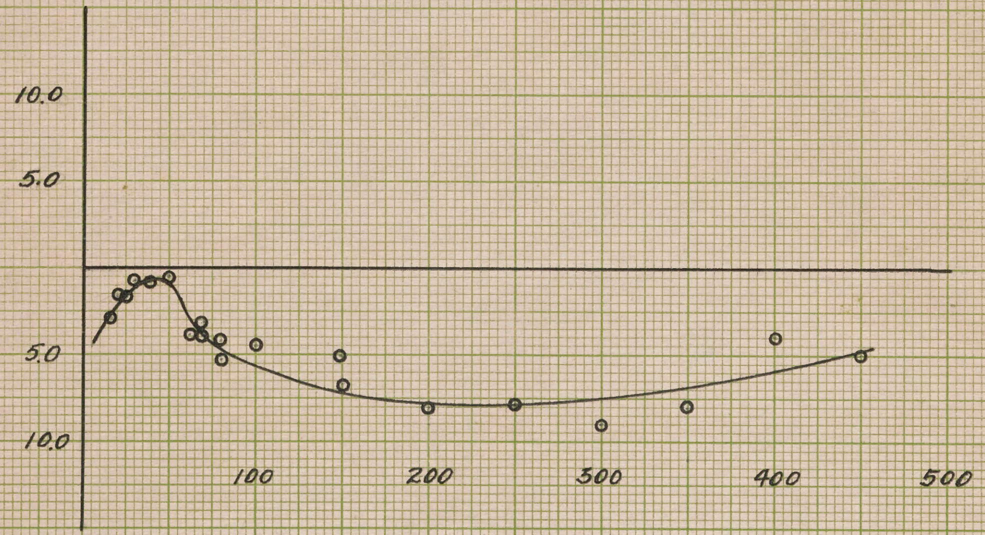

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APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves this thesis only for the purpose for which it is submitted.

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Professor of Electrical Engineering.