

THESIS

TEST OF A 20 K.W.D.C. EDISON GENERATOR

For the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

Under

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By

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1912

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The machine tested is located in the Mechanical building of the University of Tennessee. It is driven by a 35 H.P. straight-line engine belt connected. It is an old type of generator and is only used in cases of breakdowns or other emergencies.

The rating of the generator is as follows:--20 K.W. delivering 160 amperes at 125 volts, running at the speed of 1500 R.P.M. The type of machine is bipole, shunt wound field, smooth drum wound armature simplex winding. The following is a table of dimensions:

	Area sq. in.	Volume cu. in.
Field core $9\frac{1}{4}$ ", diam. $14\frac{1}{4}$ " long	67.20	1915 two pieces
Yoke $7\frac{1}{2}$ " x $9\frac{1}{2}$ " x $24\frac{1}{4}$ " long	71.25	1740
Pole face piece 9" x 15" x 9"	135.00	24300 two pieces
Armature core $\frac{61}{64}$ ", diam 15" long	119.25	754
Commutator and shaft		196
Bearings		691

7726 Total

Part	Volume	Weight
Field core	1915	498 lbs
Yoke	1740	453
Pole face piece	2430	623
Armature core	754	196
Commutator and shaft	196	51
Bearings	691	179
Armature winding		30
Field winding		222

2261 Total

The following is a list of instruments used on the test:

Instrument.	Maker's No.	Range.
Simplex D.C. voltmeter		0 to 150
Standard millivoltmeter	669	0 " 240
Millivoltmeter No. I	7864	0 " 200
Keystone D.C. ammeter	11508	0 " 10

All instruments used on this test were calibrated by me.

The tests made were as follows:

1. Heat run
2. Amount of armature reaction
3. Flux density in field and armature
4. Saturation curve
5. Weight per K.W. output
6. Size of conductors in circular mils per ampere in field and armature.

The standard millivoltmeter was calibrated by comparing it with the potentiometer and a table of errors made out. From this a curve of corrections was plotted.

Potentiometer	Standard Millimeter	Error	:	Potentometer	Standard Millimeter	Error
115.61	114.7	-.91	:	92.36	91.55	-.81
113.47	112.6	-.87	:	90.22	89.50	-.72
111.31	110.5	-.81	:	88.17	87.50	-.67
109.20	108.4	-.80	:	86.07	85.40	-.67
107.10	106.2	-.80	:	83.99	83.35	-.64
104.97	104.0	-.97	:	81.95	81.30	-.65
102.87	102.0	-.87	:	79.90	79.35	-.55
100.79	99.9	-.88	:	77.84	77.25	-.59
98.70	97.7	-1.00	:	75.75	75.25	-.50
94.44	93.65	-.79	:	73.69	73.15	-.54

The simplex voltmeter was connected in parallel with the standard and a series of pressures were applied and the reading of each instrument taken. By means of the correction curve we got the true values of the voltages from the standard and made out a table of errors for the simplex voltmeter. From this a correction curve was plotted.

Standard	Corrected Standard	Simplex	Error	:	Standard	Corrected Standard	Simplex	Error
77.4	77.98	77.90	-.08	:	110.80	111.62	112.70	+1.08
85.4	86.07	86.00	-.07	:	113.50	114.38	115.50	+1.12
95.2	96.07	95.50	-.57	:	114.40	115.30	116.20	+ .90
97.3	98.28	98.10	-.18	:	117.8	118.75	119.50	+ .85
99.4	100.32	100.60	+.28	:	101.3	102.18	102.70	+ .52
103.3	104.23	104.90	+.67	:	105.4	106.33	107.0	+ .67
86				:				

The millivoltmeter No. I, was calibrated by comparison with the potentiometer and the shunt was examined. From the calibration of the millivoltmeter we plotted a correction curve which was to be used with the instrument when used as an ammeter. When the millivoltmeter is used as a millivoltmeter the readings must be multiplied by 5 to get the correct value, but when it is used with its shunt as an ammeter, the scale is all right. Therefore, the potentiometer readings must be multiplied by .2 in order that the millivoltmeter readings may be compared with them and the error of the instrument as an ammeter obtained.

Potentiometer:	Potent X.2:	Millivoltmeter	Reduced to amperes		
:	:	:	Potent X.2:	Millivoltmeter:	Error.
:	:	:	:	:	:
.00895	.00179	.00840	1.79	1.68	-.11
.01408	.00282	.01360	2.82	2.72	-.10
.01911	.00382	.01880	3.82	3.76	-.06
.02410	.00482	.02390	4.82	4.78	-.04
.02710	.00542	.02695	5.42	5.39	-.04
.03207	.00641	.03195	6.41	6.39	-.02
.03810	.00762	.03820	7.62	7.64	+.02
.04512	.00902	.04530	9.02	9.06	+.04
.050101	.01002	.05040	10.02	10.08	+.06
.05512	.01102	.05555	11.02	11.11	+.09
.06608	.01322	.06675	13.22	13.35	+.13
.07695	.01539	.07790	15.39	15.58	+.19
.08782	.01756	.08905	17.56	17.81	+.25
.09807	.01961	.09960	19.61	19.92	+.31

The Keystone ammeter was calibrated by connecting it in series with millivoltmeter No. I and its shunt. By recording the readings of each instrument and correcting the millivoltmeter with its correction curve we can get the error of the Keystone ammeter and plot its correction curve.

Milli V	Milli V Corrected	Keystone	Error	:	Milli V	Milli V Corrected	Keystone	Error
.40	.52	.48	-.04	:	2.95	3.04	3.10	+.06
.74	.86	.80	-.06	:	3.80	3.86	4.00	+.14
.93	1.05	1.00	-.05	:	4.20	4.25	4.40	+.15
1.40	1.52	1.54	+.02	:	4.60	4.64	4.80	+.16
1.80	1.91	1.95	+.04	:	4.80	4.84	5.00	+.16
2.35	2.46	2.50	+.04	:	5.80	5.83	6.00	+.17

The *heat* run was made to see how much the temperature of the fields and other parts of the generator would rise when the machine was run at full load until the temperature became constant. Then the machine was run at as much overload as possible and the rise in temperature was noted. From the Proceedings of the American Institute of Electrical Engineers, we see that a rise of 50°C is allowed in the field and armature while a rise of 55°C is allowable in the commutator.

The machine was started at 8:15 p.m. with the armature and field temperature of 23.6°C . The load was applied somewhat gradually owing to the fact that we were running the head run on two generators at the same time and the lighting and idle *shop* load were not enough to load both machines. Therefore, rheostats were connected to the lines to absorb the remaining power. At the end of six hours the temperature had become constant for full load. The field temperature being 42.2°C , giving a rise of 18.6°C . This is well within the limit of the allowable rise, not taking into account the rise of the temperature of the room. The

room temperature rose from 23.6°C to 28.3°C or 4.7°C . Fifty per cent of the room temperature rise is added to the allowable rise of any part of the machine, thus making the allowable rise of temperature 52.35°C for the field and armature and 57.35°C for the commutator for these conditions. For the over load run the armature temperature rise was 50.0°C , field 21.6°C and the commutator 52.5°C , all of which are allowable.

Time	Field Temp	Volts	Amperes	:	Time	Field Temp.	Volts.	Amp.
8-15	23.6°	0	0	:	12-15	40.8	116	144
8-35	25.3	106	27	:	12-25	41.1	114	150
9-00	27.1	102	64	:	12-45	41.7	115	146
9-15	28.6	112	90	:	1-00	41.7	115	160
9-45	30.0	129	44	:	1-20	42.2	115	170
10-00	31.5	128	66	:	1-40	42.2	113	175
10-20	32.9	125	85	:	1-50	42.2	110	175
10-40	33.9	126	86	:	2-00	43.6	120	196
11-20	38.8	130	48	:	2-15	44.4	120	196
11-35	38.9	126	80	:	2-30	45.3	120	197
11-50	39.7	124	78	:	2-45	45.6	120	196
				:	3-00	45.6	120	196
				:	3-15	46.6	120	196

It is seen from the heat run curve that we ran the machine only at 3.50 K.W. or 17.5% over load. This was as high as we could go under existing conditions.

By armature reaction, we mean the amount the field flux is *distorted* distributed or shifted over by the reaction of the current flowing in the conductors of the armature.

The machine was run at no load and the central position of no sparking was marked. Then the machine was loaded to full load and the central position of no sparking marked. Again the load was taken off and the central position of no sparking was found to be the same as at first. The angle between these two *marks* ~~machines~~ is the amount the flux is distorted. The brushes had to be ^{*h*}sifted one-fourth of an inch on a circle six inches in diameter, giving an angle of $4^{\circ}-46'-28''$. The *pilot* brush method was also tried and it gave approximately the same angle. This method consists of connecting one terminal of a voltmeter to one brush and the other terminal to a steel pen which was moved along the commutator bars till the voltmeter read a maximum at no load. Then the load was applied and the pen shifted till the voltmeter again read a maximum giving the required angle.

The voltmeter will read a maximum when the pen is on the commutator bar which is connected to the armature conductor cutting the flux of maximum density. Therefore, when the field is distorted the position of this armature conductor is shifted through the same angle that the flux is ^{*h*}sifted.

To get the flux density in the armature we ran the machine on no load with the field excited by some external source and recorded the speed and voltage between the brushes. This voltage was the voltage generated in the armature since the armature current was practically zero.

The fundamental equation of the D.C. generator is

$$E_a = \frac{p \phi Z N}{p' \times 10^8}; \quad \phi = \text{flux passing from one pole to the armature.}$$

z - the number of conductors on the outside of the armature.

n = number of revolutions of armature per sec.

p' = the number of electrical paths in parallel between brushes.

Knowing the area of the longitudinal section of the armature we can get the flux density in the armature. To get the flux density in the field, we must first determine the ratio of the flux treading the field core to the flux entering the armature. This required a galvanometer, or some other instrument which would record a low voltage, of very slow period of vibration. The period of vibration must be long in comparison with the time required for the field to establish itself, in order that the field may have the maximum effect in throwing the needle. By putting weight on the disc in a galvanometer we succeeded in making the period of vibration considerably longer than the time required for the field to establish itself.

Winding a single turn of fine wire around the pole and putting about 500 ohms resistance in series with the galvanometer, we sent a current equal to the field current at nominal voltage, no load, through the field and recorded the deflections. Then breaking the circuit, we recorded the deflection caused by the collapsing of the lines of force.

See Table II, Page 9

A turn of wire was then put around the armature half way between the poles so that it would cut all the flux entering the armature and the above process was repeated. The ratio of the flux going through the field to that going through the armature was 1.50. If this ratio is correct, by winding four turns of wire around the field and six turns

around the armature in the opposite direction and connecting them in series, the galvanometer should give no deflection. We made this test and obtained the results as tabulated in Table II.

-I-

One Turn Around Field Make	Field Break	Average	One Turn Around Armature Make	Armature Break	Average.
5.00	5.80	5.40	3.20	4.00	3.60
5.00	5.80	5.40	3.20	4.00	3.60
5.00	5.80	5.40	3.20	4.00	3.60

$$\text{Ratio} = \frac{5.40}{3.60} = 1.50$$

-II-

4 Turns on Field. Make	6 on Armature Break	Average	4 Turns on Field Make	7 on Armature Break	Average.
.5 to left	.6 to right	.55	2.7 to rt.	3.2 to L	2.95
.5 " "	.6 " "	.55	2.7 " "	3.2 " "	2.95
.5 " "	.6 " "	.55	2.7 " "	3.2 " "	2.95

From Table II, it is seen that we did not have enough turns on the armature to neutralize the field turns. Since one turn more on the armature make on break 3.8 cm difference in deflection, and we needed only a difference of .6 cm, we ought to have 6-6/38 turns on armature to four on the field. This is equivalent to 23 turns on armature to 15 on field.

A test was made with this ratio of turns and the following results obtained.

15 Turns on Field 23 or Armature:	:	15 Turns on Field 24 or Armature
	:	

Break	Break
.3 am to right	2.6 am to left
.3 " " "	2.6 " " "
.3 " " "	2.6 " " "

From the above it is seen that we need more turns on the armature to neutralize the field turns, and that the ratio of armature turns to field turns should be 23.1 to 15. Therefore, the ratio of the flux in the field to the flux in the armature is:

$$\frac{23.1}{15} = 1.54$$

Knowing the flux in the armature and this ratio we can get the flux in the field. By dividing the flux by the area we get the flux density in each.

The generator was run at 1500 R.P.M. and developed a voltage of 120.5 volts. The values of the other factors of the fundamental equation have the values as follows:

$$p = 2$$

$$z = 132$$

$$n = 25$$

$$p' = 2$$

ϕ was found to have the value 3651000

Area of longitudinal section of the armature core is 74.5 square inches making allowance for laminations and shaft. Therefore, the flux density in the armature is 49000 lines per square inch.

From the ratio of the flux in the field to the flux in the armature, we get the flux in the field to be 5622000 lines.

Part	Area Sq. In.	Flux Density Lines <i>per</i> Sq. In.
Pole face	135	41640
Field core	667.2	83660
Yoke	68.8	78000

The magnetization or saturation curve shows the relation between the magnetizing current and the corresponding pressure generated in the armature the speed being constant. Since the speed is kept constant, the voltage generated in the armature varies directly as the flux, for the number of conductors cutting the flux is constant. Great care was exercised in increasing the field current not to exceed the value for which the pressure was taken, on account of the hysteresis effect of the iron. Care was taken not to break the field current while it was greater than one ampere for fear of puncturing the insulation.

A rheostat was put in series with the field to vary the current and an ammeter to measure the current. A voltmeter was connected across the terminals of the armature. The field current was increased by small steps and the corresponding pressure taken and a curve plotted.

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Volts	Current	Speed	Volts	Current	Speed.
56.08	1.09	1502	101.75	2.22	1499
65.08	1.11	1502	109.58	2.46	1499
75.58	1.40	1500	115.05	2.64	1503
84.08	1.67	1500	119.67	2.80	1503
90.50	1.88	1500	127.00	3.12	1498
97.37	2.08	1500	129.50	3.34	1498

The variation in speed is very small and can be accounted for by the error in reading. The above data have been corrected by calibration curves.

The weight of the machine was obtained by measuring all the active parts of the machine and computing the volume. In finding the weight one cubic inch of iron is assumed to weigh .26 pounds. The weight of the wire on the field and armature was added to the weight of the frame, making a total weight of 2261 pounds. Some of the parts such as shaft, commutator and armature core were not made of cast iron. The greater density of these is approximately balanced by the air spaces and insulations.

The generator is a 20 K.W. machine and weighs 113 pounds per K.W. output.

The field winding consists of 111 pounds of No. 14 Birmingham gage wire and 111 pounds of No. 15, Birmingham gage wire.

The cross section of No. 14, Birmingham wire gage wire is 6889 circular mils and of No. 15 Birmingham wire gage wire is 5184 circular mils. The field current at normal voltage is 2.8 amperes which give .000406 amperes per circular mils for the No. 14 wire and .00054 amperes per circular mil for the No. 15 wire.

On the armature there are two paths in parallel between the brushes. Each path is composed of six strands of No. 14 Birmingham wire thus making 12 wires in parallel to carry the current. The full load current is 160 amperes. Therefore each wire carries 13.3 amperes, making .00193 amperes per circular mil.

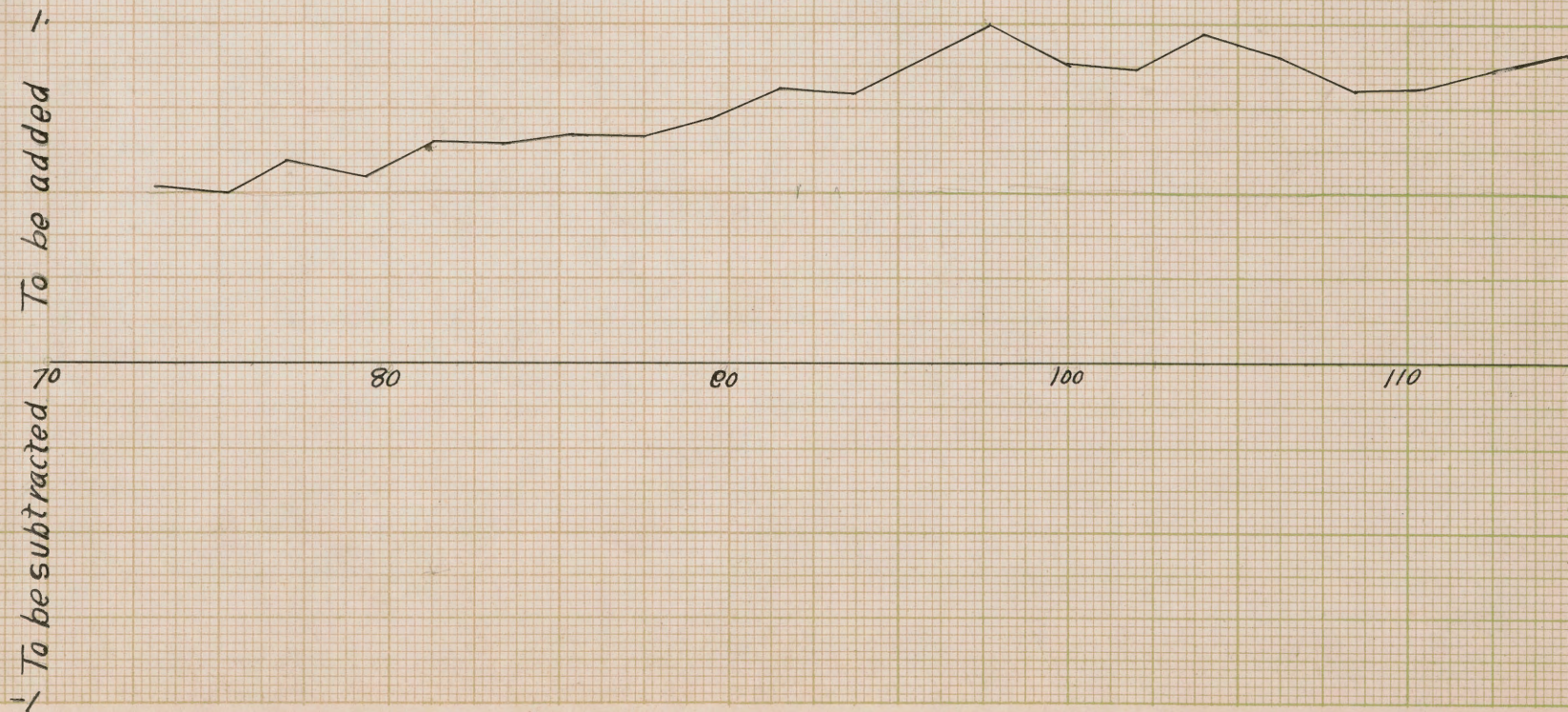
There were similar test runs on two other generators and the results are tabulated and compared with these results below. The other machines were a 50 K.W.D.C. generator built by the General Electric Company and a 25 K.W. Thompson Ryan D.C. Generator.

Part	Edison.		Thompson Ryan.		General Electric.	
	Flux Dens- ity	Current Density	Flux Dens- ity	Current Density	Flux Dens- ity	Current Density
	Lines per Amp sq. in per circu. mil					
Field core	83660				124000	
Yoke	78000					
Pole face	41640					
Armature teeth					134000	
Armature core	49000				118000	
Field wire large shunt		.000406		.000919		.00110
Field wire small shunt		.00054				
Series field winding				.000803		.00090
Armature winding		.00193		.000629		.0017

Part	Edison	Thompson Ryan	General Electric
	Weight	Weight	Weight
Field Core	498		3800
Yoke	453		
Pole face piece	623		
Armature core	196		1400
Armature wire	30		
Field wire	222		
Weight per K.W. output	113		104

Calibration of The Standard Voltmeter.

2
1.
To be added
70
To be subtracted
80
90
100
110



Calibration of The Simplex Voltmete

To be added

To be subtracted

2

1

70

80

90

100

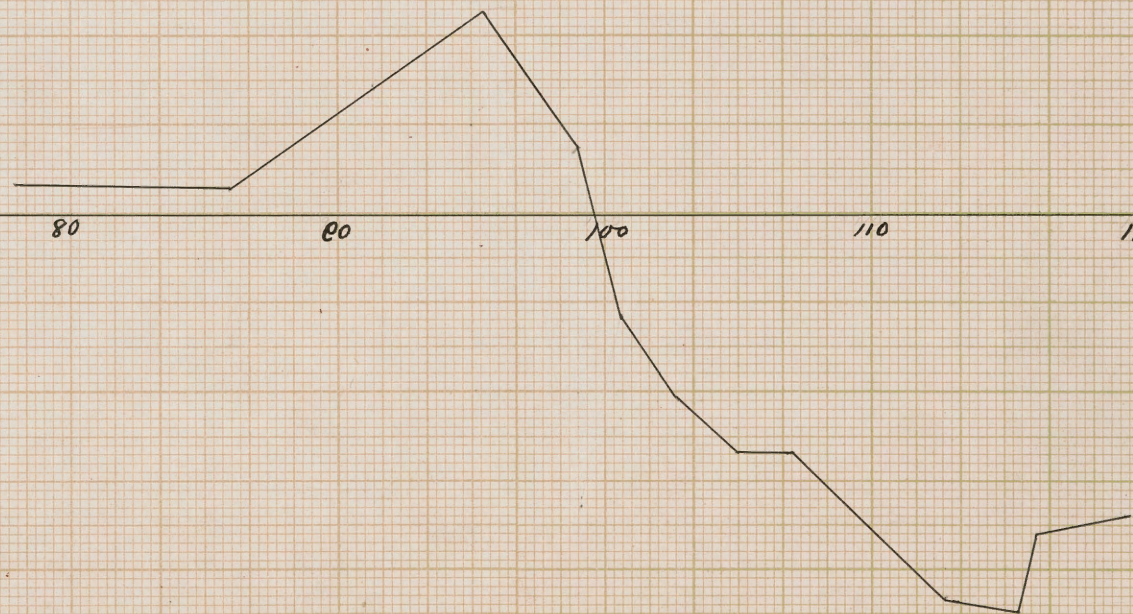
110

120

130

1

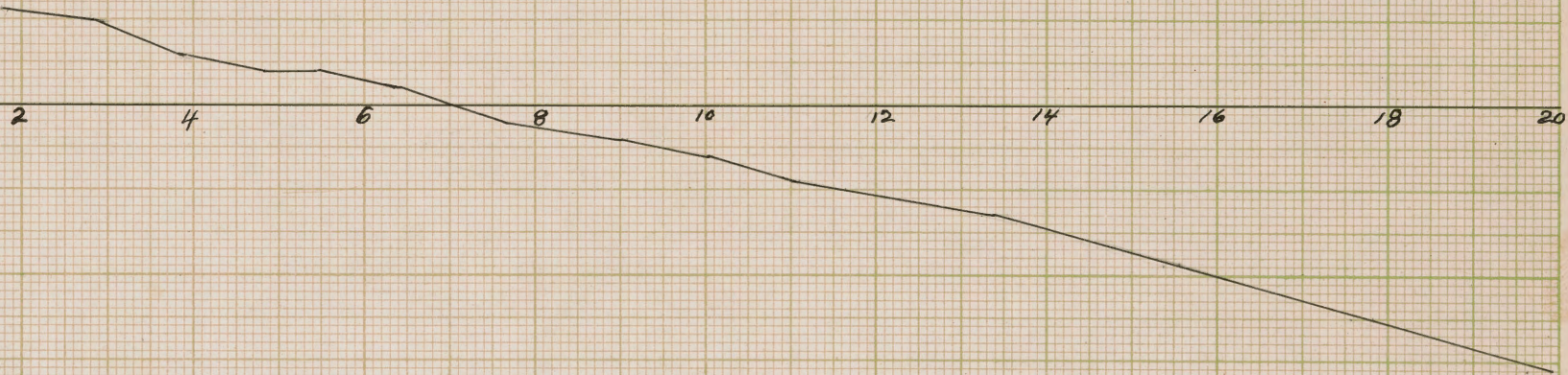
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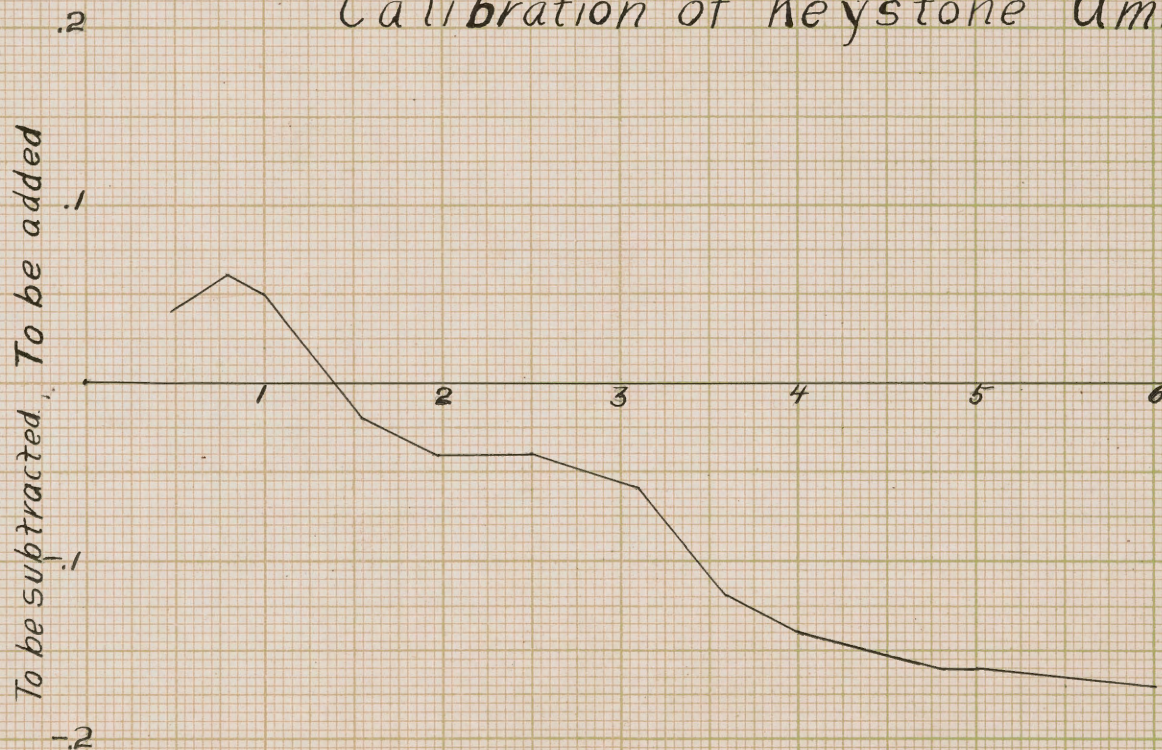
Calibration of Millivoltmer as an ammeter

To be added

To be subtracted



Calibration of Keystone Ammeter



Amperes
1
2

Saturation Curve

Volts
86
96
106
116
126
136

56
66
76

70°

60°

Temperature

50°

Heat Run Curve.

Time

8-00

9-00

10-00

11-00

12-00

1-00

2-00

3-00

4-00

2.76 KW

6.53

10.08

5.68

8.45

10.62

10.82

62.5

10.08

9.68

16.70

17.10

16.70

18.40

10.55

10.76

10.25

23.50

23.50

23.62

23.60

23.50

23.50