T H E S I S

COMPARISON TESTS ON A TWENTY KILO WATT WOOD MOTOR-GENERATOR SET.

by

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COMPARISON TESTS ON A TWENTY KILO WATT WOOD MOTOR-GENERATOR SET.

The purpose of the following tests has been to compare the indirect with the direct methods of testing. The methods used were those such as we have found described in recent copies of electric journals and will be more particularly described later. The first work was the adjustment and calibration of the instruments to be used in the tests. A water tachometer was used as a continuous speed indicator. The tachometer consists of a small centrifugal pump which was attached to the shaft of the machine whose speed was to be indicated. The pump delivered water to a graduated glass tube. The proper adjustment of the water column in the tube was obtained by attaching the tube to holes drilled in the pump at different distances from the center. The calibration of the tachometer is plate I.

Instruments were calibrated as follows:

Water Tachometer	Plate I.
Voltmeter No. 16901) Voltmeter No. 2909)	Plate II.
A.C.Ammeter No. 42221	Plate III.
A.C.Voltmeter No. 145086	Plate IV.
Ammeter No. 7864	Plate V.

The methods of calibration are indicated on the plates. The following instruments were calibrated and found to be practically correct.

Millivoltmeter No. 13962 to Botentiometer

Ammeter No. 2909 to Millivoltmeter No. 13962

Simplex Ammeter 0-10 to Millivoltmeter No. 13962

A.C.Voltmeter No. 140940 to D.C.Voltmeter

"Howe" (Elec. Lab.) Scales.

Next, a ten inch pulley was keyed to the end of the motor shaft and a wooden prony brake was constructed to fit it, the effective length of which was 23.25 inches.

Stray Power Losses of Motor.

The motor was disconnected from the generator, and the stray power losses of the motor were found, readings being taken of the field current, armature current and voltage applied to armature at a constant speed of 1800 R.P.M. (See Table I, also Plate VII.)

To determine the copper losses, the resistances of the field and armature respectively were measured, the latter both including and not including brush resistance. To determine the drop in voltage due to brush contact, the two sections of a brush were insulated from each other, a current passed through them, with the armature still and the armature running at various speeds.

At zero speed the drop between brush and armature is found to be about one tenth of a volt. It did not vary with different speeds, but for any speed was about two volts.

This was calculated from the equations. $E_1 = R\,I_1 + X$

$E_2 = R\,I_2 + X$

where X is the drop in voltage between brush and armature, and E, R, and I have their usual meaning.

Owing to the fact that the brushes were new and did not fit snugly to the commutator, it was impossible to determine the current density, but the results check up with an experiment conducted by Miles Walker (See Electric Journal, May 1907) who used a varying current density and found X = 1.9 at a density of 25 amperes. To run the motor without having a current in the armature, it was coupled to its alternator, which was connected to a rotary converter. The switch between the two machines was opened, the machines started up - the generator by means of its motor - and the two thrown into synchronism by regulating the speed of the rotary. The switch between the two machines was then closed, and at the same time the switch between the mains and the Wood motor was opened, and the generator was then running as a synchronous motor, receiving current from the rotary and driving the motor. The rotary was delivering current at sixty-eight volts and the alternator at one hundred ten. Either alternator would drive the other as a synchronous motor, and no perceptible change took place when the change occurred, though the alternator was adjuested for 110 volts and the rotary for 68. On account of this difference in E.M.F., the D.C. switch had to be opened on one machine the instant the A.C. switch was closed on the other.

Power Intake Method.

To determine the losses in the alternator due to hysteresis and eddy-currents, and friction and windage, the alternator was coupled to the motor and with the generator field excited the input of the motor was taken. The same was done with the generator field unexcited,

and again the input of the motor was taken with the alternator disconnected. The excess of input in the first two cases over the last case is due to the losses in the alternator. (See Table No. IV.) By this method the friction of the generator was found to be 319 Watts and the hysteresis 1850 Watts.

The above method is liable to error with these particular machines from the fact that the friction load of the alternator is such a small part of the losses of the motor. It is also liable to an error due to the inertia of the alternator. Several efforts were made before staisfactory results were obtained, because of changes in voltage. When the voltage dropped, the speed of the motor was reduced, and the generator ran ahead, helping to pull the motor. Then when the voltage was raised, the speed increased and part of the intake of the motor was used to overcome the inertia of the armatures. It was found that it was necessary to have the voltage stay constant within one volt to obtain satisfactory results.

The Dying-Down Method.

The following method was described by W.E.Sumpner in Vol. 48, page 621 of the "London Electrician". The machine was run at a certain speed, R, then allowed to slow down to another speed R_2, and the tume of same was observed by counting the ticks of a watch. The loss of Kinetic Energy due to the load ia $a(R_1^2 - R_2^2)$ where a is a constant depending upon the moment of inertia of the motor which may be shown as follows.

The K.E. of a rotating body is given by the equation,

$$K.E. = \frac{2\pi^2 R^2 I}{(60)^2}$$, where I is the moment of inertia of the revolving

mass and R is the number of revolutions per minute. Then the difference of K.E. for speed R_1 & R_2 is $\frac{2\pi^2 R_1^2}{(60)^2} \frac{I}{g} - \frac{2\pi^2 R_2^2}{(60)^2} \frac{I}{g}$

$$\frac{2\pi^2}{(60)^2} \frac{I}{g} (R_1^2 - R_2^2) \text{ or } A(R_1^2 - R_2^2)$$

The constant in the equation was determined electrically by applying a known load due to a current generated by the machine.

Let $\overline{W}$ = watts wasted, due to the machine losses, and

w = watts generated by the machine, we have then,

$$\overline{W} t = (\overline{W} + w) t_1 = a(R_1^2 - R_2^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where t is the time in seconds which it takes the machine to run down from R_1 to R2 with the hysteresis load on and t_1 the time to die down with a known additional load.

Solving equation (3) we have, $\overline{W}t = \frac{wtt_1}{t - t_1} = a(R_1^2 - R_2^2) \ldots (4)$

$$a = \frac{wtt_1}{(t - t_1)(R_1^2 - R_2^2)}$$

To determine the losses let T be the torque and assume that T varies very little with the speed (that is for values not exceeding 10% of R.) and R may be considered to vary uniformly

Then $2\pi T t \left(\frac{R_1 + R_2}{2}\right) = a(R_1^2 - R_2^2)$ $\quad T = \frac{a}{\pi t} (R_1 - R_2)$

$$\overline{W} = 2T\pi R = \frac{a}{\pi} (R_1 - R_2) R 2\pi$$

$$= 2 a R (R_1 - R_2)$$

But this is liable to some error, due to the fact that T is not constant and also that in small machines the time cannot be observed accurately enough as will be shown by the following example. The

machine was run at 1800 R.P.M. and allowed to die down to 1650 R.P.M. Several observations were made and the average was as follows: for friction load 9.20 seconds, for core and friction load, 2.19 seconds and with an additional known load of 2177 watts, the time was 1.10 seconds. From this data a is found to be .0082 and the friction loss 273 watts, and hysteresis and friction loss 1160 watts.

Since the time is liable to an error of one-fifth of a second, this method is liable to a large error as may be seen by the following:

$$a = \frac{wtt_1}{(t-t_1)(R_1^2-R_2^2)}, \text{ or substituting } t = 2_119,\ t_1 = 11$$

$$= \frac{w(2.19)(1.1)}{(2.19-1.1)(R_1^2-R_2^2)} \text{ from which we may see by inspection}$$

that an error of one fifth of a second in t_1 will induce an error of about 35% in a.

The Brake Method.

The motor was coupled to the alternator and the input to the motor was noted with the friction, hysteresis, and variouss measured electrical loads on the alternator. Then the alternator was disconnected and by means of the brake, the motor was loaded to exactly the same intake currents and voltage as had been observed before the alternator was disconnected. Then by meaduring the power absorbed by the brake, the previous inputs to the alternator were determined. In this way the inaccuracy of the electrical instruments and the calculations of brush and $R I^2$ losses were avoided. This method also furnishes a direct means of determining the efficiency both of the alternator and the motor. (See Table III). The three phases of the

alternator were loaded with rheostats which were adjusted to give nearly balanced loads on the three phases. Owing to the fact that we had no ammeter of sufficient capacity to read the entire current, two series transformers with ratio of turns 20 to 1 were used, and switches inserted so that the current in each of the three legs could be read with one ammeter. (See Plate __ for connections.)

To avoid the determination of the tare of the brake in most of the calculations, a small initial load was put on the brake and kept constant throughout the entire test. (See Table No. 111).

Table I.

Stray Power Losses of Motor.

Speed 1800.

Ia	RI_a^2	Brush	input $EI+RI^2$	Total Loss	Out put	% Effic.
40	5.6	80	4615	2210	2404	52.2
118	487.	236	13005	2848	10157	78.0
140	685.	280	15525	3090	12435	80.2
165	951.	330	18025	3406	14619	81.2
175	1070.	350.	19125.	3545	15580	81.7
190	1260.	380	20725	3765	16960	82.0
210	1538.	420	23925	4083	18842	83.2
230	1850.	460	25025	4435	20590	82.

Constant field loss 325 watts.

Constant core and friction loss 1800 watts.

To determine the Core and Friction loss the motor was run at no load and the input was found to be 16.5 amperes at 108.65 volts, which gives core and friction loss equal to 1800 watts.

The field resistance was calculated from an experiment where Ef = 93, and It 3.3, giving a resistance of 28.2.

It might be possible to do this, leaving the motor attached to the A.C. machine – if necessary, have a fly wheel also attached.

Would it be possible to apply a very small negative load instead of + load?

Table II.

Data for Drop in Brushes.

Voltmeter No. 16901

Ammeter No. 823

No.	Amperes	Volts	Speed	Resistance	Contact Drop	Remarks
1	16	20/30	0	.0345(No.1&6)	.12	
2	24	29/30	0	.0357(1&2)	.15	
3	27.5	33/30	0	.0380(2&3)	.14	
4	16.5	21/30	0	.0333(4&5)	.12	
5	29.5	34/30	0	.0350	.11	This Resistance
6	30.5	35/30	0	.0350	.17	is the average
7	16	80/30	1225	.0350	2.2	of the above
8	25	85/30	1225	.0350	2.0	values and is
9	27.9	90/30	1225	.0350	2.3	used during the
10	16	75/30	1150	.0350	1.9	rest of the ex-
11	16	77/30	1075	.0350	1.9	periment.
12	24	85/30	1075	.0350	2.0	
13	35	91/30	1075	.0350	1.9	

The Resistance and Contact Drop were calculated from the following equations:

$$E_1 = R I_1 + x$$

$$E_2 = R I_2 + x$$

where R is the resistance of the armature and x is the contact drop.

Table III.

Brake Test of D. C. Motor.

No.	Amp.	Volts.	# Brake lbs.	Initial Brake Load	Load	Input	Output	Effic.
1	28.8	115	0	1700	0	3210	1700	55
2	47.3	116	3.75	1700	1858	5487	3558	65
3	103.6	116.5	16.00	1700	7926	12069	9626	79.5
4	113	116	18.00	1700	8918	13108	10718	80.5
5	155.9	116	27.25	1700	13500	18200	15200	83.5
6	169.9	116	31.00	1700	15358	19800	17058	86.5
7	204	116	38.00	1700	18826	24128	20526	84.5

#The column marked "Brake lbs." is the brake readings in excess of the tare.

Table IV.

Hysteresis and Friction Loss of Alternator

by Motor Intake Method.

I a	E a	Input	Remarks.
43.5	111	4828	Field off Alternator on
26.5	110.5	2928	Field of Alternator off
23.6	110.5	2603	Alternator disconnected

Hysteresis = 1858 (corrected for R I and Brush Drop.)

Friction = 319(corrected for Brush Drop.)

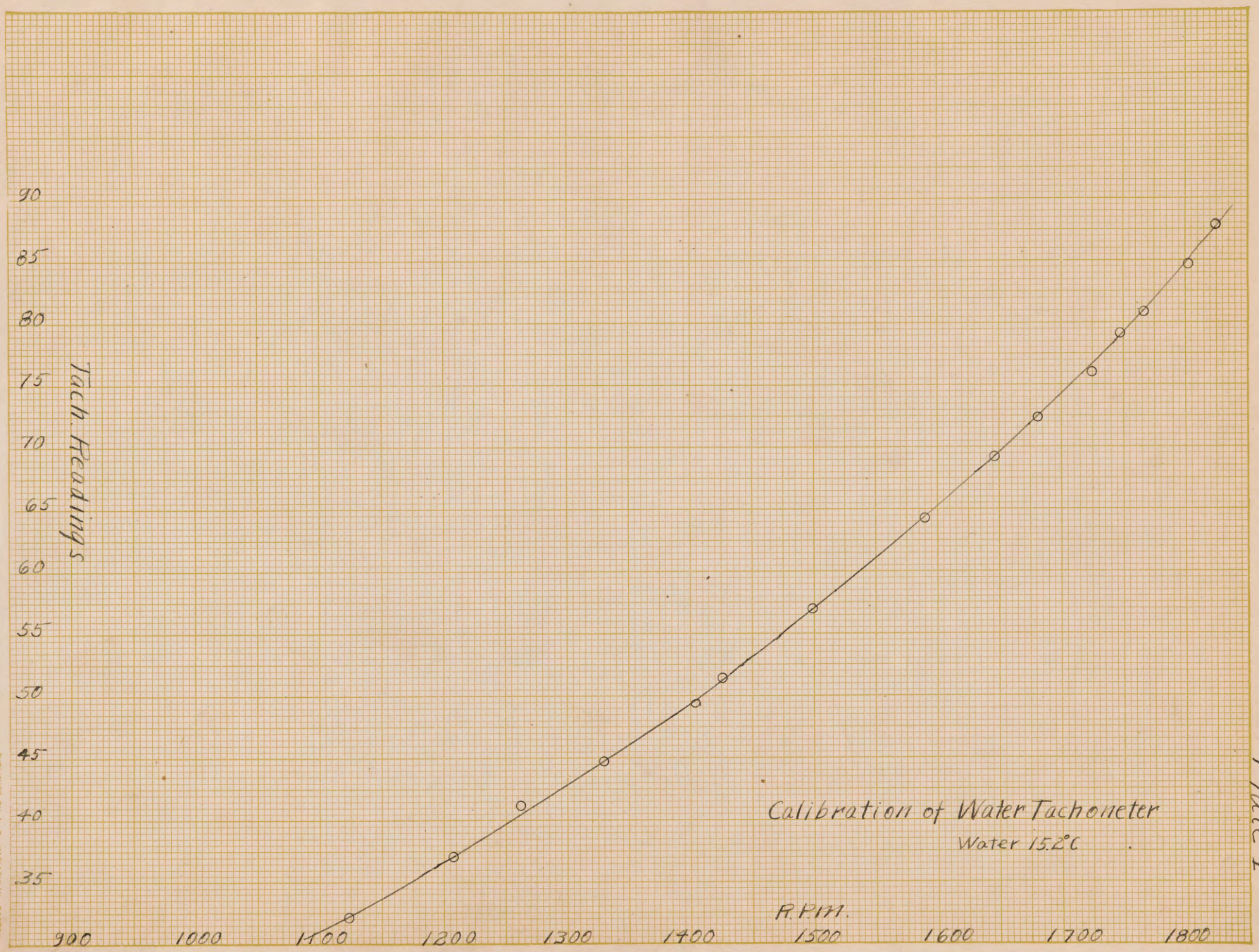


Plate I

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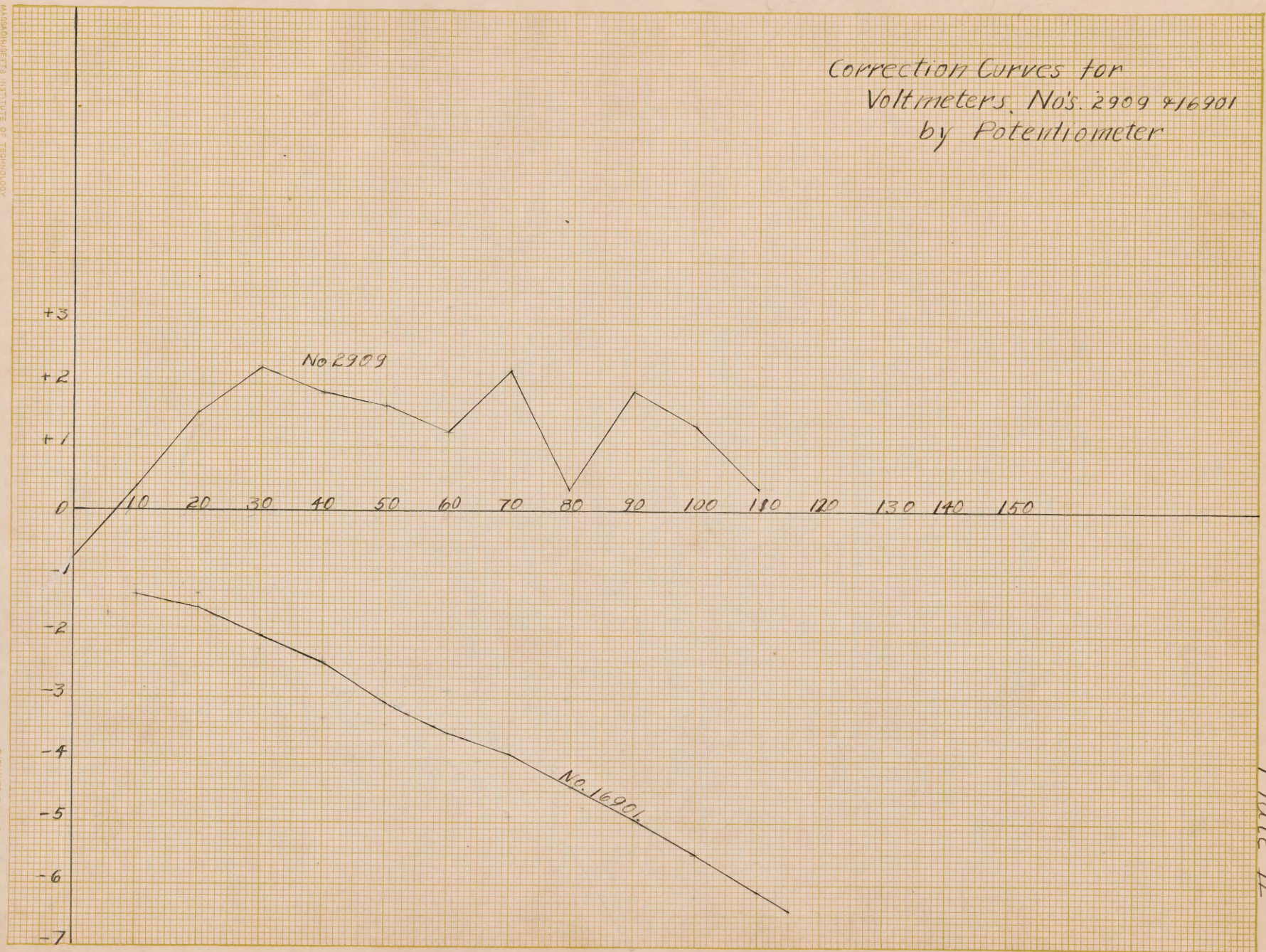
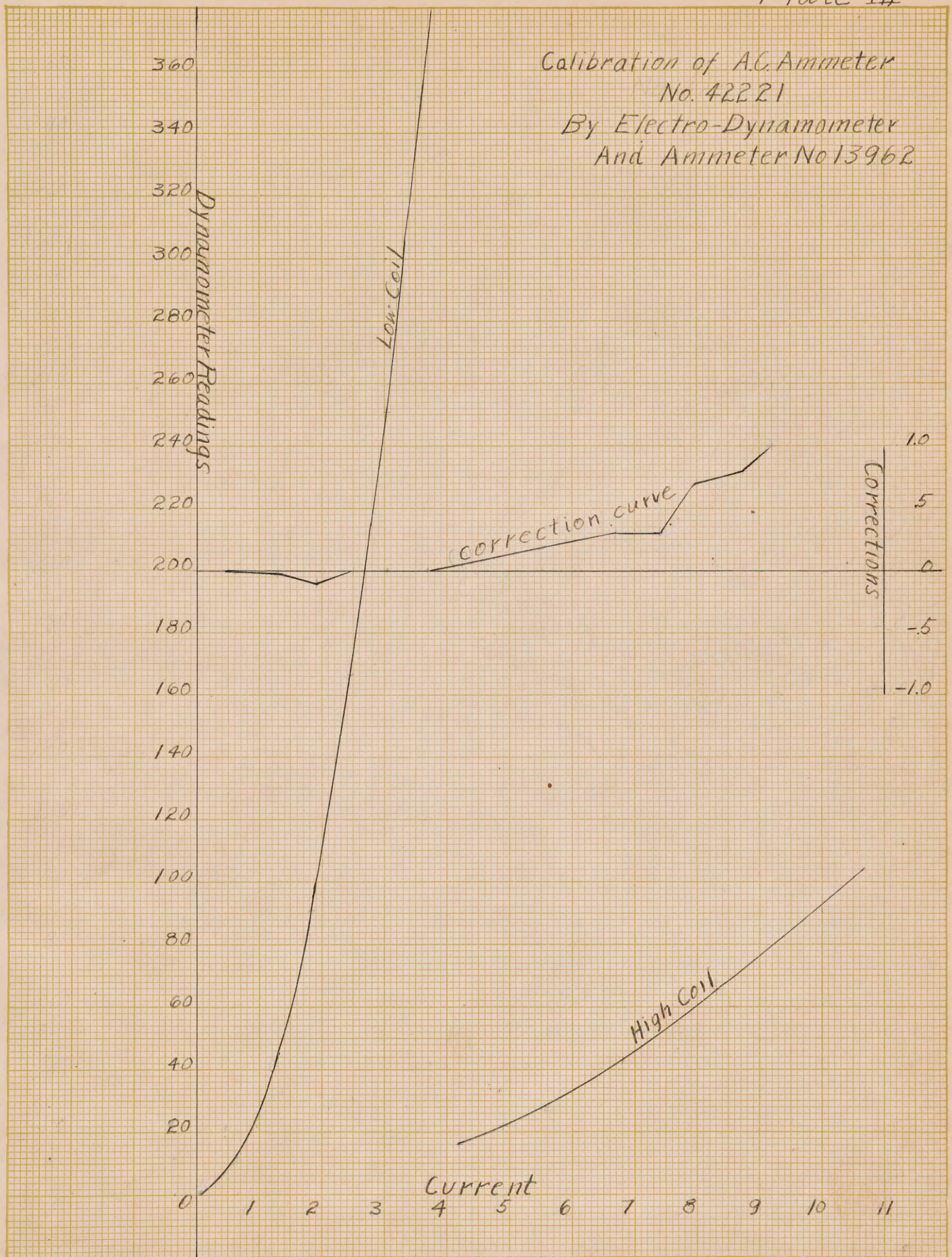


Plate II

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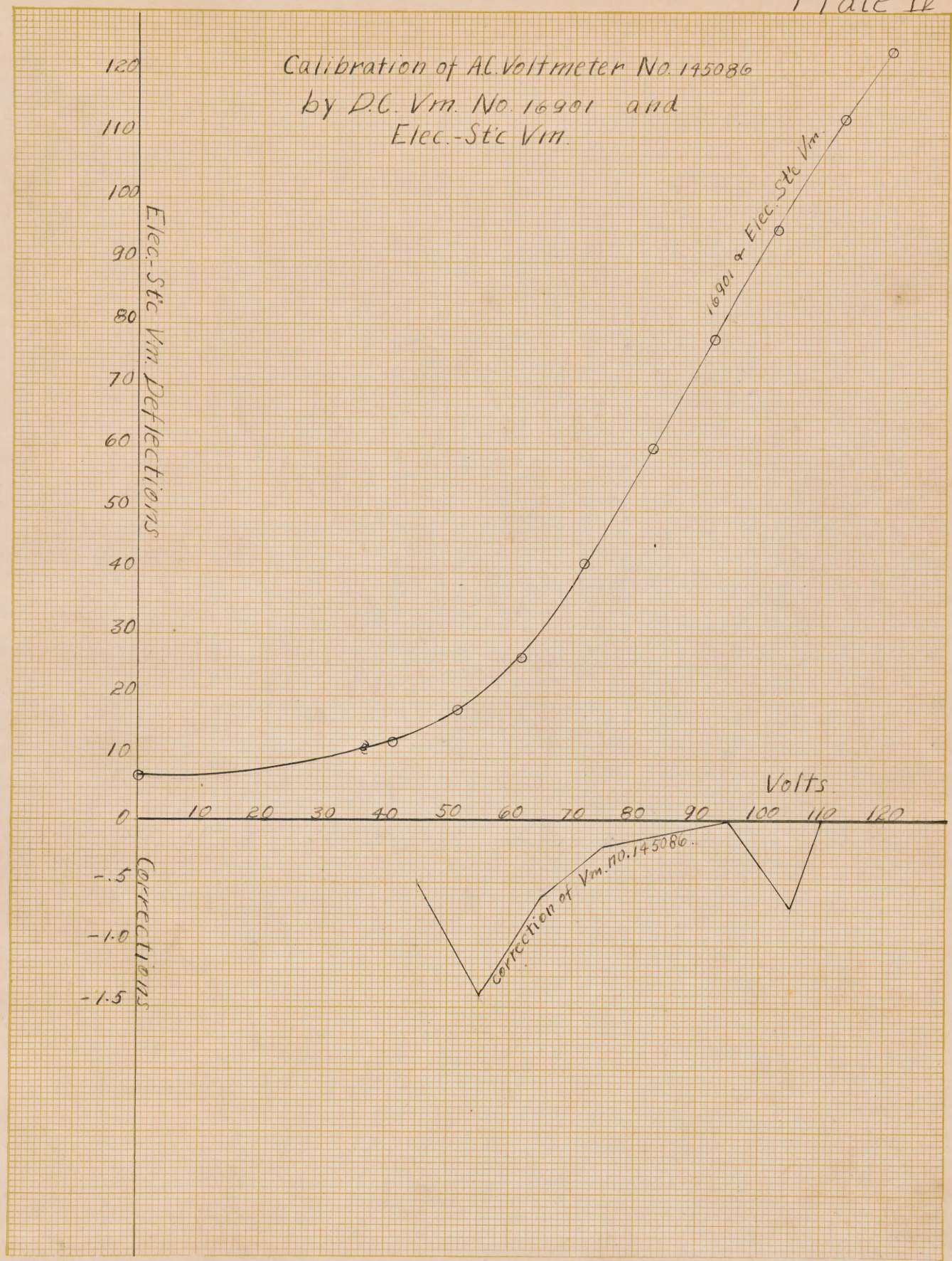
Plate III



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Plate IV



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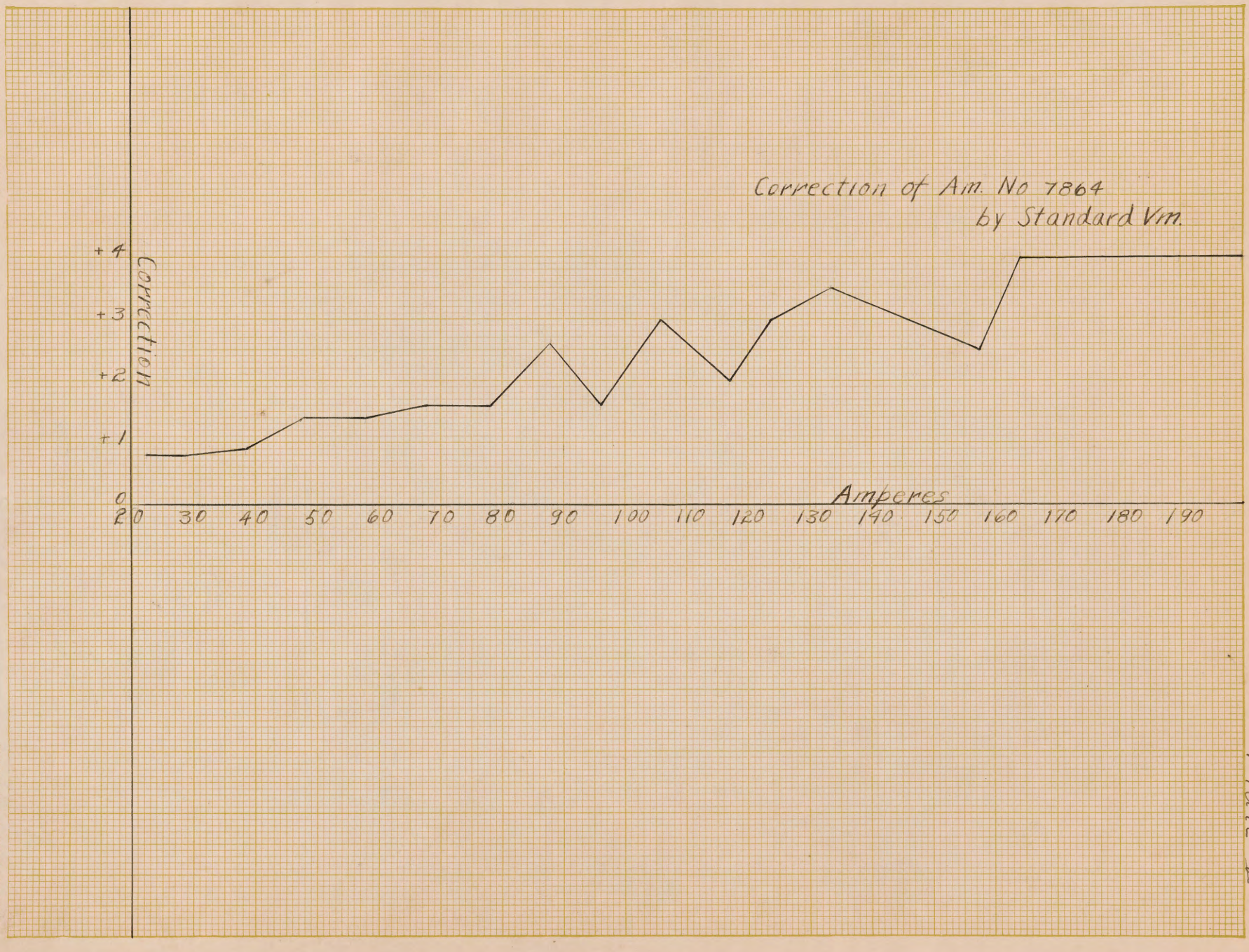
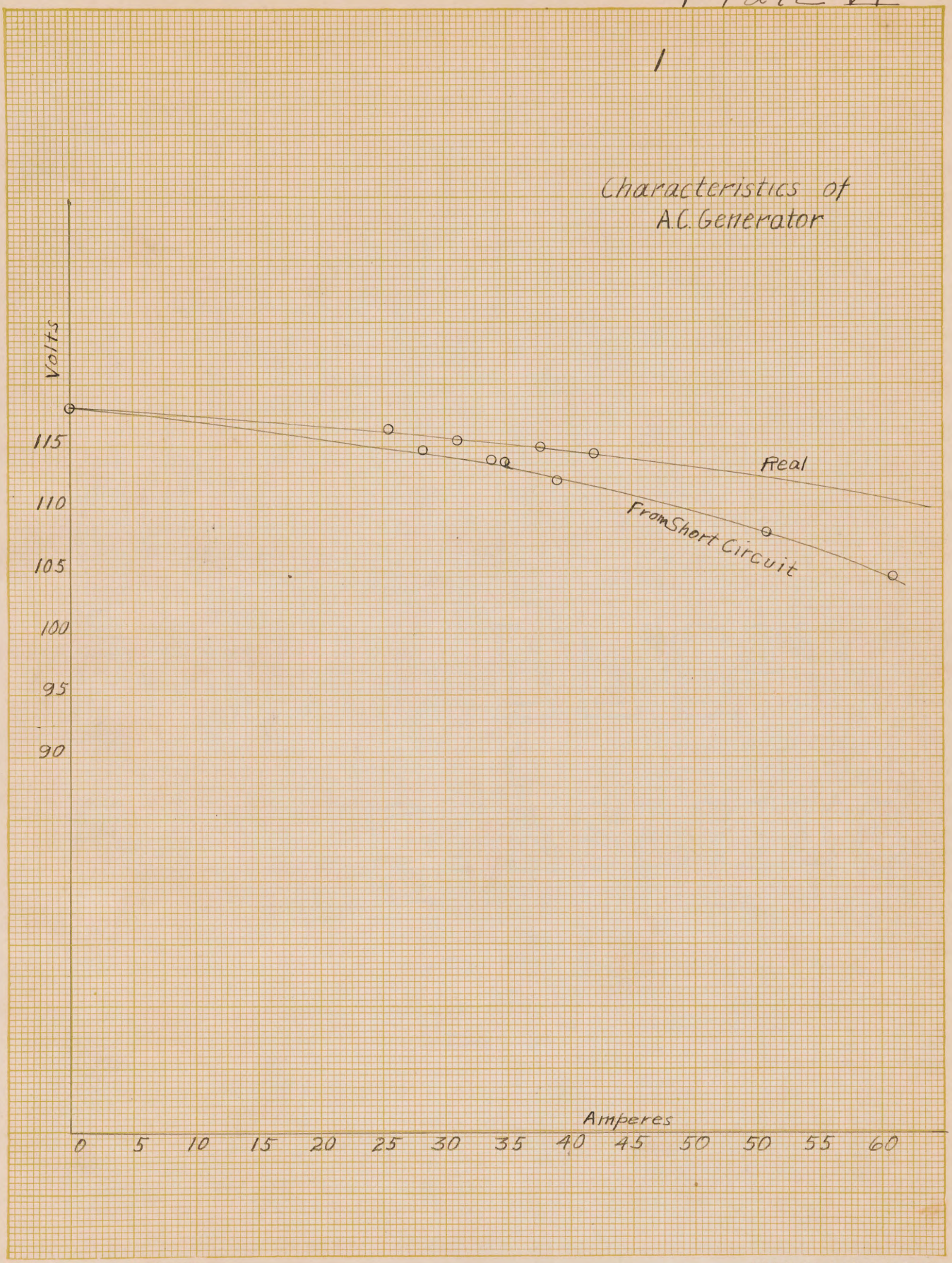


Plate V

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Plate VI

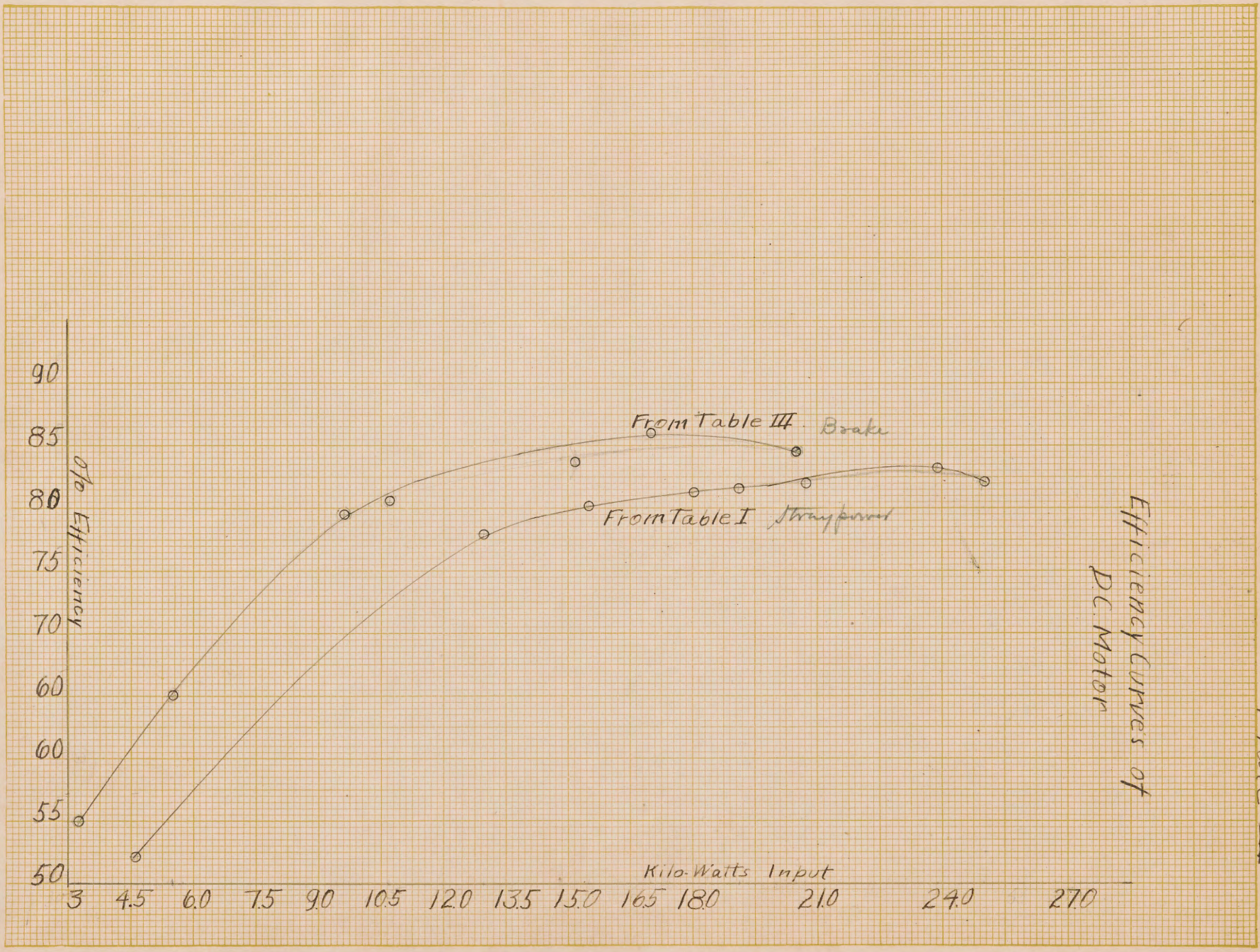
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Efficiency Curves of D.C. Motor

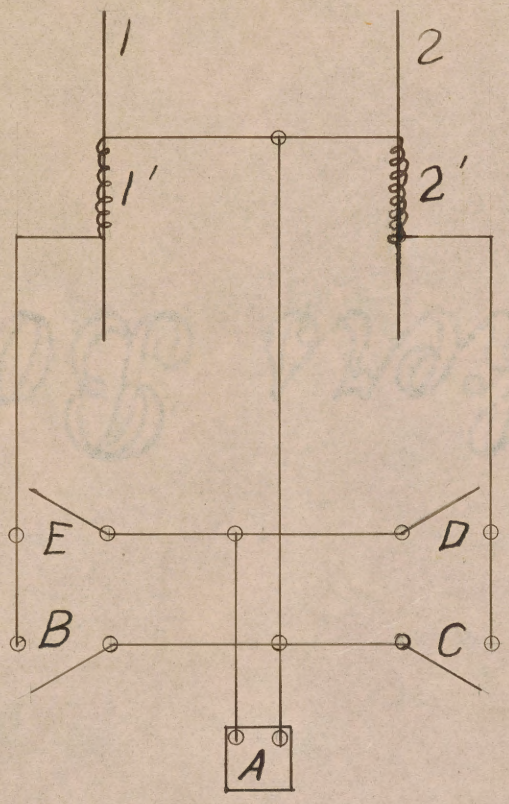
Plate VII

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Draw a curve between
2 & 3 (total drop.) -
this R, is not the res. of arma-
ture as stated, but the constant
part of brush res. while x is
the part $\propto \frac{1}{I}$

PLATE VIII

Connections for Reading Current in Three-Phase Circuit



1 + 2 are legs of a 3-Phase circuit

1' + 2' are series transformers

A is an ammeter

To read current in leg 1 C + E, are closed

To read current in leg 2 B + D are Closed

To read current in leg 3 B + C are closed