LOSSES AND EFFICIENCIES OF TRANSFORMERS

by

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INTRODUCTION

This Thesis was written to show the losses of a home build transformer as compared to a factory built transformer. The home built transformer was built by J. E. Crowder in 1927. The factory built transformer was built by Westinghouse Electric & Manufacturing Company, and is an old model which has recently been junked by the Knoxville Power & Light Company, because of new design and construction in transformers which make this type obsolete. The home built transformer was designed for a 3 K.V.-A. capacity and voltage ratio of 1 to 2. The primary voltage is 110 and the secondary 220. Four coils were used.

The factory built transformer is a 2½ K V.-A capacity with voltage ratio of 10 to 1. It has four coils giving the voltage ratios of 2200 to 220 or 1100 to 110 volts. Frequency of 50 - 140 cycles per second.

HIGH POTENTIAL COILS

HOME BUILT

220 Volts

3 K V.-A.

Current $= \frac{3000}{220} = 13.6$ Amps.

FACTORY BUILT

1,100 Volts

2.5 K V.-A.

Current $= \frac{2500}{1100} = 2.28$ Amps.

LOW POTENTIAL COILS

110 Volts

Current $= \frac{3000}{110} = 27.2$ Amps.

110 Volts

Current $= \frac{2500}{110} = 22.8$ Amps.

CORE

$$E = \sqrt{2}\,\Pi\, N\, \phi\, 10^{-8}$$

$$\phi = \frac{E \times 10^8}{\sqrt{2}\,\Pi \times N}$$

$$\text{Flux} = \frac{110 \times 10^8}{4.44 \times 110} = 380{,}000$$

Flux density $= 60{,}000$

$380{,}000 \div 60{,}000 = 6.3$ sq." Core Area.

LOSSES AT FULL LOAD

I^2R

HOME BUILT

Primary R = .07 ohm

Primary $I^2R = (27.2)^2 \times .07 = 51$ Watts

Secondary R = .51 ohms

Secondary $I^2R = (13.6)^2 \times .51 = 94$ Watts

Total I^2R Losses

$51 + 94 = 145$ Watts

Percent Loss $= \frac{145 \times 100}{3000} = 4.8$

FACTORY BUILT

Primary R = .054 ohms

Primary $(I)^2R = (22.8)^2 \times .054 = 28.1$

Secondary R = 4.67 ohms

Secondary $I^2R = (22.8)^2 \times .054 = 28.1$

Total I^2R Losses

$28.1 + 24.2 = 52.3$

Percent Loss $= \frac{52.3}{2500} \times 100 = 2.1$

CORE LOSS

Total Core Loss

= 135 Watts

Total Core Loss

= 35 Watts

$135 - 35 = 100$ Watts

EFFICIENCY, CORE LOSS CONTSTANT

1/4 Load

HOME BUILT	FACTORY BUILT
Secondary I^2R = 3 Watts	Secondary I^2R = 1.50 Watts
Primary I^2R = 6	Primary I^2R = 1.35
Core Loss = 135	Core Loss = 35.00
Total Loss 144 Watts	Total Loss 37.85
Eff. $\frac{750}{750+144} = 84.\%$	Eff. $\frac{625}{625 + 37.85} = 94.5\%$

$\frac{1}{2}$ Load

HOME BUILT	FACTORY BUILT
Secondary I^2R = 12	Secondary I^2R = 6.00
Primary I^2R = 24	Primary I^2R = 7.45
Core Loss = 135	Core Loss = 35.00
Total Loss = 171	Total Loss = 48.45
Eff. $\frac{1500}{1500 + 171} = 90\%$	Eff. $\frac{1250}{1250 + 48.45} = 96.3\%$

$\frac{3}{4}$ Load

HOME BUILT	FACTORY BUILT
Primary I^2R = 29	Primary I^2R = 15.60
Secondary I^2R = 53	Secondary I^2R = 13.60
Core Loss = 135	Core Loss = 35.00
Total Loss = 217	Total Loss = 64.20
Eff. $\frac{2250}{2250 + 217} = 91$	Eff. $\frac{1875}{1875 + 64.20} = 96.9\%$

EFFICIENCY TEST (CONTINUED)

HOME BUILT

FACTORY BUILT

Full Load

Home built

Primary I^2R = 51

Secondary I^2R = 94

Core Loss = 135

Total Loss = 280 Watts

Eff. $\frac{3000}{3000 + 280} = 91.4\%$

Factory built

Primary I^2R = 28.1

Secondary I^2R = 24.2

Core Loss = 35.0

Total Loss = 87.3 Watts

Eff. $\frac{2500}{2500 + 87.3} = 96.8\%$

1/8 Load

Secondary I^2R = 0.38

Primary I^2R = 0.43

Core Loss = 35.00

Total Loss = 35.81 Watts

Eff. $\frac{312}{312 + 35.81} = 90.0\%$

5/8 Load

Secondary I^2R = 9.5

Primary I^2R = 10.82

Core Loss = 35.00

Total Loss = 55.32 Watts

Eff. $\frac{1564}{1564 + 55.32} = 96.5\%$

7/8 Load

Secondary I^2R = 18.5

Primary I^2R = 21.3

Core Loss = 35.0

Total Loss = 74.8 Watts

Eff. $\frac{2186}{2186 + 74.8} = 96.8\%$

EFFICIENCY TEST

E	I	P	E_2	I_2	P_2	Eff.
111	12.5	350	231	0	0	0
109.5	13.2	1080	225	1.7	750	69.5
108	16.5	1530	221	2.6	1150	75
107.5	17.5	1600	220	2.73	1200	75
107	18.5	1700	219	2.9	1260	74
106.5	18.8	1750	219	3.1	1360	77.5
105.5	16.8	2080	216	3.97	1750	84
106.5	15.6	2130	217	4.2	1840	86.4
106.5	15.8	2240	217	4.4	1940	86.6
105.5	16.4	2480	215	5	2150	87
105	17.5	2870	211	6	2600	90.5
104	18.2	3200	210	6.8	2950	92.5
103.5	18.9	3450	208	7.4	3180	92.4
103.3	20.7	3520	206	8	3250	92.4
102.5	22.4	3940	203	9.15	3650	92.7
101	25.5	4650	198	10.1	4250	91.5
100	27	5000	196	11	4650	93
102	22.1	3800	204	9	3570	94
100.5	24.5	4350	199	10.5	4080	93.5
100	25.8	4600	198	11	4300	93.5
97.5	29.5	5300	185	13	4950	91.5
97	31.3	5550	189	13.7	5190	93.5
96	32.4	5000	186	14.5	5450	94
95	33.5	6050	184	15.1	5550	92
94	35.4	6300	180	16.1	5900	94

(Efficiency Test Continued)

E	I	P	E_2	I_2	P_2	Eff.
93.5	36.5	6450	178	16.6	6000	93
92	38.3	6750	174	17.6	6220	92.3
90.5	41.9	7400	168	19.5	6600	89

HEAT TEST

Home Built Transformer

Load 3000 Watts

Temp. (cent.)	Time (Min.)
28	0
31	10
37.5	20
43	30
48	40
52	50
56	60
59	70
62	80
64.5	90
68	100
70	110
72.5	120
75	130
77	140
78.5	150
79	155

RESISTANCE MEASUREMENTS

Primary

HOME BUILT

E	I	R
.5	7	.071
1.1	15.3	.072
1.6	21.5	.074
1.9	26	.073

Mean R = .073 ohms

FACTORY BUILT

E	I	R
.3	5.5	.054
.9	16	.056
1.5	27.3	.055
2.0	37	.054

Mean R = .054 ohms

Secondary

HOME BUILT

E	I	R
2.05	3.5	.585
2.95	5	.590
3.9	6.5	.600
4.9	8.5	.585

Mean R = .589 ohms

FACTORY BUILT

E	I	R
12.5	2.6	4.65
14.5	3.2	4.54
22.0	4.7	4.68
24.0	5.0	4.80

Mean R = 4.67 ohms

REGULATION

HOME BUILT

Full Load

$E_1 = 93.5$

$E_2 = 178$

$E_1^o = 112$

$112 - 93.5 = 28.5$

$E_2^o = 232$

$28.5 \div 112 = .248$

$178 \times 1.248 = 222$ corrected

Value of E_2

$$\text{Reg.} = \frac{232 - 222}{232} \times 100 = 4.3\%$$

$\frac{3}{4}$ Full Load

$E_1 = 100.5$ $E_2 = 199$

$112 - 100.5 = 11.5$

$11.5 \div 112 = .103$

$199 \times 1.103 = 220$

$$\text{Reg.} = \frac{232 - 220}{232} \times 100 = 5.17\%$$

$1\frac{1}{4}$ Full Load

$E_1 = 88$ $E_2 = 160$

$112 - 88 = 24$ volts

$24 \div 112 = 214$

$160 \times 1.214 = 194$

$$\text{Reg.} = \frac{232 - 194}{232} \times 100 = 16.4\%$$

REGULATION

FACTORY BUILT

Full Load	I	E	W
	2.27	128	245

$$\text{Equiv. } R = \frac{P}{I_2} = \frac{245}{(2.27)}^2 = 47.6 \text{ ohms}$$

$$E_R = IR = 2.27 \times 47.6 = 108 \text{ volts}$$

$$\text{Equiv. } Xl = \sqrt{(ZI)^2 - (Rl)^2} = \sqrt{(128)^2 - (108)^2}$$

$$= 21.2 \text{ volts}$$

$$\text{N.L. Voltage } E = \sqrt{(2308)^2 + (21.2)^2}$$

$$= 2310$$

$$\text{Reg.} = \frac{2310 - 2200}{2200} \times 100 = 5.0\%$$

$\frac{3}{4}$ Full Load	I	E	W
	1.71	106	155

$$\text{Equiv. } R = \frac{P}{I_2} = \frac{155}{(1.71)}^2 = 55 \text{ ohms}$$

$$E_R = IR = 1.71 \times 55 = 94 \text{ volts}$$

$$\text{Equiv. } Xl = \sqrt{(106)^2 - (94)^2}$$

$$= 41.8 \text{ volts}$$

$$\text{N.L. Voltage } E = \sqrt{(2294)^2 + (41.8)^2}$$

$$= 2298$$

$$\text{Reg.} = \frac{2298 - 2200}{2200} \times 100 = 4.46\%$$

(Regulation continued)

$\frac{1}{2}$ Full Load	I	E	W
	1.14	108	108

$$\text{Equiv. } R = \frac{P}{I_2} = \frac{108}{(1.14)}2 = 83 \text{ ohms}$$

$$E_R = IR = 1.14 \times 83 = 94.5 \text{ volts}$$

$$\text{Equiv. } XI = \sqrt{(108)^2 - (94.5)^2}$$

$$= 43.8 \text{ volts}$$

$$\text{N.L. Voltage } E = \sqrt{(2294)^2 + (43.8)^2}$$

$$= 2299$$

$$\text{Reg.} = \frac{2299 - 2200}{2200} \times 100 = 4.5\%$$

$1\frac{1}{4}$ Full Load	I	E	W
	2.85	142	332

$$\text{Equiv. } R = \frac{P_2}{I} = \frac{332}{(2.85)}2 = 41 \text{ ohms}$$

$$E_R = IR = 2.85 \times 41 = 115 \text{ Volts}$$

$$\text{Equiv. } XI = \sqrt{(142)^2 - (115)^2}$$

$$= 82.5 \text{ volts}$$

$$\text{N.L. Voltage } E = \sqrt{(2315)^2 + (82.5)^2}$$

$$= 2319$$

$$\text{Reg.} = \frac{2319 - 2200}{2200} \times 100 = 5.4\%$$

CALIBRATION OF VOLTMETER (STD.)

Voltmeter	Potentiometer	Error
0	0	0
.10	0.10094	0.00094
.20	0.20086	0.00086
.30	0.30200	0.00200
.40	0.40184	0.00184
.50	0.50266	0.00266
.60	0.60334	0.00334
.70	0.70250	0.00250
.80	0.80100	0.00100
.90	0.90294	0.00294
1.00	1.00254	0.00254
1.10	1.10443	0.00443
1.20	1.20350	0.00350

CALIBRATION VOLTMETER

Std.	Voltmeter	Ave.	Error
30	26 - 30	28	2
40	38 - 40	39	1
50	48 - 52	50	0
60	49 - 61	60	0
70	70 - 71.2	70.6	- .6
80	79.2 - 80.2	89.7	.3
90	89.8 - 90.4	90.1	- .1
100	100.8 - 100.5	100.6	- .6
110	111.7 - 110	110.8	- .8
120	120 - 122	121	- 1.

CALIBRATION OF WATTMETER

Rev. S	W_M	T	W_S	Error
4.88	98	60 Sec.	97.0	-1
5.82	100	60	99.0	-1
9.9	195	60	191.0	-4
13.04	290	60	291.0	-1
15.54	370	60	371.2	-1.2
16.8	400	60	401.1	1.1
23.13	455	60	456	-1
23.17	460	60	461	-1

CALIBRATION OF AMMETER

W	E	I_M	I_M	Ave.	I_C	Error
40	114	.4	.42	.41	.352	-.05
60	114	.6	.58	.59	.525	-.06
87	114	.8	.82	.81	.764	-.04
107	114	1.0	.98	.99	.94	-.05
134	116	1.2	1.23	1.2	1.16	-.04
153	116	1.4	1.37	1.39	1.32	-.07
180	117	1.6	1.59	1.6	1.59	-.01
202	117	1.8	1.78	1.79	1.73	-.06
223	117	2.0	1.98	1.99	1.91	-.08

CONCLUSION

From this thesis we see that the factory built transformer has a much better efficiency and regulation, for all loads, than the home built one has. The efficiencies range from five to nine percent better, while the regulation ranges from one to four percent better.

The I^2R losses at full load, are twice as high in the home built transformer, and the core losses for the transformers show a difference of one hundred watts in favor of the factory built one.

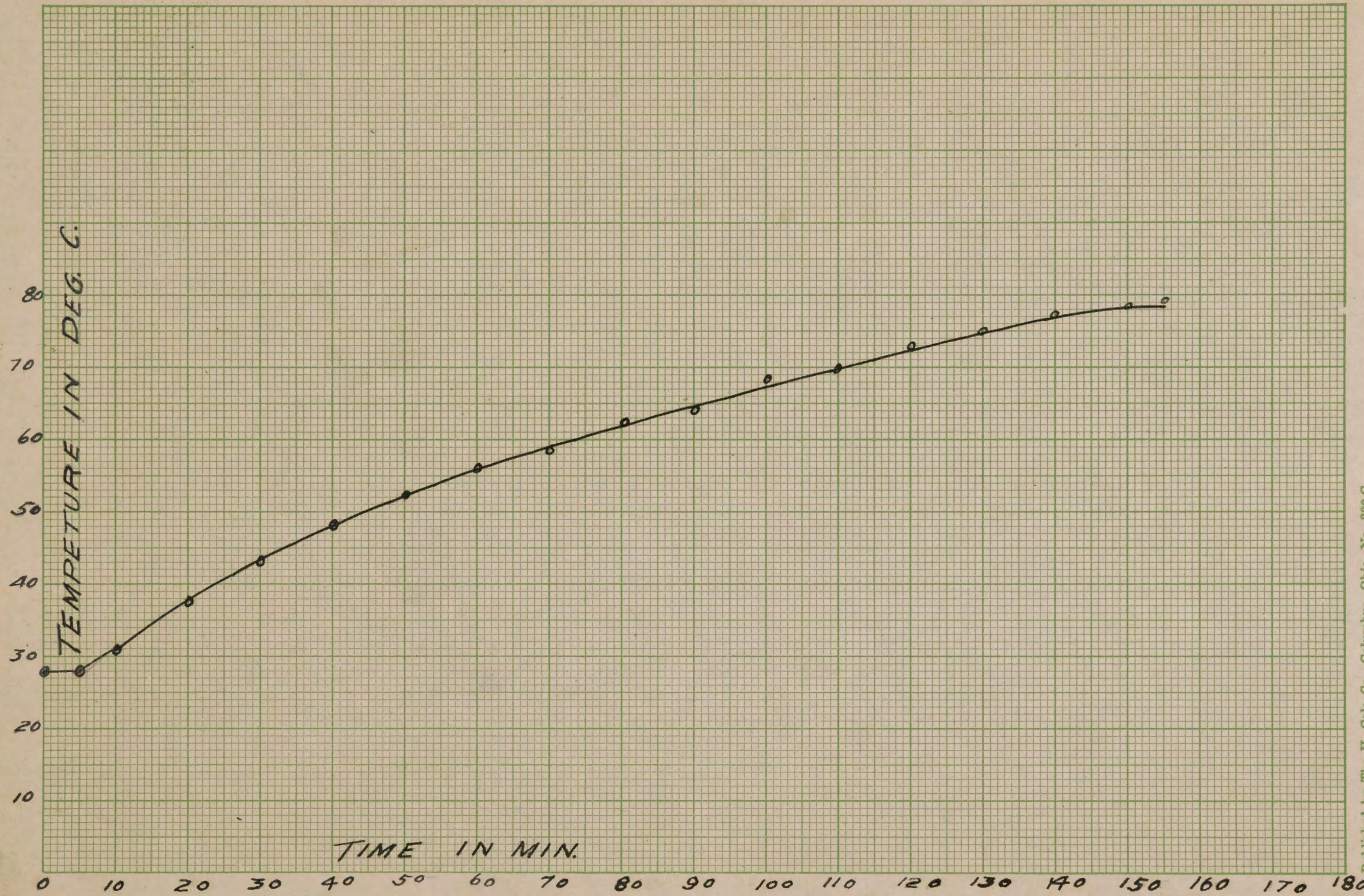
This comparison gives an idea of what has been gained, in transformer design and construction by years of study and construction, up to the time of this transformer. Since that time newer points of design and construction have been worked out, and today they are able to build transformers of even better efficiency and regulation than was shown in this thesis.

APPROVAL

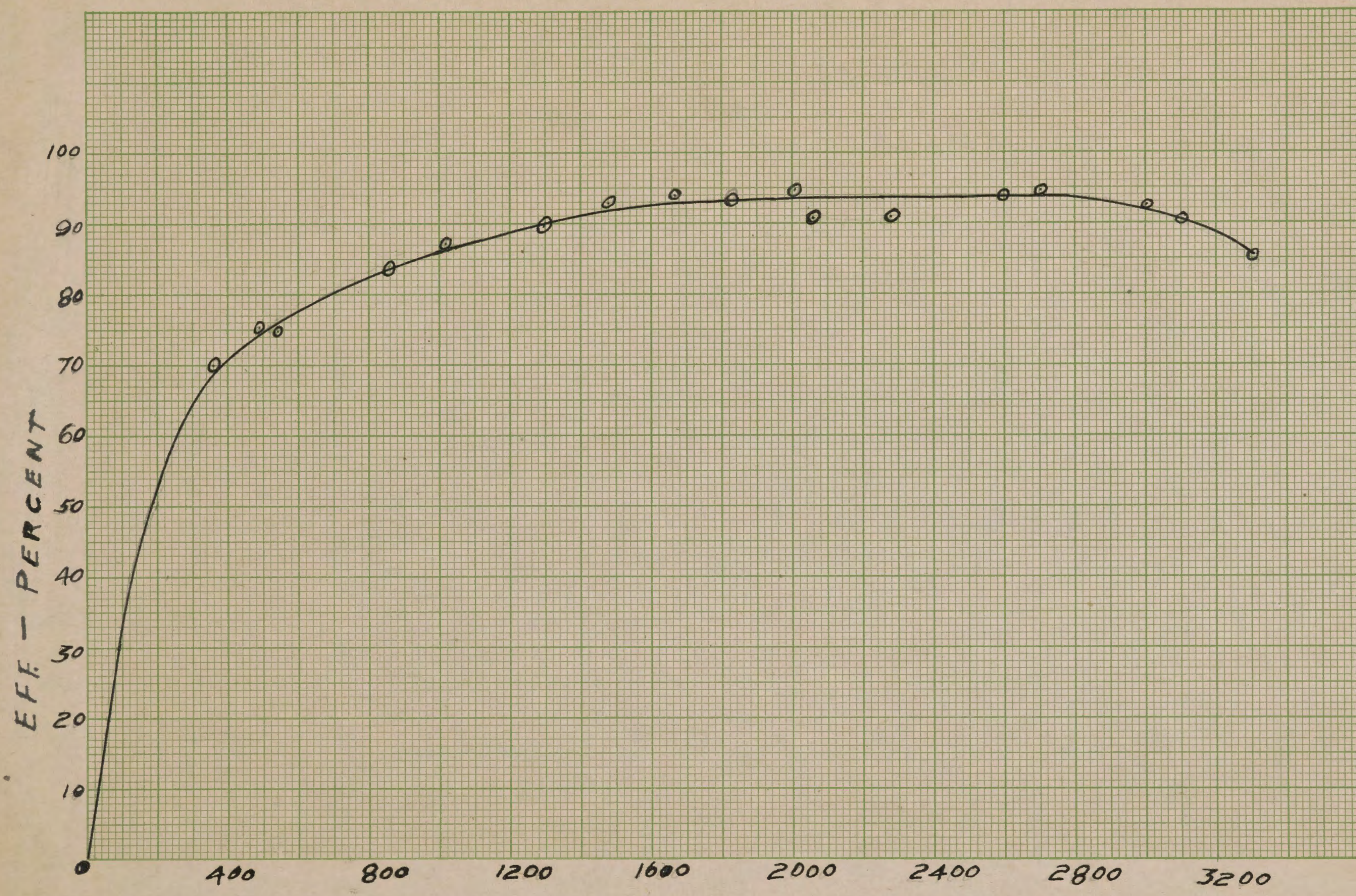
The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrent its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned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

Name Chas A Perkins

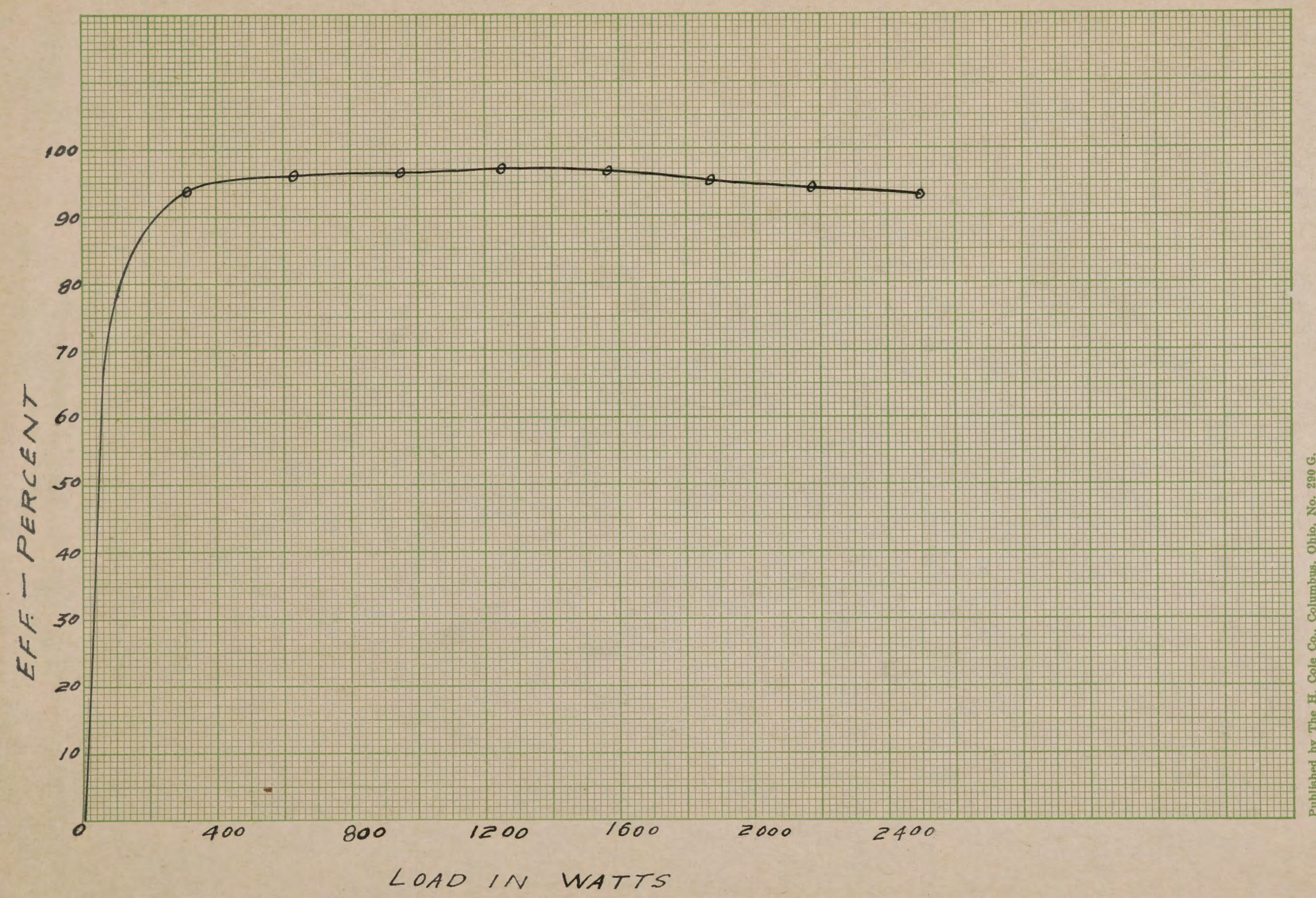
TITLE Professor of Electrical Engineering.



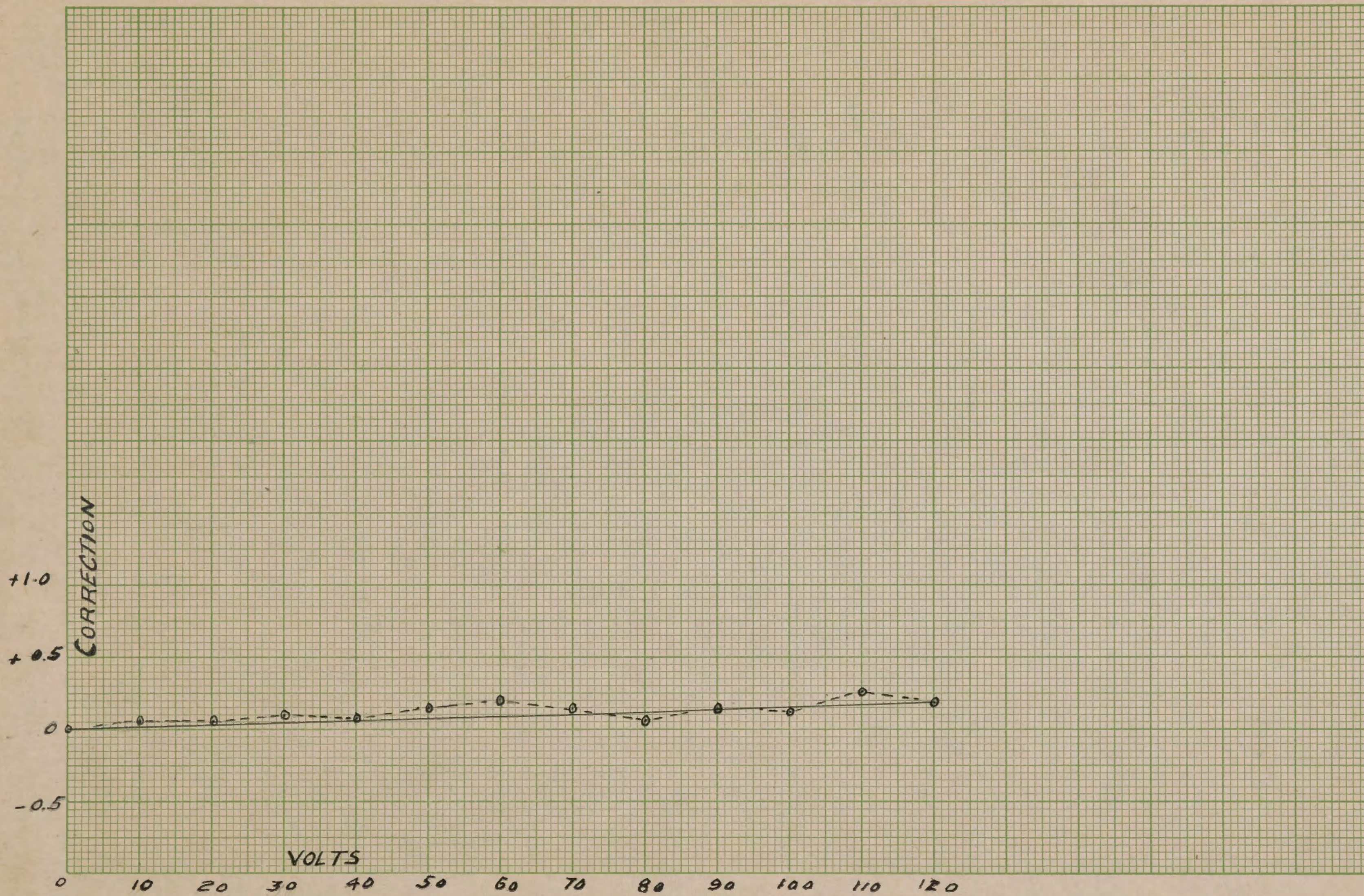
HEAT TEST FOR HOME BUILT TRANSFORMER



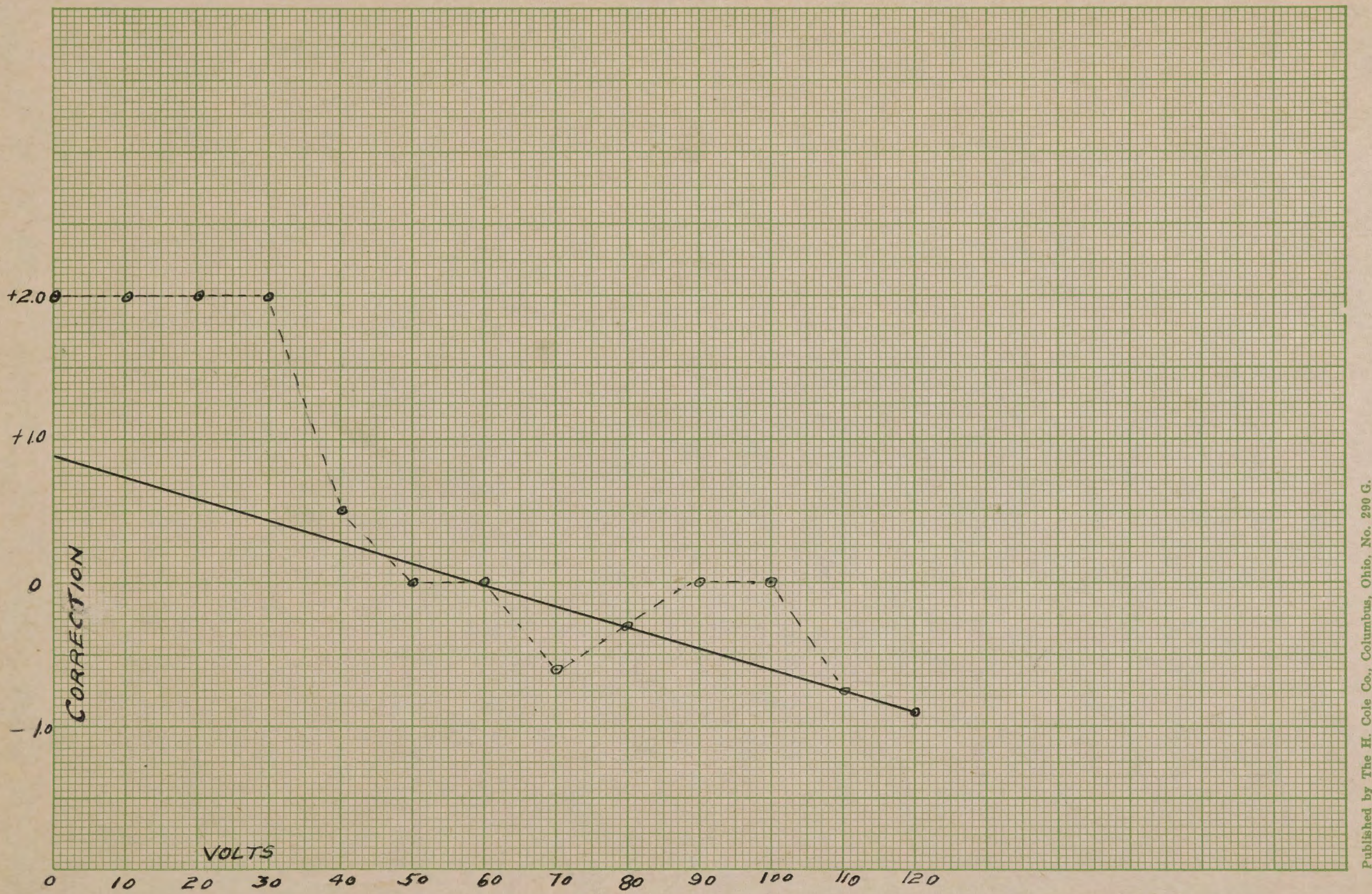
HOME BUILT TRANSFORMER



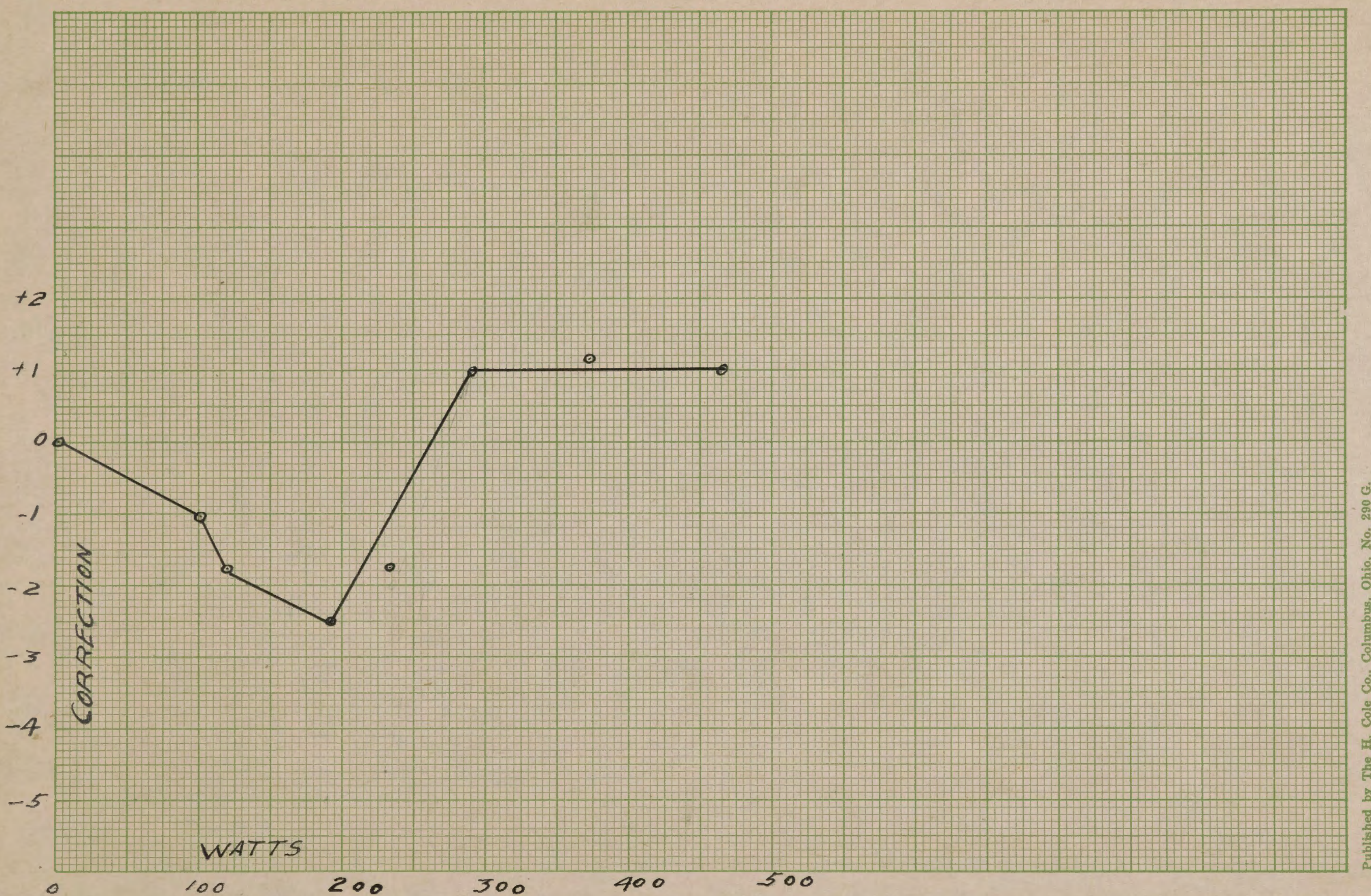
FACTORY BUILT TRANSFORMER



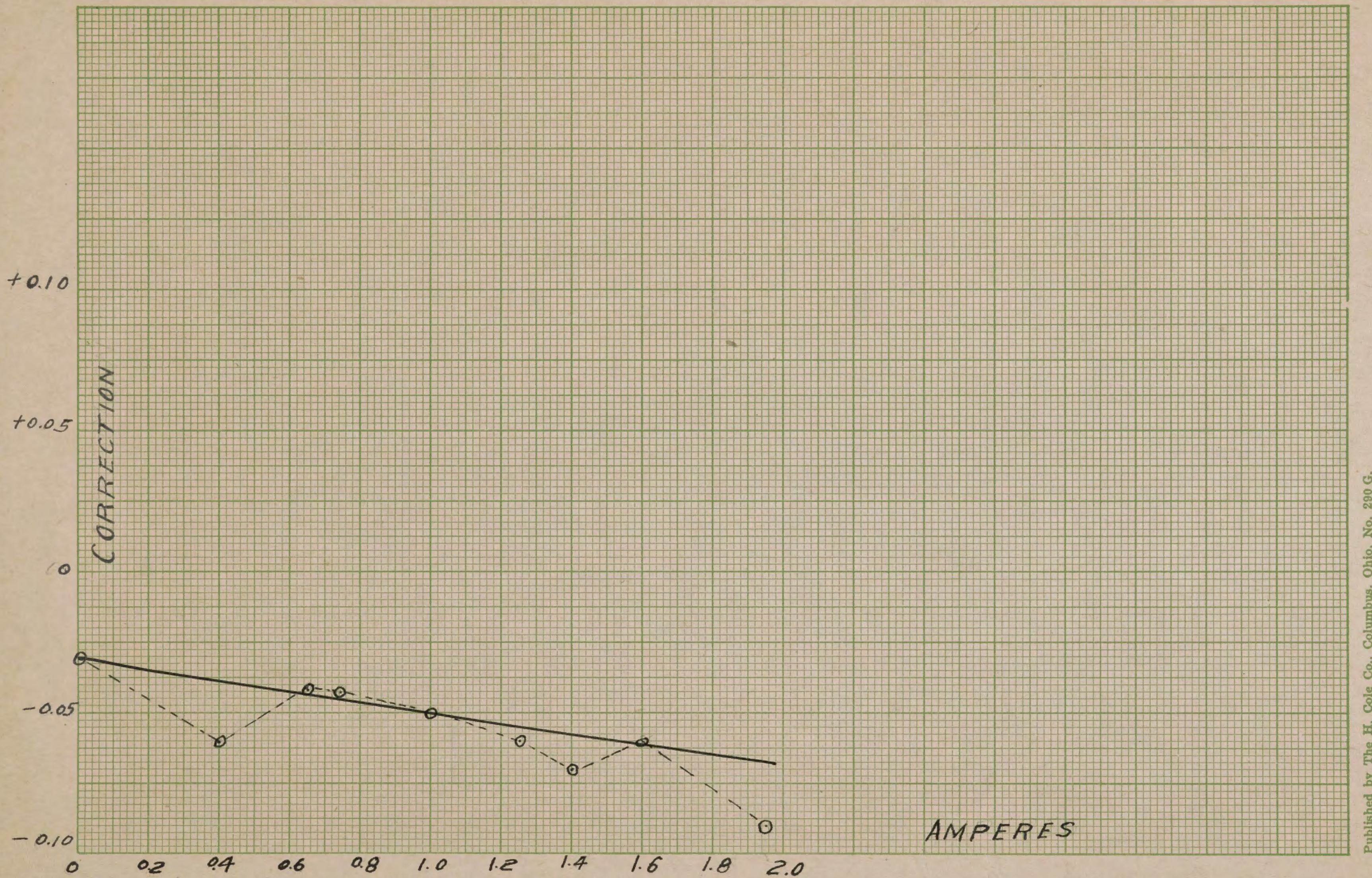
CALIBRATION CURVE FOR STANDARD VOLTMETER



CALIBRATION CURVE FOR THOMPSON A-C VOLTMETER #3



CALIBRATION CURVE FOR G. E. WATTMETER #14



CALIBRATION CURVE FOR AMMETER # 7 0-2 A-C