T H E S I S.

TEST OF A SERIES TRANSFORMER.

by

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for

DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING.

Under

Dr. Chas. A. Perkins.

1906

Series Transformer No. 29266 made by Westinghouse Electric and Manufacturing Co.

For description see Electric Club Journal, Vol.I. No. 8.

The series transformer, as its name indicates, has its primary winding in series with the line, and its primary current is determined by the main circuit, the primary E.M.F. being the drop across the transformer due to its impedance. If the secondary is on open circuit the primary current will set up a magnetic field in the iron of the transformer and generate in the secondary an E.M.F. equal to the voltage drop in the primary multiplied by the ratio of secondary to primary turns. As there is no opposing flux (on open circuit) there results an abnormally large secondary voltage. Hence the secondary of a series transformer should always be short circuited.

The principal use of the series transformer is to measure the current in heavy feeders by transforming the current to a value that can be read by low reading instruments. The maximum current capacity of the secondary of the transformer tested is 5 amperes. The secondary winding consists of 120 turns and with a primary winding of 1 turn, there is required a primary current of 600 amperes to cause 5 amperes to flow in the secondary. The primary ampere-turns are almost equalled by the secondary ampere-turns. They are not exactly equal because a magnetizing current is required. To keep this magnetizing current as small as possible, the iron is worked at a low magnetic density. The magnetic density is about one tenth that of a shunt transformer.

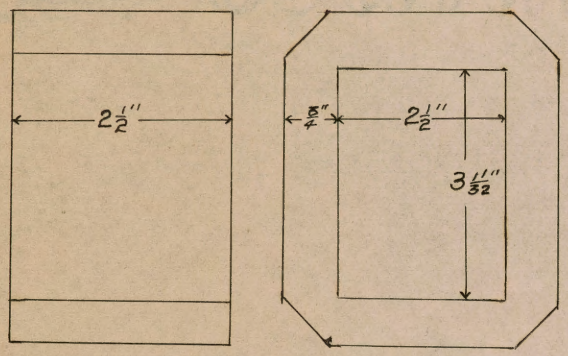
Formulae.

$$\Phi_m = \frac{10^8 \sqrt{2}\, Ep}{n\, w}$$ in which n = No. turns primary

Ep = primary E.M.F. A = area sq. cm. and $\Phi_m = B_m A$

A = .9 of 12.06 = 10.8 sq. cm. (allowing 10% of the thickness for air space) $\Phi_m = \frac{10^8 \sqrt{2}\, Ep}{120 \times \frac{2000}{30} 2\pi} = 2822. \times Ep$ $\therefore B_m = 256 \times Ep$

In these tests the primary was wound with 120 turns for convenience in measuring the current.



Core.

Laminations of core of sheet iron .014 inches thick.

Resistance of secondary .144 ohms.

Calibration of Instruments.

Calibration of Centiampere Balance by Potentiometer.

Centiampere Balance	Potentiometer.
.0424	.0417
.0872	.0865
.1313	.1310
.1762	.1758
.2196	.2191
.2453	.2450
.2626	.2620

Calibration of Weston Voltmeter No. 16901 by Potentiometer.

Voltmeter No.16901	Potentiometer.
2.473	2.469
4.286	4.286
47.80	47.80

Millivoltmeter No. 13962 (with shunt) used as an ammeter was compared with the potentiometer on direct current and found to be correct. The electro dynamometer was then compared with this ammeter, and the Westinghouse Alternating Ammeter was then compared with the electro dynamometer. Curves were drawn for both of these comparisons and did not differ appreciably. The following are the data and the curves are shown on sheets Nos. 1 and 2.

Ammeter No. 13962 and Electro dynamometer.

Plotted on Sheet 1.

Ammeter 13962	Electro dynamometer. Direct	Reversed	Average
.3	3.	3.	3.
.4	4.5	5.	4.75
.6	10.	9.5	9.75
.8	18.	17.5	17.75
1.0	28.	27.	27.5
1.2	39.5	39.	39.25
1.41	54.5	54.	54.25
1.61	72.5	71.5	72.
1.81	93.	92.	92.5
2.	113.	111.5	112.25
2.18	134.5	133.	133.75
2.40	164.	162.	163.
2.60	192.	191.	191.5
2.78	221.	218.	219.5
2.94	246.	245.	245.5
3.2	285.	285.	285.
3.39	314.	313.	313.5
3.62	362.	361.	361.5

Westinghouse Ammeter No. 65063 and Electro dynamometer

Alternating Current.

Plotted on Sheet 2.

Ammeter 5 Amp. side.	Electro dynamometer L and O
.72	17
1.05	31
1.12	37
1.4	56
1.62	74
1.82	95
2.	114.5
2.07	123.5
2.21	137
2.39	160
2.60	189
2.76	212
3.04	257
3.52	342
3.74	387

Self induction of Westinghouse Ammeter. 5 Ampere Side.

Plotted on Sheet 8.

Speed	Frequency	Amperes	Volts	L
1942	64.4	2.7	.85	$\frac{1}{1290}$
1922	64.1	3.11	1.	$\frac{1}{1260}$
1937	64.6	3.92	1.25	$\frac{1}{1260}$
1878	62.6	4.67	1.50	$\frac{1}{1290}$
1850	61.7	4.95	1.60	$\frac{1}{1260}$

The induction was calculated by the formula $L = \frac{\sqrt{E^2 - I^2R^2}}{2\pi f I}$

Calibration of Electro-static Voltmeter by Weston Voltmeter No. 16901.

Electrostatic No.16901.	
50.	51.4
55.	56.
60.	61.1
65.	66.4
70	71.2
75	75.
80	80.
85	85.3
90	90.
95	95.
100	100.
110	110.
120	120.
130	130.
140	140.
150	150.

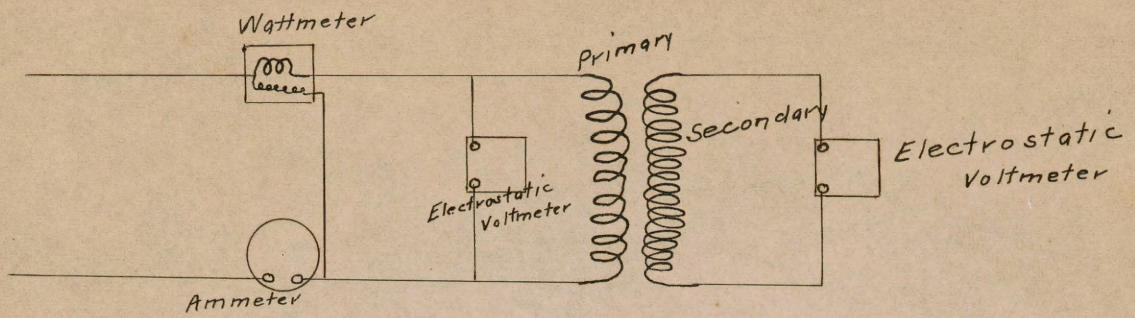
Calibration of Thompson 75 Volt-meter by Weston Voltmeter No.16901.

Thompson Direct	Thompson Reversed	Thompson Average	Weston. No. 16901
18.	22.5	20.25	20.
22.75	27.25	25.	25.
28.25	32.25	30.25	30.
34.	37.	35.5	35.
39.5	42.	40.75	40.5
44.25	46.5	45.37	45.
49.25	51.75	50.5	50.25
54.25	56.5	55.37	55.
58.5	61.5	60.	60.
64.	66.	65.	65.
68.5	71.5	70.	70.

These curves above are plotted on sheet 5. Calibration of Weston Wattmeter No.407 by Electrostatic voltmeter and Centiampere Balance. Alternating Current. Lamps for load.

Plotted on Sheet No. 3.

Volts	Volts Corrected	Amperes	Watts	Wattmeter readings.
63.	64.	.088	5.54	1.8
73.	73.5	.102	7.5	2.5
55.	56.	.163	9.13	6.
64.	65	.195	12.67	8.5
59.	60	.24	14.4	11.
52.	53.	.342	18.13	15.1
55.	56.	.365	20.44	16.75
60.	61.	.41	25.01	21.2
65.	66.	.456	30.10	25.8
68.5	69.5	.485	32.82	28.8
75.	75.	.536	40.2	35.
58.5	59.5	.736	43.06	40.
62.	63.	.788	48.86	45.5
65.	66.	.841	54.66	50.75
66.	67.	.852	56.23	52.6



Iron and Copper Loss.

For different primary currents, the watts, primary volts, and secondary open circuit volts were observed. Curves were plotted between magnetizing current and secondary volts, and between percent power factor and secondary volts. The following are the data.

Plotted on Sheet 4.

Primary.							Secondary
Electro dynamometer	Amps.	Volts.	Apparent Watts	Wattmeter	Corrected Watts	Power factor	Volts
10.	.6	42	25.2	14.8	19.	.754	40
19.5	.85	48	40.8	19.7	24.	.588	46
31.	1.06	53	56.2	23.5	27.5	.489	50
51.	1.37	57	78.1	28.75	30.	.384	55
97.	1.87	63	117.8	38.5	40.	.340	60
132.	2.17	66.5	144.3	45.1	48.8	.338	63

Ratio of Transformation.

The secondary of the transformer was connected to the ammeter and primary currents were observed. The following are the data.

Plotted on Sheet 7.

Primary	Secondary.	
Electro dynamometer.	Amperes	Amperes	Ratio.
9	.51	.5	1.02
20	.77	.75	1.027
31	1.05	1.	1.05
52	1.32	1.25	1.056
69	1.55	1.5	1.033
95.5	1.81	1.75	1.034
123.5	2.07	2.	1.035
151.	2.30	2.25	1.022
185	2.61	2.5	1.044
224	2.81	2.75	1.022
266	3.08	3.	1.026
254	3.57	3.5	1.02
	4.12	4.	1.03
	4.62	4.5	1.026

Effect on ratio of transformation of introducing extreme resistance into secondary of transformer. In this test primary and secondary currents were observed for different amounts of external resistance in the secondary. The internal resistance of secondary winding was .144 ohms. The resistance of the ammeter was .101 ohms. For each external resistance, a curve was plotted between primary and secondary currents. See sheet No. 6. Curves were also plotted between secondary currents and ratio of transformation. See sheet 7 for curves.

External resistance of 5.62 ohms.

Electro dynamometer	Primary current	Secondary current	Ratio.
100	1.89	1.72	1.10
201	2.67	2.52	1.06
270	3.10	2.95	1.05

External resistance of 9.24 ohms.

Electro dynamometer	Primary current	Secondary current	Ratio.
24.5	.94	.75	1.25
82.	1.72	1.5	1.15
164	2.42	2.18	1.11
204	2.65	2.39	1.11

External Resistance 14.62 ohms.

Electro dynamometer	Primary current	Secondary current	Ratio
22	.9	.66	1.36
69	1.58	1.31	1.21
122	2.09	1.75	1.19
158	2.36	2.	1.18

External Resistance 23.61 ohms.

Electro	P.C.	S.C.	Ratio
19.	.85	.61	1.4
55.5	1.41	1.11	1.27
93.	1.83	1.41	1.3
121.	2.08	1.58	1.32

External Resistance 33.9 ohms.

Electro	P.C.	S.C.	Ratio
17.5	.8	.52	1.54
47.	1.31	.93	1.41
78.	1.68	1.15	1.46
106.	1.94	1.25	1.55

External Resistance 43.85 ohms.

Electro	P.C.	S.C.	Ratio
15.	.75	.40	1.85
42.	1.25	.77	1.62
72.	1.60	1.	1.6
101.	1.91	1.06	1.8

External Resistance 54.17 ohms.

Electro	P.C.	S.C.	Ratio.
14.5	.73	.30	2.43
39.	1.22	.66	1.85
70	1.59	.8	1.99
100	1.89	.89	2.12

External Resistance 73 ohms.

Electro dynamometer	primary current	secondary current	Ratio
13	.7	.25	2.8
37	1.18	.62	1.9
68	1.56	.61	2.56
103	1.92	.65	2.95

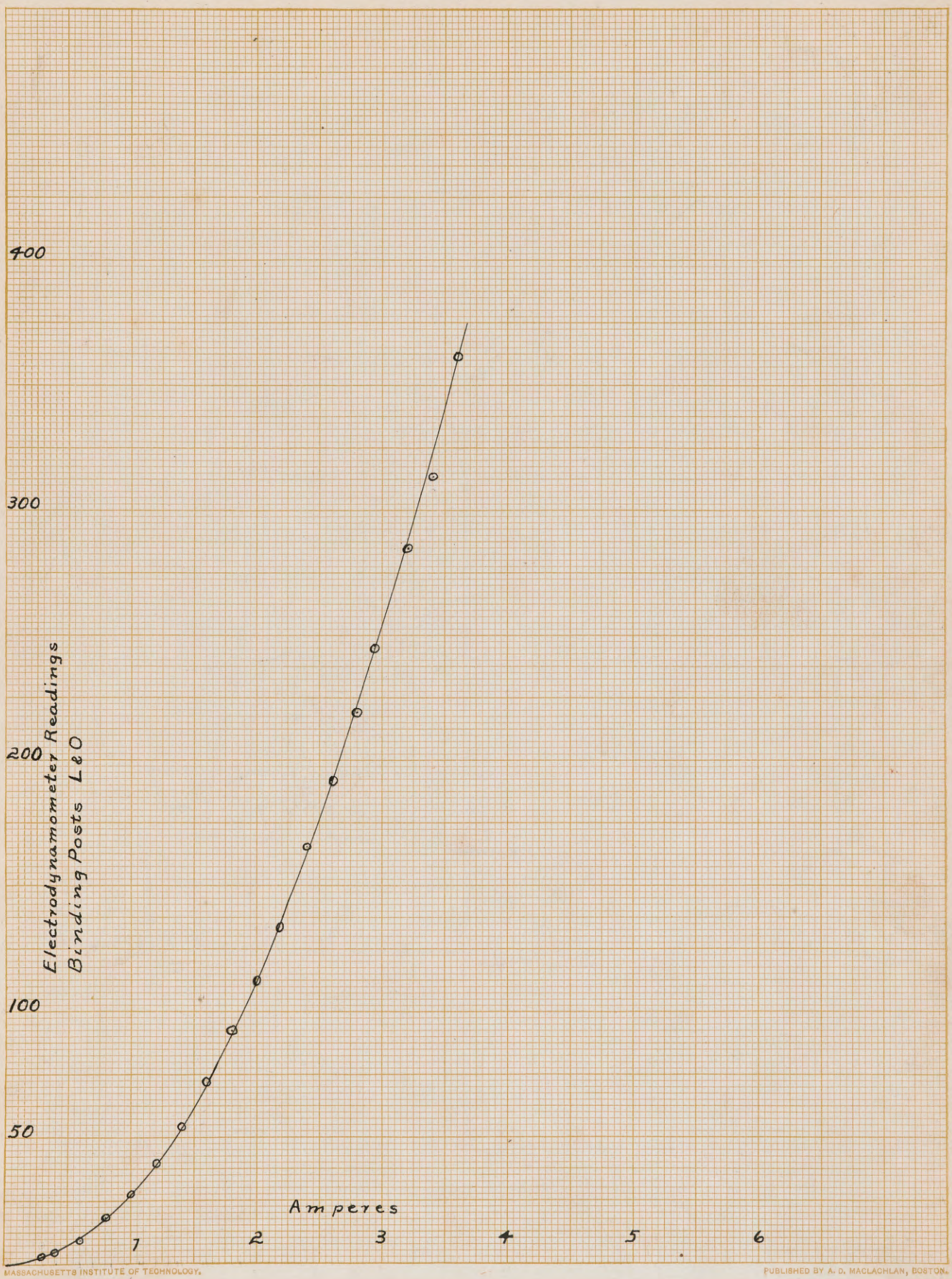
Vector Diagrams Series Transformer.

With 5 amperes in secondary, primary current is 5.13- from ratio of transformation. From curve 8 find secondary volts necessary to send this current. = 1.62 volts. From curve 4 find magnetizing current and power factor at this voltage. Magnetizing current = .13 Power factor could not be found from curve because it is at a point so low that the curve loses its value, but by drawing diagram, it is found to be 1, since the difference between the primary and secondary current is .13, which is also the magnetizing current as read on sheet 4.

Even in case the power factor = 0 the phase of the primary and se-

condary would not be changed more than a very small angle. Hence a wattmeter can be used on the secondary to indicate watts in the primary.

Diagrams are shown for 3 amperes and 2 amperes. The diagrams are drawn with a power-factor of zero which is an extreme case and does not coincide with the experiments. (?)



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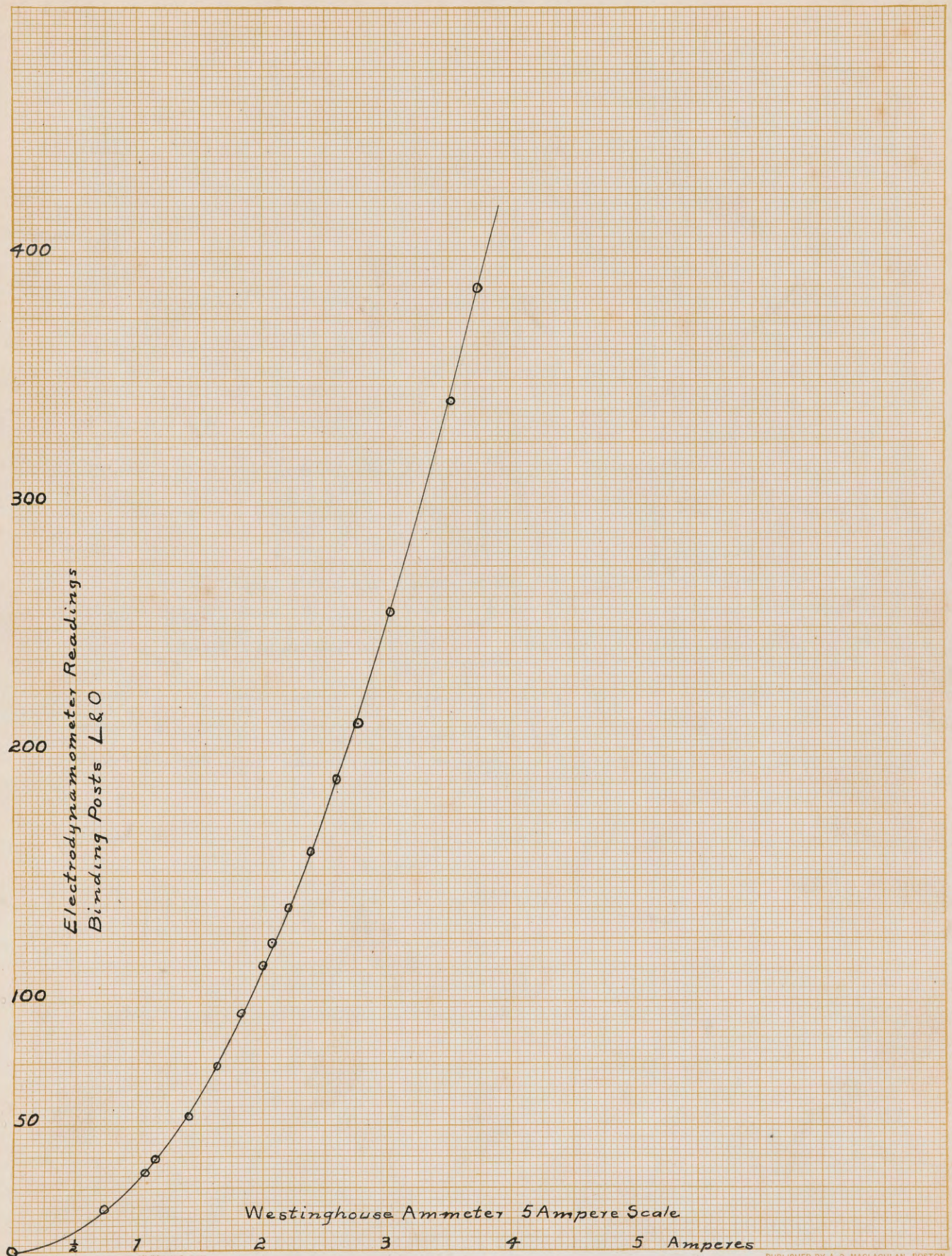

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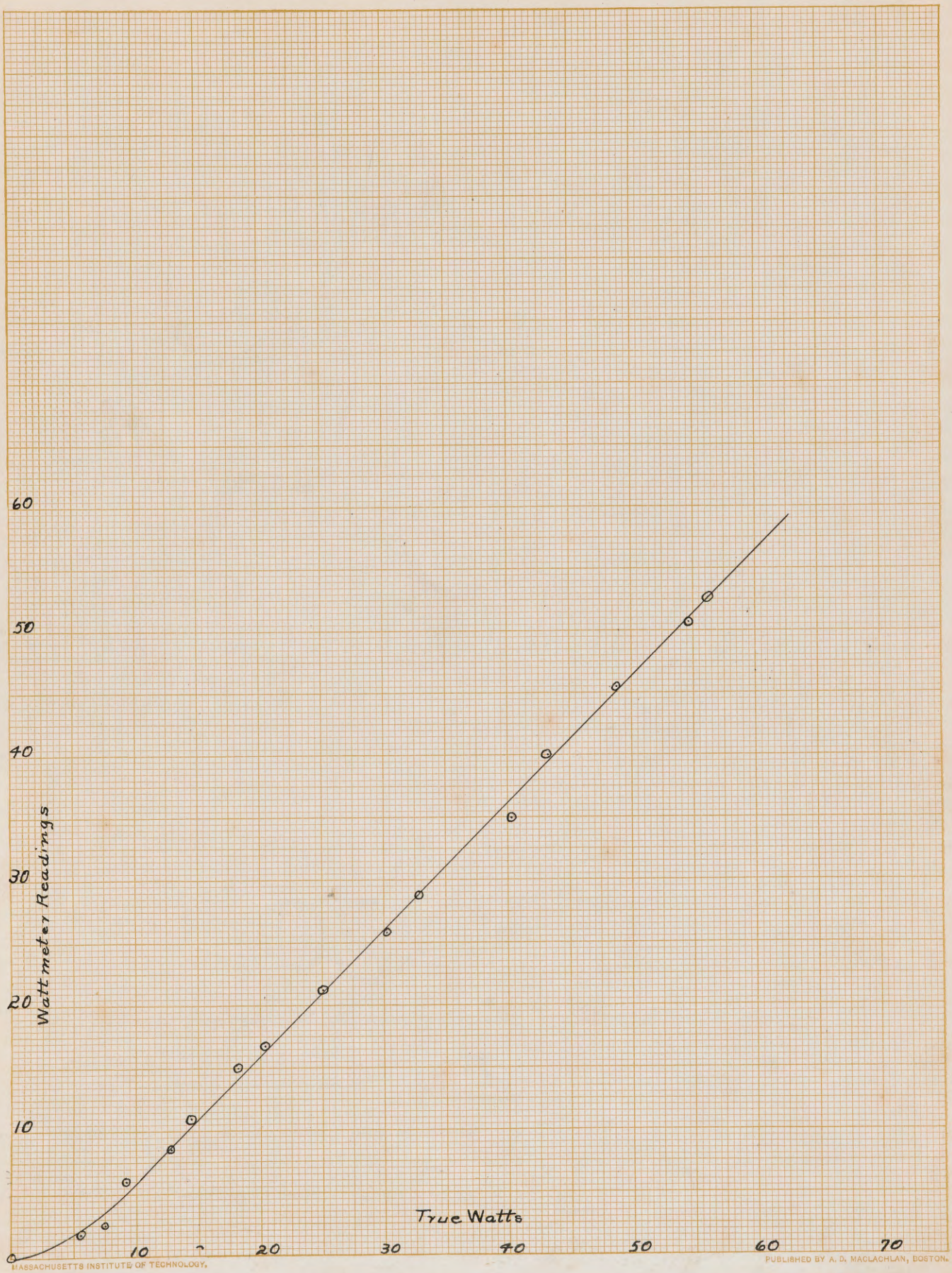

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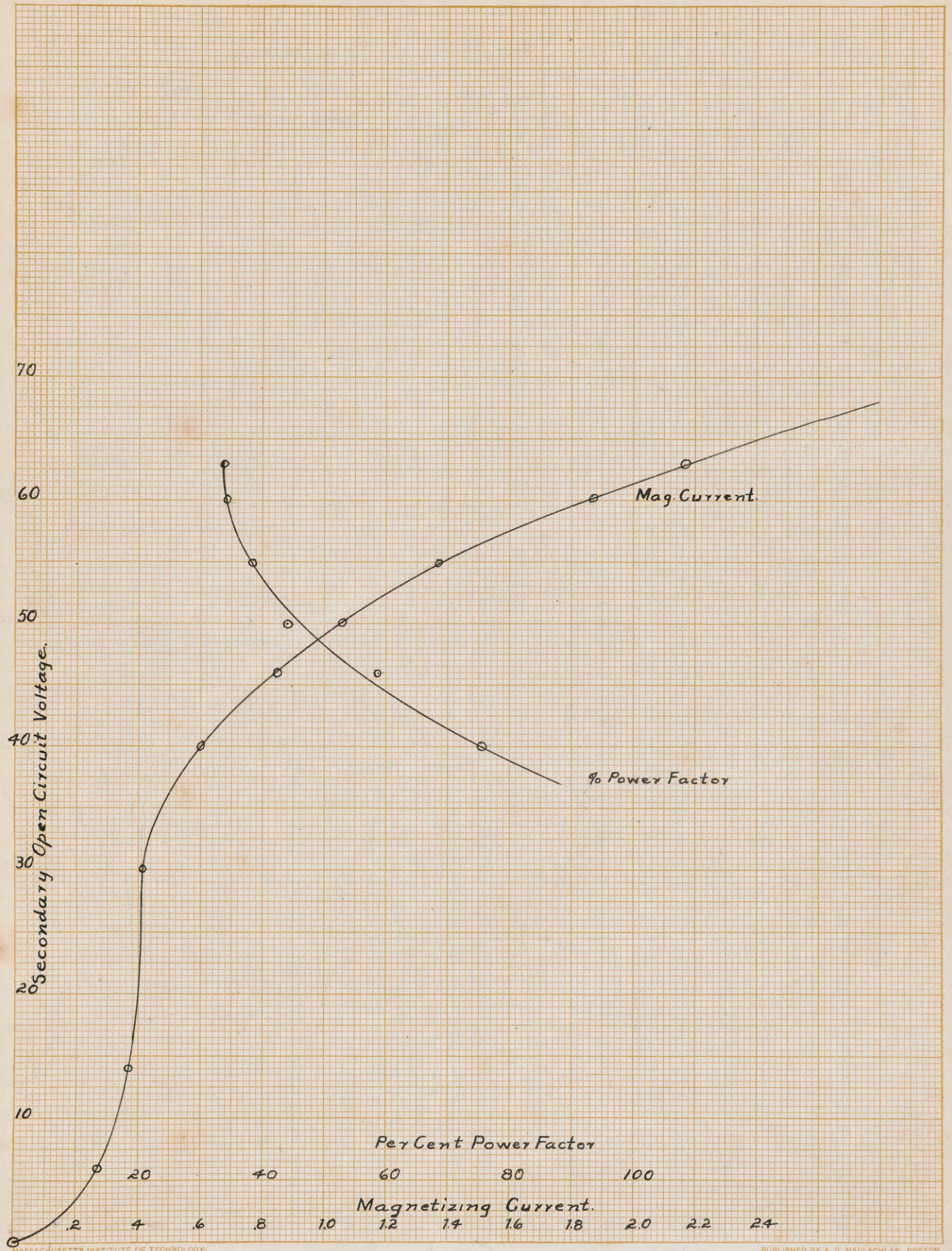

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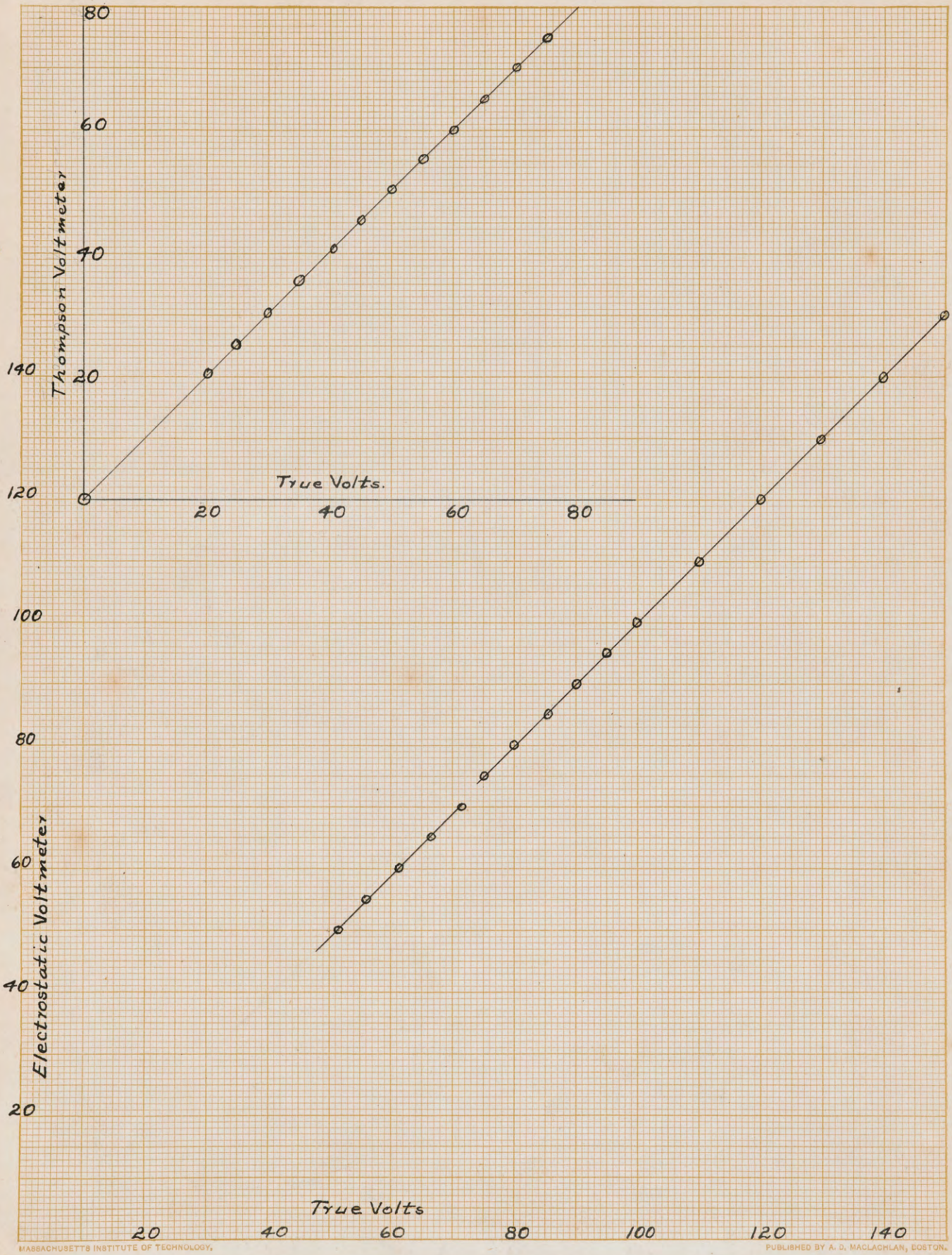

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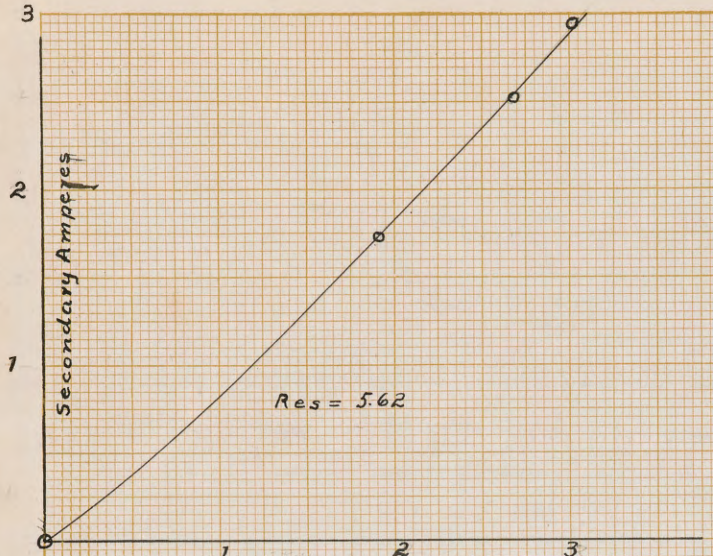

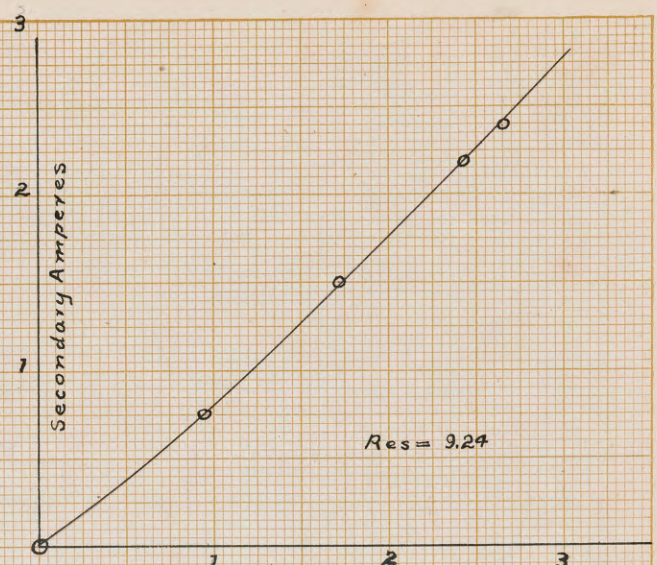

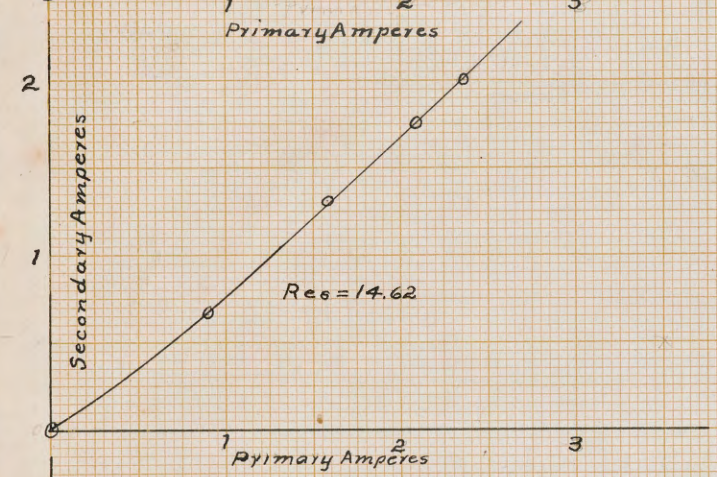

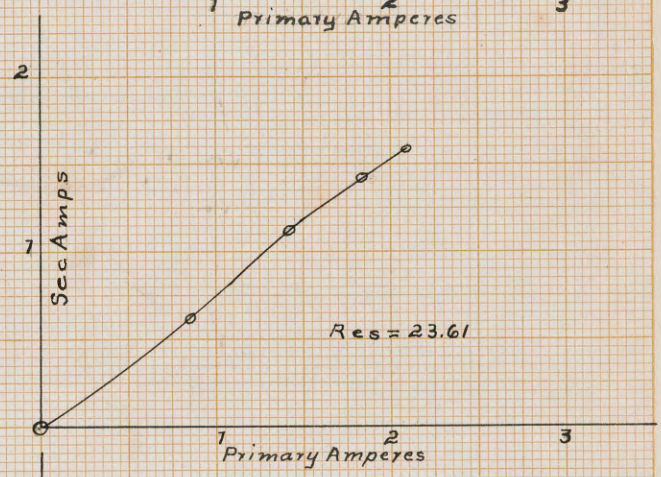

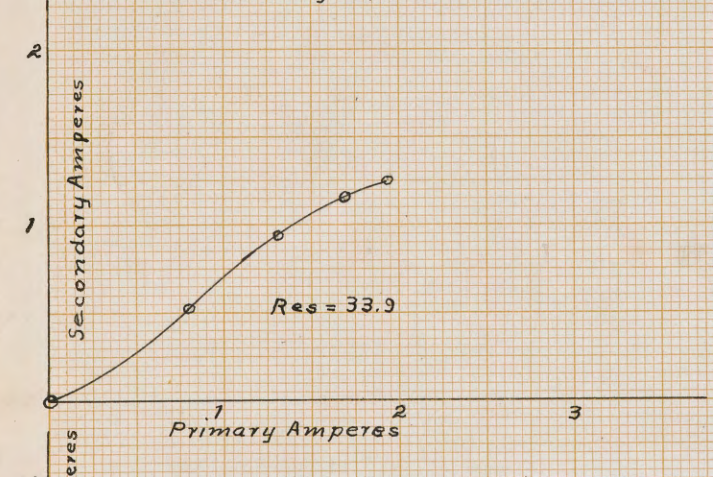

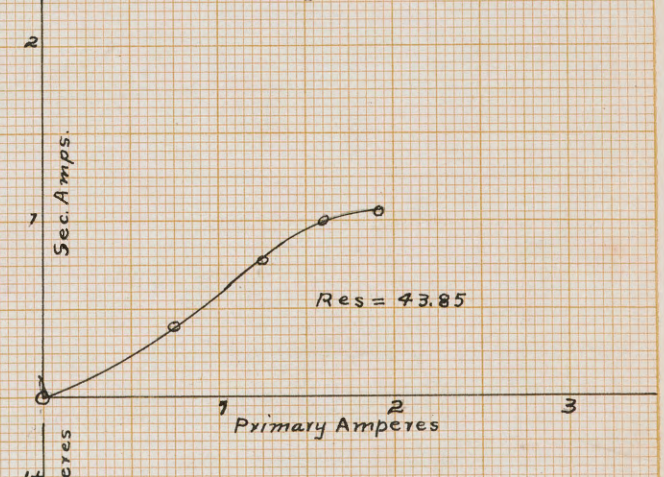

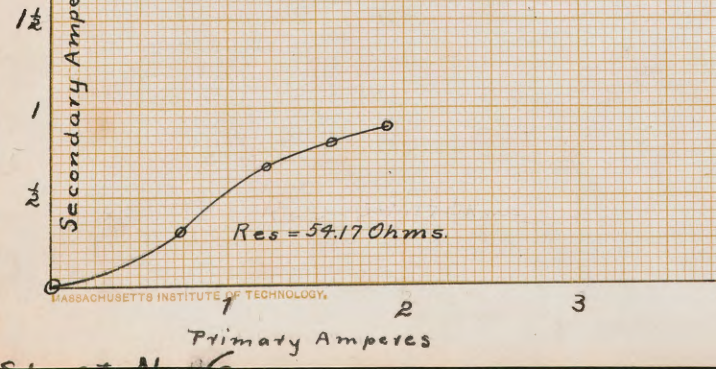

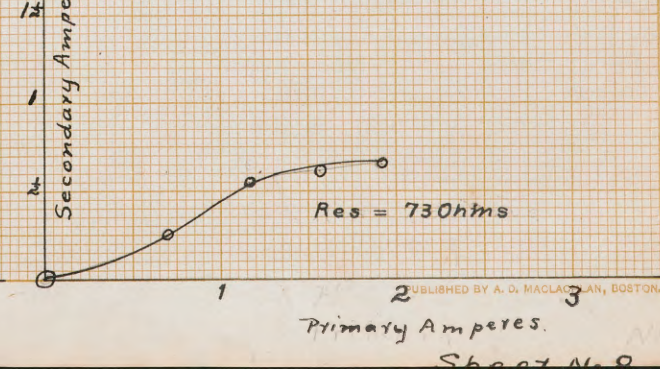

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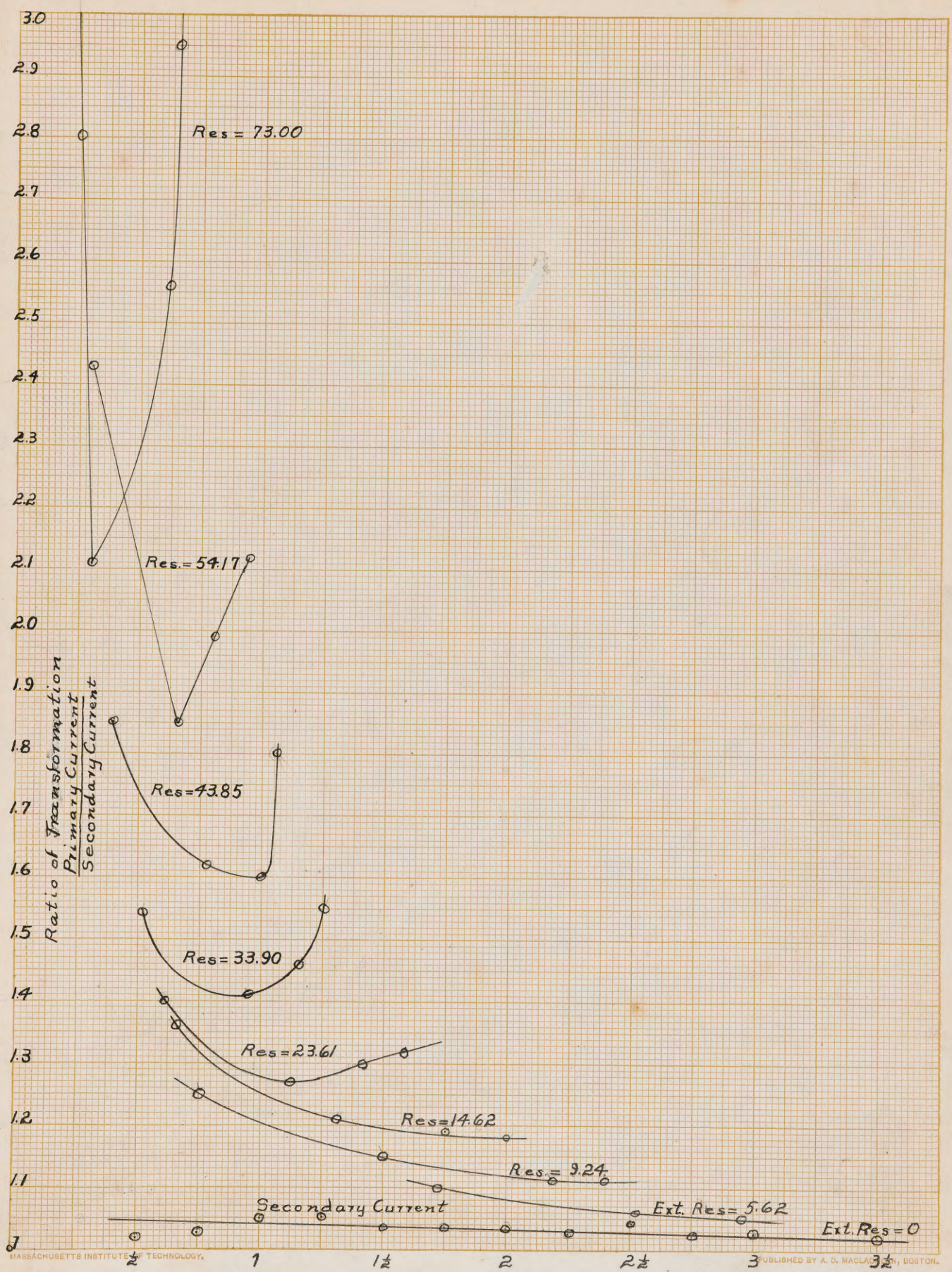

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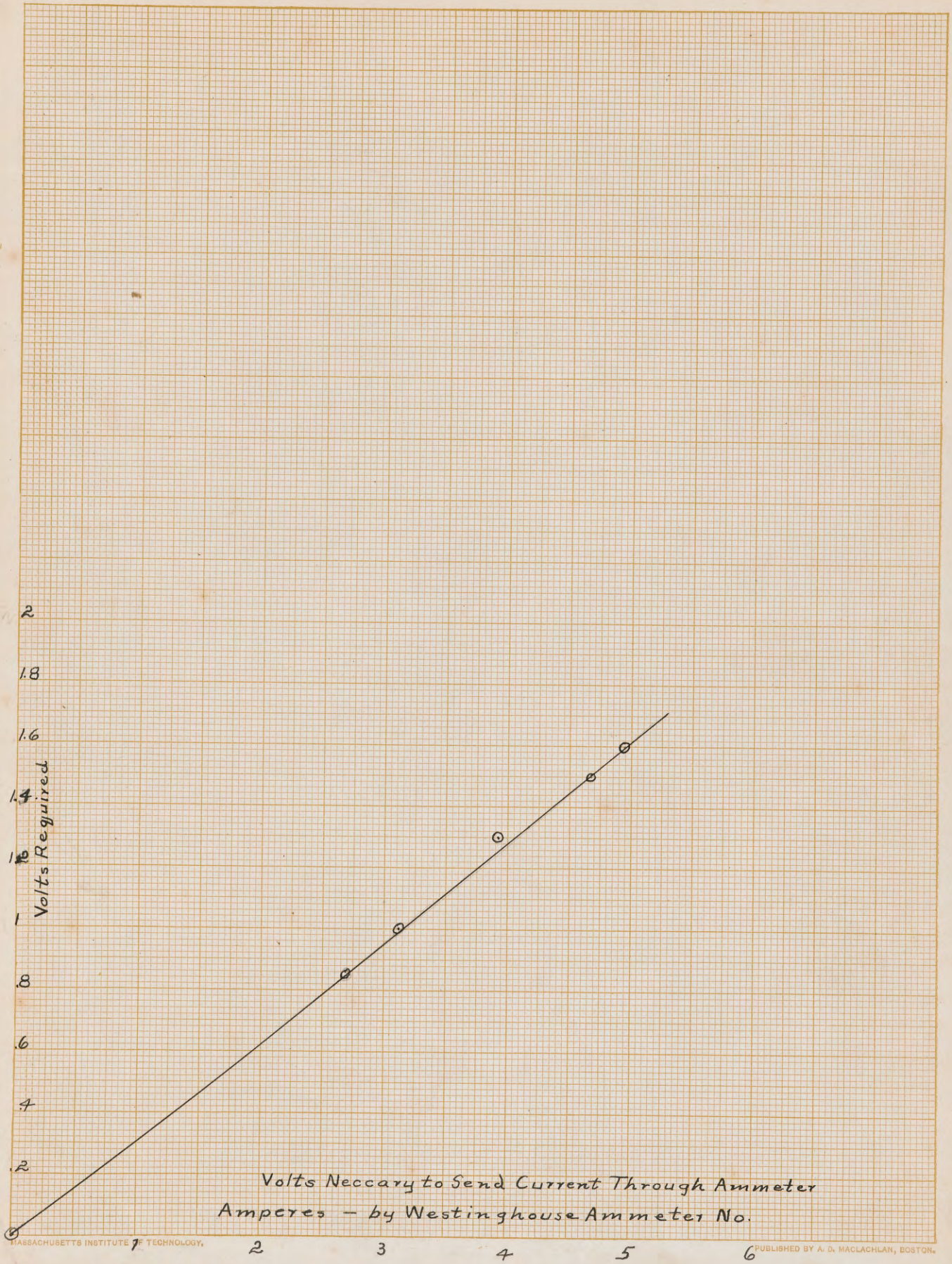

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