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# AN EFFICIENCY TEST OF A ROTARY CONVERTER

## CAPACITY 7.5 K. W.

BY

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## PREFACE

This thesis is a study of a rotary converter and a test upon the machine. The author desires to set forth the characteristics and working possibilities of this machine in such a way that it will be known to those desiring a deep study in this machine just what to expect from it, how it operates and the results one may expect from it. It is hoped that it will be of some benefit to those interested in the operation of rotary converters.

In the preparation of this subject matter and in the actual operation of the tests material has been drawn from technical magazines, books, and other sources available. Even a casual examination of this thesis will show the authors indebtedness to Mr. C. W. Magnusson for his treatise on the heat run and much other valuable information. Many helpful suggestions were drawn from Dr. Chas. A. Perkins under whos directions this test was carried out. Mr. J. M. Harris furnished me with the saturation curve for this machine for which I am indebted.

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May 23 1923

TABLE OF CONTENTS


| | | Page |
|---|---|---|
| 1 | The rotary converter | 1 |
| 2 | Description of the machine | 1 |
| 3 | Data from G. E. Co. | 2 |
| 4 | Resistance | 5 |
| 5 | Calibratoin of instruments | 6 |
| 6 | Stray power loss | 7 |
| 7 | Ratio of voltages | 10 |
| 8 | Current relations | 13 |
| 9 | Efficiency | 14 |
| 10 | The heat run | 17 |
| 11 | Hunting of the converter | 23 |
| 12 | Starting of the converter | 23 |
| 13 | Heating of the converter | 23 |
| 14 | The saturation curve | 24 |
| 15 | Curves and diagrams | 25 |

## THE SYNCHRONOUS CONVERTER

The synchronous converter is essentially a direct current dynamo with the addition of collector rings connected to suitable points of the armature winding. This machine is generally used for converting polyphase current to direct current. If two opposite commutator bars are considered it will be seen that the E.M.F. alternates as the armature rotates and if we should tap in on this winding and attach the tap to a slip ring we would secure alternating current. The alternations depend on the number of poles, one for each pole and one cycle per pair of poles. Such a machine driven from the A.C. side will deliver direct current, if driven from the D.C. side will deliver A.C. current, and if driven by a prime mover is capable of delivering both A.C. & D.C. or either of the two.

## DESCRIPTION OF MACHINE TESTED

The machine tested is a 7.5 K.W. general electric synchronous converter specially built for the University of Tennessee. It is rated at 1800 R.P.M. The current output as rated at factory is 47-68 amps. and the corresponding voltages of 160-110 on D.C. side. The converter is a four pole shunt wound machine. The armature has 96 bars for commutation and 6 slip rings to provide for variable voltages. To get the variation in voltage taps are brought out at 90-120-180-270 electrical degrees apart as shown in diagram # 10 of curves. This arangement gives symetrical two and three phase current.

Copy of letter from G. E. Co.

Sept. 27th 1907

Mr. Charles S. Perkins,
Dept. of physics,
U. of T. 1547 West Clinch Ave.,
Knoxville Tennessee.

Dear Sir;-

I beg to acknowledge receipt of your favor of sept. 22nd.

We wish to state regarding the no. of turns in the field and armature windings of the A.C.S. 4-7 ⅔ - 1800- 110/160 V rotary converter, there are 1260 turns of 0.051" diameter wire per spool. The armature winding consists of #10 B. & S. conductors, 48 slots, containing 12 conductors per slot, and commutating over a total no. of three turns.

The winding of the armature is of the multiple drum type and the effective length of the armature is 5.4". We are attaching a copy of print no. 14165, which contains the switchboard wiring for the rotary converter. This diagram will be found in the back of thesis.

It will be seen that the circuit breaker is supplied with a low voltage release coil, one end of which is connected in series with some resistanceto the posative bus, and the other end to the negative bus. The speed limiting device is connected across this low voltage release coil in such a way that when the circuit is made through this device the release coil is short circuited.

This release will trip the breaker under two conditions; first,when the voltage of the line drops below a certain point, and second, when it is short circuited by the speed limiting device. This device is so arranged that it does not short circuit the machine.

Trusting that this will give you all the desired information, I beg to remain,

Very truly yours,

C. D. Haskins

Mgr. Lighting Dept.

STANDARD 7 1/2K.W. LABRATORY ROTARY CONVERTER

Schenectady N.Y., June 7 1906.

This machine is rated A.C.S. 4-7½-1800-110/160 V. shunt wound and is provided with six collector rings, which enable its operation single, two or three-phase. These rings are numbered from generator outward.

The generator can be operated as a 60 cycle machine with voltage variation of 110 to 160 on the D.C. side, under any of the following conditions:

1 As Rotary Converter.

Machine will give approximately the following voltages. D.C. 110 to 160 V.

Three phase 70-102 V.,with leads taken from rings 1-3- and 5.

Two phase 81-115 V., with leads taken from rings 1-4 and 2-6.

Single phase 81-115 V., with leads taken from rings 1-4 or 2-6.

Additional single phase voltage of 70-102 may be obtainedfrom rings 1-5, or 3-5, or 1-3.

The above voltages are the minimum and the maximum respectively of the range for which the machine was designed. They are settled of course, by the impressed voltage and no apreciable change can be made by movement of the field rheostat.

2 As a double current generator

Machine is built to give satisfactory operation for all the voltages mentioned under heading no. 1. In this case these voltages being obtained by means of its own shunt field, being varied by movement of the field rheostat.

3 As a Direct current Generator.

This machine has a range of 110- 160 V.

4 As an alternating current generator.

Machine designed for V mentioned in # 1.

5 As a direct current motor.

Machine is designed to operate on 110-160 V inc.

6 As a synchronous motor.

This machine is designed to operate on circuits of approximately the V mentioned in section # 1.

7 As an inverted rotary converter. (The way this test was carried out ).

Machine will operate with same voltages as mentioned in # 1.

Under all the above mentioned conditions machine is capable of satisfactory operation with an out put of 7 1/5 K. W. except single phase, which will be about 5 K. W.

With a 2 coil choke coil in one phase (across $180^{0}$) of armature) will supply a 3 wire D.C. circuit 55-55 V either as a generator or a balancer floating on the line.

## RESISTANCE OF THE FIELD

| Obs | E | I | R |
|---|---|---|---|
| 1 | 75.5 | 2.02 | 37.5 |
| 2 | 98 | 2.62 | 37.45 |
| 3 | 107 | 2.85 | 37.5 |
| | | Average | 37.5 |

| Obs | R |
|---|---|
| 1 | 37.68 |
| 2 | 37.69 |
| 3 | 37.68 |
| 4 | 37.68 |
| 5 | 37.7 |
| 6 | 37.7 |
| 7 | 37.7 |
| Average | 37.59 |

Average field resistance ---------- 37.545

## RESISTANCE OF ARMATURE INCLUDING BRUSHES AND BRUSH CONTACTS

| Obs | E | I | R |
|---|---|---|---|
| 1 | 0.406 | 5.1 | 0.0796 |
| 2 | 0.266 | 2.9 | 0.0916 |
| 3 | 0.550 | 8.1 | 0.0680 |
| | | Averages | 0.07976 |

| Obs | D.C. Side | A.C. Side |
|---|---|---|
| 1 | 0.0580 | 0.0860 |
| 2 | 0.0953 | 0.0650 |
| 3 | 0.0953 | 0.0730 |
| 4 | 0.0601 | 0.0507 |
| 5 | 0.1010 | 0.0850 |
| 6 | 0.1018 | 0.0800 |
| Averages | 0.08525 | 0.07490 |

0.08525 ---------- 0.07490 ---------- 0.07976

Averages of all three above resistances ----- 0.07997 Ohms.

## CALIBRATION OF INSTRUMENTS D.C.

The direct current instruments were calibrated by comparison with the standard voltmeter in the Electrics labratory.This standard was first calibrated by the use of the potentiometer shown in diagramatic form on diagram # 8 in back. The milliviltmeters were calibrated by comparison with the standard millivoltmeter. Corrections for the direct current instruments are shown in diagrammes # 1 to 6 inclusive.

## Calibration of A. C. Instruments.

The alternating current instruments were calibrated by comparison with a standard direct current instrument,a multicellular voltmeter, which deflects the same amounts for equal values of A. C. and D. C. current,having been placed in paralel with the two instruments. Correction curves for the A. C. instruments will be found on diagrammes # 1 to 6 Inc.

## STRAY POWER LOSS

To determine the stray power loss of an electric machine the following losses must be determined and added,

Stray losses
- Mechanical losses
  - Windage
  - Bearings
  - Brushes
- Iron losses
  - Hysteresis losses
  - Eddy current

Copper losses $I_a^2R_a + I_f^2R_f$ vary directly with the load, and the stray loss is practically independent of the load. The speed was kept constant at 1800 R.P.M. and the field excitation and voltage and the armature current and voltage were taken, The copper losses were subtracted from the total inputand the remainder called stray power loss. The stray power curve will be found in the back of this paper.

Let $E_x$ = brush pressure.

" $I_a$ = Armature current.

" $I_f$ = Field current.

" S = Stray power loss.

" $R_a$ = Resistance of armature.

" $R_f$ = Resistance of field.

The total power delivered to machine = $E_xI$ (I = Line current) The armature copper loss equals to $I_a^2R_a$ and the field loss is equal to $I_f^2R_f$. Since the machine is operated at no load, the total power delivered to the machine less the sum of the armature and field resistance losses thus, $E_xI - R_aI_a^2 - R_fI_f^2$, is

is lost in hysteresis, eddy currents and friction. Now the stray power loss is the sum of the hysteresis, eddy currents, and friction losses.

Thus $S = E_x I - R_a I_a^2 - R_f I_f^2$.

A curve is plotted which shows the stray power loss as ordinates and field current as abscissas. This curve can be found among diagrams at back. This curve is made use of in figuring the efficiency of the machine.

Stray power loss readings.

| | As read | | | Corrected for | |
|---|---|---|---|---|---|
| Obs. | $I_a$ | $I_f$ | E | $I_a$ | $I_f$ |
| 1 | 8 | 2.35 | 178 | 7.9 | 2.20 |
| 2 | 8.5 | 2.6 | 183 | 8.4 | 2.4 |
| 3 | 9 | 2.9 | 190 | 8.9 | 2.8 |
| 4 | 9.5 | 3.1 | 195 | 9.4 | 2.9 |
| 5 | 9.5 | 3.3 | 200 | 9.4 | 3.1 |
| 6 | 8 | 2 | 165 | 7.9 | 1.85 |
| 7 | 7.5 | 1.72 | 156 | 7.4 | 1.57 |
| 8 | 7.5 | 1.8 | 156 | 7.4 | 1.60 |
| 9 | 7.5 | 1.45 | 140 | 7.4 | 1.35 |
| 10 | 7.5 | 1.15 | 124 | 7.4 | 1.05 |
| 11 | 7.5 | 1.35 | 125 | 7.4 | 1.25 |
| 12 | 7.5 | 0.90 | 102.5 | 7.4 | 0.90 |
| 13 | 7.5 | 1.00 | 110 | 7.4 | 0.95 |

R. P. M. = 1800.

| Obs | $I_a^2R_a$ | $I_f^2R_f$ | $I_a^2R_a + I_f^2R_f$ | Total I | $E_xI$ | Stray power | R.P.M. |
|---|---|---|---|---|---|---|---|
| 1 | 5.00 | 183 | 188 | 10.1 | 1800 | 1612 | 1800 |
| 2 | 5.65 | 218 | 224 | 10.80 | 1970 | 1746 | " |
| 3 | 6.35 | 295 | 301 | 11.70 | 2220 | 1919 | " |
| 4 | 7.05 | 319 | 326 | 12.30 | 2400 | 2074 | " |
| 5 | 7.05 | 365 | 372 | 12.50 | 2500 | 2128 | " |
| 6 | 5.00 | 130 | 135 | 9.75 | 1610 | 1475 | " |
| 7 | 4.40 | 94 | 98 | 8.97 | 1396 | 1298 | " |
| 8 | 4.40 | 96 | 100 | 9.00 | 1420 | 1300 | " |
| 9 | 4.40 | 68.5 | 73 | 8.75 | 1225 | 1152 | " |
| 10 | 4.40 | 41.5 | 46 | 8.45 | 1046 | 1000 | " |
| 11 | 4.40 | 59 | 63 | 8.45 | 1080 | 1017 | " |
| 12 | 4.40 | 30.5 | 35 | 8.30 | 852 | 817 | " |
| 13 | 4.40 | 34 | 38 | 8.35 | 920 | 882 | " |

$R_a$ = 0.07997 ohms.

$R_f$ = 37.545 ohms.

RATDO OF VOLTAGES

Consider the field excitation to be of the proper value to give unity power factor for the alternating current, therefore the maximum value of the current in the group of armature coils under consideration occurs when the maximum voltage is developed. If fields are not distorted the maximum voltage is developed when the coils are passing at rightangles to the flux. When the coils are midway be tween two equal strength poles the electromotive force in the coil is zero. The intermediate the instaneous values are represented by $e=E_{max}\ Sin(wt)$. the voltage between the D.C. brushes, is the sum of the voltages of one half the coils on armature for a two pole machine, and one fourth the coils on the armature for a four pole machine. The instantaneous value in each coil may be represented by vectors drawn through some point O, or arranged in a pologon as shown in figure # 10. The number of sides of the polygon correspond to the number of coils and the vertices lie in a circle, as the coils are equal. When the armature revolves the point connected to the slip rings pass under the commutator brushes at the point of maximum voltage of the alternating wave. Hence the D.C. voltage $E_0$ must be equal to the maximum value of $E_2$, the A.C. single phase voltage.

$$E_2 = \frac{E_0}{\sqrt{2}} = 0.7071\ E_0.$$

In the two phase converter the slip ring connections are 90° apart and the voltage relation for the single phase and the quarter phase circuits are shown in figure # 10, by the relative lengths of the diameters and chords, for 90°

$$E_4 = E_2 \text{ Sin } 45^0 = \frac{E_0}{\sqrt{2}} \text{ Sin } 45^0 = 0.5\ E_0$$

Similarly for a three phase converter, the slip rings are connected at 120 electrical degrees apart and the relative lengths of the chords and diameters gives the relation between the magnitude of the three phase voltage $E_3$ and the single phase voltage $E_2$.

$$E_3 = E_2 \text{ Sin } 60^0 = \frac{E_0}{\sqrt{2}} \text{ Sin } 60^0 = 0.612\ E_0$$

In the same manner the voltage $E_6$ between the slip rings of a six phase converter is,

$$E_6 = E_2 \text{ Sin } 30^0 = \frac{E_0}{\sqrt{2}} \text{ Sin } 30^0 = 0.354\ E_0$$

These results may be expressed by one equation by letting n equal the number of slip rings on the converter.

$$E_n = \frac{E_n}{\sqrt{2}} \text{ Sin } \frac{\pi}{n}$$

For single phase n = 2

" three " n = 3

" two " n = 4

" six " n = 6

ACTUAL VOLTAGE RATIO UNDER TEST

Two phase

| A. C. Voltage | D. C. Voltage | Ratio $E_o$ |
|---|---|---|
| 56.5 | 111.0 | 0.504 $E_o$ |
| Three phase | | |
| 71.0 | 104.5 | 0.683 $E_o$ |
| Six phase | | |
| 39.9 | 111.0 | 0.359 $E_o$ |
| Twelve phase | | |
| 20.5 | 114.5 | 0.180 $E_o$ |
| Single phase | | |
| 79.6 | 104.5 | 0.764 $E_o$ |

ERROR IN VOLTAGE RATIO

Two phase = + 0.004 $E_o$

Three phase = + 0.071 $E_o$

Six phase = + 0.005 $E_o$

Twelve phase = Only 6 rings on converter.

Single phase = + 0.0569 $E_o$

CURRENT RELATIONS

Under the aasumption of unity power factor and no load losses the current relations are readily found by equating the A.C. input to the D.C. out put and substituting the voltage ratio as shown above.

$I_0$ = D.C. I delivered through brushes.

$I_2$ = I in single phase winding.

$I_3$ = I in three phase winding.

$I_4$ = I in two phase winding.

$I_6$ = I in six phase winding.

FOR SINGLE PHASE CONVERTER

$E_0I_0 = 2\ E_2I_2$ .Therefore $I_2 = 0.7071\ I_0$

FOR THREE PHASE CONVERTER

$E_0I_0 = 3\ E_3I_3$ Therefore $I_3 = 0.544\ I_0$

FOR TWO PHASE CONVERTER

$E_0I_0 = 4\ E_4I_4$ Therefore $I_4 = 0.500\ I_0$

FOR SIX PHASE CONVERTER

$E_0I_0 = 6E_6I_6$ Therefore $I_6 = 0.471\ I_0$

For an n ring converter, the current in the armature circuit is,

$$I_n = \frac{\sqrt{2}\ I_0}{N \sin \frac{\pi}{n}}$$

Since two circuits are connected to each collector ring the current in the buss bars are the vector differences of the currents in the circuits. Letting subscripts r indicate at the slip ring, the current will be for unity power factor and,

A 2 ring converter (1 phase) $I_{2r} = 2\ I_2 = 1.41\ I_o$

A 3 " " $I_{3r}$ (3 " ) $= I_3 \sqrt{3} = 0.943\ I_o$

A 4 " " $I_{4r}$ (2 " ) $= I_4 \sqrt{2} = 0.7071\ I_o$

A 6 " " $I_{6r}$ (6 " ) $= I_6 \sqrt{1} = 0.471\ I_o$

The general expression for the current in the mains or the collector rings, (n = number of collector rings)

$$I_{nr} = 2\ I_n \sin \frac{\pi}{n} = \frac{2\sqrt{2}\ I_o}{n}\ .$$

MEASURED EFFICIENCY OF CONVERTER

The efficiency of the machine is determined by measuring the input and the output, and calculated by the equation:-

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

Efficiency Calculated

Since the losses which occur in the machine are known, the efficiency at different outputs is calculated from the equation:-

$$\text{Efficiency} = \frac{\text{Input} - \text{Losses}}{\text{Input}}$$

The losses are, - the $I_f^2 R_f$ losses, the stray power losses, and the loss due to the current flowing through the armature. The loss due to the current flowing through the armature will be taken up under the subject of heat loss and for a thorough analysis of this look up this topic.

The efficiency is calculated for constant impressed voltage on the D.C. line. The efficiency curve as calculated is plotted on the same sheet as the measured efficiency curve is plotted. These curves will be found in the back of thesis.

| Obs. | output. I/20 | E | W/20 | INPUT $I_a$ | E | $I_f$ | R.P.M. |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 96.5 | 0 | 7.8 | 160.0 | 1.88 | 1800 |
| 2 | 0.135 | 93.7 | 11 | 10.7 | " | 1.90 | " |
| 3 | 0.327 | 96 | 26 | 15.2 | " | 1.95 | " |
| 4 | 1.05 | 92.8 | 85.3 | 31.8 | " | 1.94 | " |
| 5 | 1.44 | 93.7 | 113 | 39 | " | 2 | " |
| 6 | 2.55 | 93.7 | 201.5 | 62 | " | 2 | " |
| 7 | 2.20 | 92.9 | 133 | 42 | " | 1.96 | " |
| 8 | 1.66 | 94.5 | 172 | 53.5 | " | 2. | " |
| 9 | 1.05 | 92.9 | 85.3 | 31.5 | " | 1.98 | " |
| 10 | 0.56 | 95.3 | 49 | 20 | " | 1.90 | " |
| 11 | 0.28 | 95.3 | 22.5 | 13.7 | " | 1.85 | " |

$R_a = 0.07997$

$R_f = 97.545$

D.C. INPUT. CORRECTED FOR INSTRUMENTS

| Obs | $I_a$ | $I_f$ | I total | Volts | K.W. | R.P.M. |
|---|---|---|---|---|---|---|
| 1 | 7.9 | 1.75 | 9.65 | 160 | 1.54 | 1800 |
| 2 | 10.7 | 1.8 | 11.5 | " | 1.84 | " |
| 3 | 15.3 | 1.85 | 16.15 | " | 2.64 | " |
| 4 | 31.83 | 1.84 | 33.68 | " | 5.38 | " |
| 5 | 39.07 | 1.90 | 40.97 | ", | 6.55 | " |
| 6 | 62.07 | 1.90 | 63.97 | " | 10.2 | " |
| 7 | 53.58 | 1.86 | 55.44 | " | 8.86 | " |
| 8 | 42.08 | 1.90 | 43.98 | " | 7.04 | " |
| 9 | 31.57 | 1.88 | 33.45 | " | 5.36 | " |
| 10 | 20.02 | 1.80 | 21.82 | " | 3.49 | " |
| 11 | 13.17 | 1.75 | 14.92 | " | 2.39 | " |

A.C. OUTPUT CORRECTED FOR INSTRUMENTS

| Obs | I | E | K.W.output | K.W. Figured | Power Factor | Eff.% |
|---|---|---|---|---|---|---|
| 1 | 0.00 | 96.3 | 0.00 | 0.00 | ---- | 0 |
| 2 | 5.72 | 93.8 | 0.44 | 0.536 | 0.823 | 23.9 |
| 3 | 13.32 | 96 | 1.04 | 1.28 | 0.813 | 39.4 |
| 4 | 43.52 | 92.8 | 3.50 | 4.05 | 0.865 | 65 |
| 5 | 58 | 92.8 | 4.44 | 5.38 | 0.825 | 67.8 |
| 6 | 104.8 | 93.8 | 8.06 | 9.7 | 0.832 | 79 |
| 7 | 91.12 | 92.9 | 6.88 | 8.47 | 0.813 | 77.6 |
| 8 | 68.4 | 94.5 | 5.32 | 6.48 | 0.824 | 71.6 |
| 9 | 42.64 | 92.9 | 3.42 | 3.96 | 0.865 | 63.8 |
| 10 | 22.32 | 94.8 | 1.76 | 2.12 | 0.832 | 50.4 |
| 11 | 11.92 | 94.8 | 1.13 | 0.90 | 0.797 | 37.6 |

## HEAT LOSSES AT UNITY POWER FACTOR

As a rotary converter the machine received current from the D.C. bus bars and delivered it to the A.C. mains less the losses in the armature, the loss in the fields, and the stray power loss. the loss in the armature is the loss that we are to determine from this discussion. Under the several kinds of service the armature heating is not the same for equal power passing through the machine. Since the rating of the synchronous converter depends upon the permissible temperature rise for the same reason as for alternators and synchronous motors, the difference in heat loss in the armature affects the capacity of the machine. The power rating of a rotary converter is expressed in terms of the rating the same machine would have if run as a D.C. generator by a prime mover. The difference in rating when used as a rotary converter as compared to a D.C. generator is determined by the $I^2R$ losses in the armature, since the eddycurrent and hysteresis losses are approximately the same in both cases. Since the slip rings and commutator bars are connected to the same armature, the instaneous value of the current in any conductor will be the algebraic sum of the simultaneous values of the currents flowing in the D.C. and A.C. circuits.

Consider a two pole n ring converter, let M be the conductor midway be tween the slip-ring connections and let S be the conductor a distance $\alpha$ from M. For the several

conductors in the circuit between these slip ring connections the value of $\alpha$ varies from 0 to $\pm \frac{\pi}{n}$. The maximum value of the A.C. current, $\sqrt{2}I_n$, flows whenconductor M passes under the center of the field poles (unity powerfactor assumed). Hence the instaneous value for any other position of the armature is for conductor M: $i = \sqrt{2}I_n \text{Cos } wt - \frac{I_o}{2}$. When conductor S reaches the posative brush, $i = \frac{\pi}{2} - wt$ and at the negative brush $i = -(\frac{\pi}{2} + wt)$ or $\frac{3\pi}{2} - wt$.

The notation in the first Equation applies to multipolar machines by using electrical degrees and letting $I_o$ represent the D.C. current passing through each set of brushes. In figure # 11 are shown the currents flowing through conductor M in a single phase converter, i,e, $n=2$ $\alpha=0$. The D.C.current reverses directionat the brushes forming a wave of rectangular shape. The neutral pointsof the A.C.current coincide with the wave reversals of the D.C.current, and the maximum value is twice that of the D.C.current. The instantaneous value is the algebraic sum of the simultaneous values of the direct and alternating currents. Hence curve C, plotted as the sum of curves A and B, represent the wave shape and magnitudeof the resultant current flowingin the armature conductor. The broken line, curve D, is plotted to the square of the instaneous values in curve C and hence its ordinates are proportional to the heat generated in the conductor due to the $I^2R$ losses. In the last set of curves on figure # 11 are shown the corresponding

curves for the conductor at the point of connection to the slip ring, when n = 2 and $\alpha = 90^0$. By shifting the relative position of the direct and alternating waves the instaneous values, and hence the heating, becomes much greater for the conductor nearest to the slipring connection than for conductor M midway between the slip rings. Similar curves for n = 2 and $\alpha = 45^0$ can be drawn. The curves for a three ring converter are similar to those on fig. # 11 when n = 3 and $\alpha = 0$. From the fig. and from the equation it is evident that in order to determine the heat loss in the armature it is necessary to find first the average loss in a conductor for a cycle, and second, the average of the loss in the several conductors between each pair of leads. From the above equations we have;

$$i = \frac{2I_0 \text{ Cos wt}}{n \text{ Sin } (\frac{\pi}{n})} - \frac{I_0}{2}$$

The heat loss is proportional to the square of the current.

$$i = \frac{4I_0^2 \text{ Cos}^2(wt)}{n^2 \text{ Sin}^2 (\frac{\pi}{n})} - \frac{2I_0^2 \text{ Cos } (wt)}{n \text{ Sin } (\frac{\pi}{n})} + \frac{I_0}{4}$$

$$= \frac{I_0^2}{4}\left[\frac{16 \text{ Cos}^2 (wt)}{n^2 \text{ Sin}^2 (\frac{\pi}{n})} - \frac{8 \text{ Cos } (wt)}{n \text{ Sin } (\frac{\pi}{n})} + 1\right]$$

The average heat loss per conductor in half a cycle,

$$= r\int_{-(90^0+\ )}^{(90^0-\ )} \frac{i^2\, dt(wt)}{\pi}$$

in which r is the resistance of one armature conductor between taps.

$$r\int \frac{i^2 d\ (wt)}{\pi} = \frac{r\ I_0^2}{4\ \pi}\int_{-(90+\ )}^{(90-\ )} \left[\frac{16\mathrm{Cos}^2(wt)}{n^2\mathrm{Sin}^2\ (\frac{\pi}{n})} - \frac{8\mathrm{Cos}(wt)}{n\mathrm{Sin}(\frac{\pi}{n})} + 1\right] d(wt)$$

$$= -\frac{r\ I_0^2}{4}\left[1 - \frac{16\ \mathrm{Cos}}{"n\mathrm{Sin}\ \frac{\pi}{n}} + \frac{8}{n^2\ \mathrm{Sin}^2\ (\frac{\pi}{n})}\right]$$

To find the average heat in the armature the average value per conductor is given in equation just above must be integrated between the limits of $\alpha = -\frac{\pi}{n}$ and $\alpha = +\frac{\pi}{n}$ and the result divided by $\frac{2\pi}{n}$.

$$= \frac{rI_0^2}{4\ \frac{2\pi}{n}}\int_{-\frac{\pi}{n}}^{\frac{\pi}{n}} \left[1 - \frac{16\ \mathrm{Cos}}{n\ \pi\ \mathrm{Sin}(\frac{\pi}{n})} + \frac{8}{n^2\mathrm{Sin}^2\ (\frac{\pi}{n})}\right] d\alpha$$

$$= \frac{rI_0^2}{4}\left[1 - \frac{16}{\pi^2} + \frac{8}{n^2\ \mathrm{Sin}^2\ (\frac{\pi}{n})}\right]$$

One half of the armature is taken into the calculation both for the alternating current and for the direct current, and hence the ratio is the same for the whole armature.

The average armature heating is therefore

$$\left[1 - \frac{16}{\pi^2} + \frac{8}{n^2 \sin^2 (\frac{\pi}{n})}\right] = 0.405$$

times the heat generated by the same direct current. Hence for the same temperature rise an n-ring rotary converter transmits

$$\frac{1}{\sqrt{1 - \frac{16}{\pi^2} + \frac{8}{n^2 \sin^2 (\frac{\pi}{n})}}} = 0.405$$

times as much current as when the machine operates as a direct current generator.

From this ratio the power rating of the synchronous converter is found in terms of the D.C.current generator as follows, As D.C. generator 1.00

As three phase converter 1.33

In the preceding discussion of the current relation, it was assumed that no energy was lost in the converter and the field excitation was adjusted for unity power factor. For powerfactors less than unity, and taking into account the efficiency of the machine, the heat losses in the armature conductors are greatly increased. The load losses are also increased for powerfactors less than unity. Any variation of wave shape from the sinusoidal form also affects the heat loss-

es in the converter. The above rating of the converter is computed on the basis of Sine waves and unity power factor.

The efficiency of the machine is calculated from the above formula which results in a ratio of 0.405 to 1 . That is the aparent loss in the armature is the $I^2R$ loss but in this calculation 0.405 times this loss was used as the actual loss in the armature. This loss is not quite high enough because of the not having unity power factor as desired.

| Obs= | K.W. Stray Power | $I_f^2 R_f$ | $I_a^2 R_a$ | 0.405 $I_a^2 R_a$ | K.W. Loss |
|---|---|---|---|---|---|
| 1 | 1.40 | 115 | 5 | 2 | 1.517 |
| 2 | 1.42 | 122 | 9.2 | 3.7 | 1.566 |
| 3 | 1.43 | 129 | 18 | 7.3 | 1.567 |
| 4 | 1.425 | 127 | 81 | 32.8 | 1.585 |
| 5 | 1.46 | 136 | 122 | 49.5 | 1.646 |
| 6 | 1.46 | 136 | 299 | 121 | 1.717 |
| 8 | 1.43 | 130 | 230 | 93 | 1.653 |
| 8 | 1.46 | 136 | 142 | 57.5 | 1.654 |
| 9 | 1.43 | 133 | 80 | 32.5 | 1.596 |
| 10 | 1.42 | 122 | 32 | 13 | 1.555 |
| 11 | 1.40 | 115 | 13.9 | 5.6 | 1.520 |

$$\text{Efficiency} = \frac{\text{Input} - \text{Losses}}{\text{Input}}$$

| Obs | Input W. | Losses W. | Input - Losses W. = Output | Eff. % |
|---|---|---|---|---|
| 1 | 1540 | 1517 | 23 | 14.95 |
| 2 | 1840 | 1546 | 294 | 15.95 |
| 3 | 2640 | 1567 | 1073 | 40.5 |
| 4 | 5380 | 1585 | 3795 | 70.7 |
| 5 | 6550 | 1646 | 4904 | 75.0 |
| 6 | 10200 | 1717 | 8483 | 83.2 |
| 7 | 8860 | 1653 | 7207 | 81.4 |
| 8 | 7040 | 1654 | 5386 | 76.6 |
| 9 | 5360 | 1596 | 3764 | 70.4 |
| 10 | 3490 | 1555 | 1835 | 52.6 |
| 11 | 2390 | 1520 | 870 | 36.4 |

Efficiency curve is plotted on the measured efficiency curve sheet number # 12 in back among curves. The curve is a bit off I think because of the resistance being greater when the machine is running than when measured at atandstill, that is the resistance of contact between the A.C. and D.C. brushes and the armature slip rings and commutator bars is greater when the machine is ~~not~~ in motion than when it is at a standstill.

## HUNTING OF THE ROTARY CONVERTER

The machine has no tendency to hunt for there are damping windings shortcircuited around each field pole and the current induced in these grids by the shifting of the field flux over the pole faces causing the hunting is opposed by short circuited windings and dampens the oscilations.

## STARTING THE CONVERTER

The machine was started as a D.C. motor. It will not start as an induction motor as was found after several attempts were made by supplying low voltage to the three phase side of the machine. The way to start the machine is to start it from the D.C. side and then senchronizing it with the power source and throwing the D.C. switch out and the A.C. in.

## HEATING OF CONVERTER

The machine was run at normal speed under full load and the temperature rise of the armature and field were measured by means of a thermometer. Results were corrected to 25° C. room temperature. A correction of 1/2 % for each degree rise of room temperaturein order to correct to 25° C. That is each degree above room temperature. A curve is plotted with time as ordinates and rise of temperature as abscissas. The temperature rise falls within the prescribed limits of the permissable rise of temperature for armature and field of rotary converters. The bearings did not heat up on test.

TEMPERATURE RISE OF MACHINE

| Obs | Time | Ta | Ia | E | Room T. | Field T. |
|---|---|---|---|---|---|---|
| 1 | 9:15 | 24.5 C | 50 | 118 | 24.5 C | 24.5 C |
| 2 | 9:45 | 44.0 C | 49 | 118 | 77.0 F | 29.0 C |
| 3 | 10:15 | 46.0 C | 48.5 | 121 | 77.0 F | 30.5 C |
| 4 | 10:45 | 47.0 C | 46.5 | 123 | 78.0 F | 31.5 C |
| 5 | 11:30 | 52.0 C | 48 | 121.5 | 79.0 F | 32.0 C |
| 6 | 12:05 | 54.0 C | 46 | 120 | 79.5 F | 33.0 C |
| 7 | 12:45 | 55.0 C | 47 | 121 | 81.0 F | 33.0 C |

TEMPERATURES CORRECTED

TO 25 DEGREES C.

| Obs | Room T | Arm. T | Field T | Arm. Rise | Field Rise |
|---|---|---|---|---|---|
| 1 | 24.5 C | 24.5 C | 24.5 C | 0.00 | 0.00 |
| 2 | 25 C | 44 C | 29 C | 19 | 4 |
| 3 | 25 C | 46 C | 30.5 C | 21 | 5.5 |
| 4 | 25.4 C | 47 C | 31.5 C | 21.4 | 6 |
| 5 | 26.6 C | 52 C | 32 C | 24.81 | 6 |
| 6 | 26.8 C | 54 C | 33 C | 27 | 6.2 |
| 7 | 27.2 C | 55 C | 33 C | 27 | 6 |

Ta = armature temperature,

## SATURATION CURVE

To secure the saturation curve, the machine was driven as a generator by mechanical means at rated speed (1800) R.P.M. The field current was observed for different A.C. voltages. To secure constant speed there was placed in series with the driving motor a rheostat of sufficient size to cover the desired range of voltages.

| Obs. | Field I. | A.C. Voltage | R.P.M. |
|---|---|---|---|
| 1 | 3.7 | 142.1 | 1800 |
| 2 | 3.02 | 134.5 | " |
| 3 | 3.61 | 127.2 | " |
| 4 | 1.9 | 110.65 | " |
| 5 | 1.74 | 105.9 | " |
| 6 | 1.46 | 95.0 | " |
| 7 | 1.36 | 84.9 | " |
| 8 | 1.28 | 79.35 | " |
| 9 | 1.20 | 74.85 | " |
| 10 | 1.16 | 64.5 | " |
| 11 | 0.856 | 60.7 | " |
| 12 | 0.738 | 54.9 | " |
| 13 | 0.47 | 40.7 | " |
| 14 | 0.23 | 33.0 | " |
| 15 | 0.15 | 18.0 | " |
| 16 | 0.08 | 11.7 | " |
| 17 | 0.00 Residual | 6.4 | " |

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 for the purpose for which it was submitted.

Name Chas A Perkins

Title _____

PLATE #1.

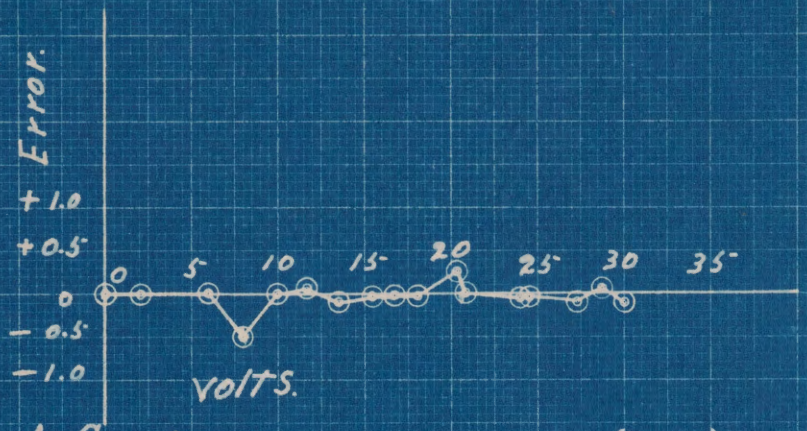



Calibration of standard Voltmeter No. 669. D.C. 1st Instrument.

2-6-22. G.R. Bryan.

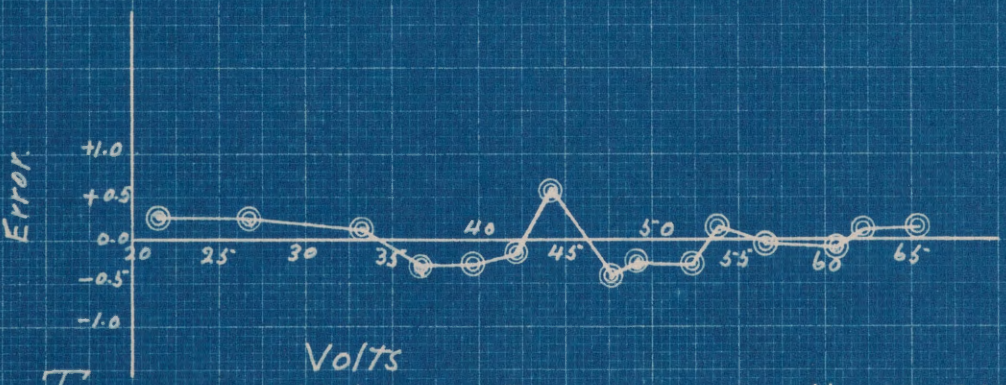
KEUFFEL & ESSER, CO., NEW YORK, NO. 334 C.R.

# #2.




A-C. voltmeter No. 55503. (0-30).

2nd Instrument.

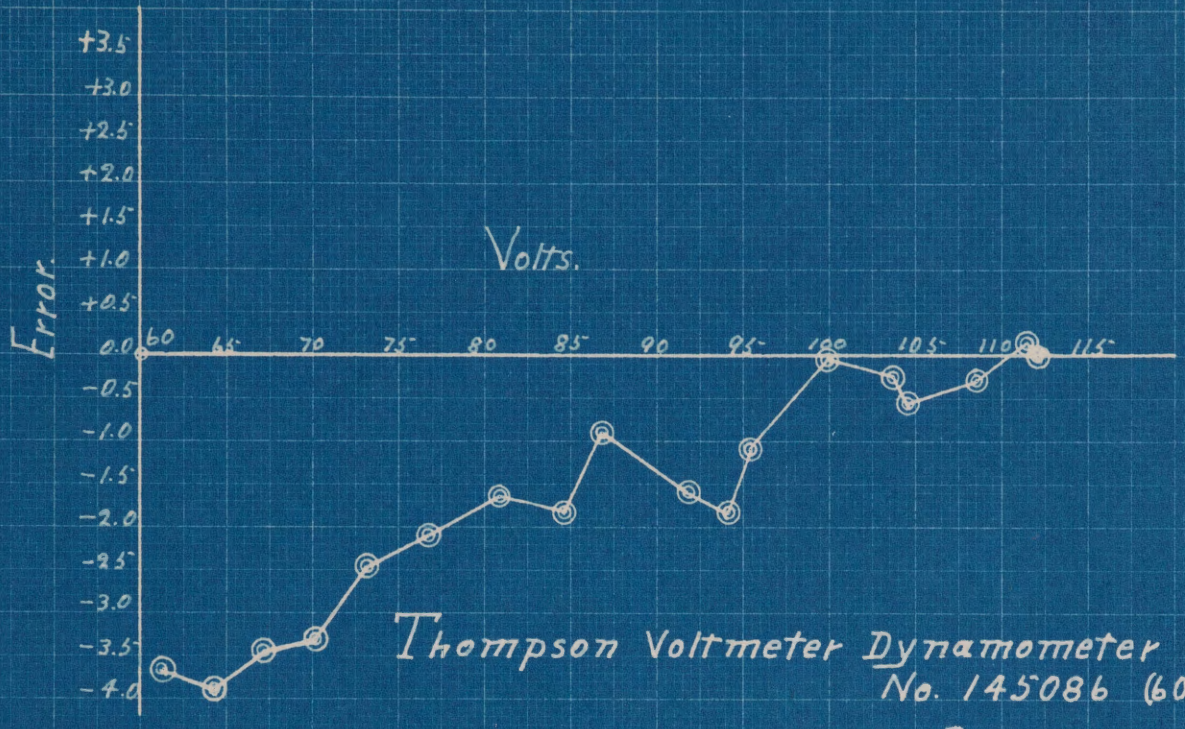



Thompsons Voltmeter Dynamometer. No. 140940 (0-65)

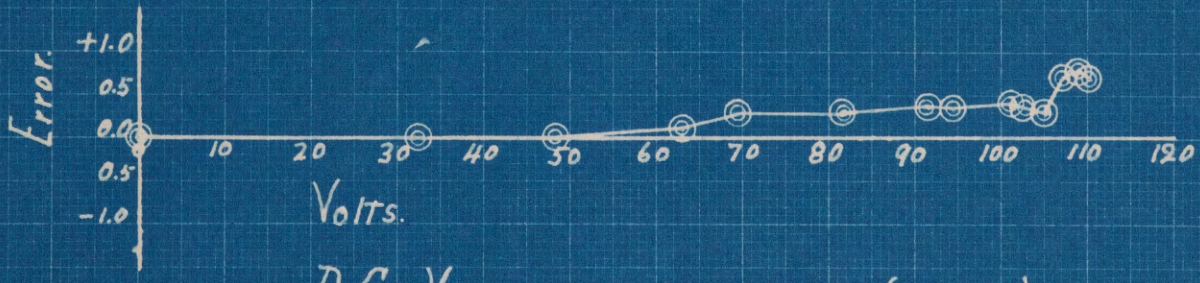
3rd Instrument.

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# #3.



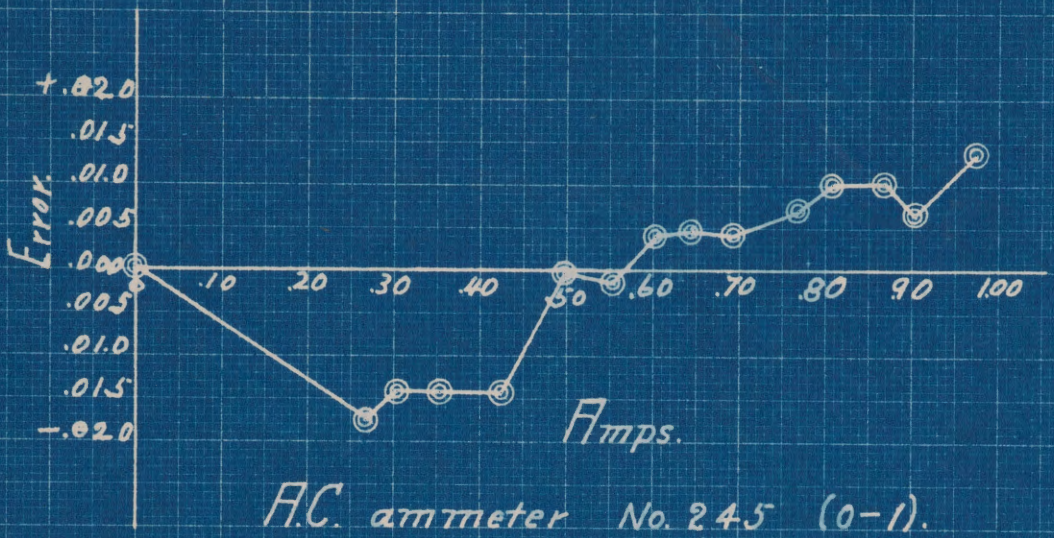

Thompson Voltmeter Dynamometer
No. 145086 (60-112)
4th Instrument.




D.C. Voltmeter No. 16901. (0-150).
5th Instrument.

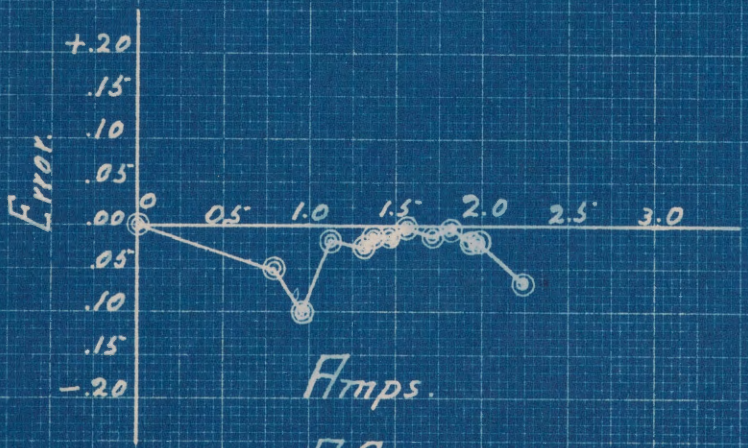
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#4.




A.C. ammeter No. 245 (0-1).

6th Instrument.

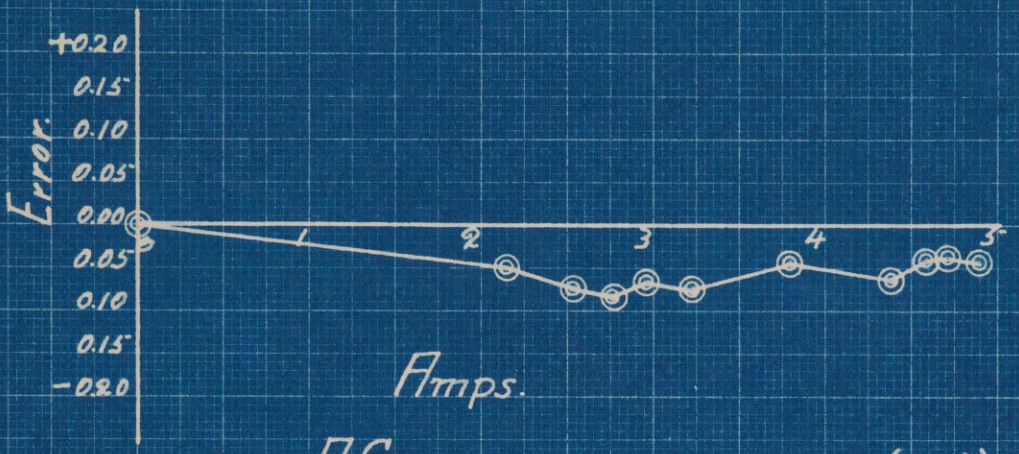



A.C. Ammeter No. 16473 (0-2).

7th Instrument.

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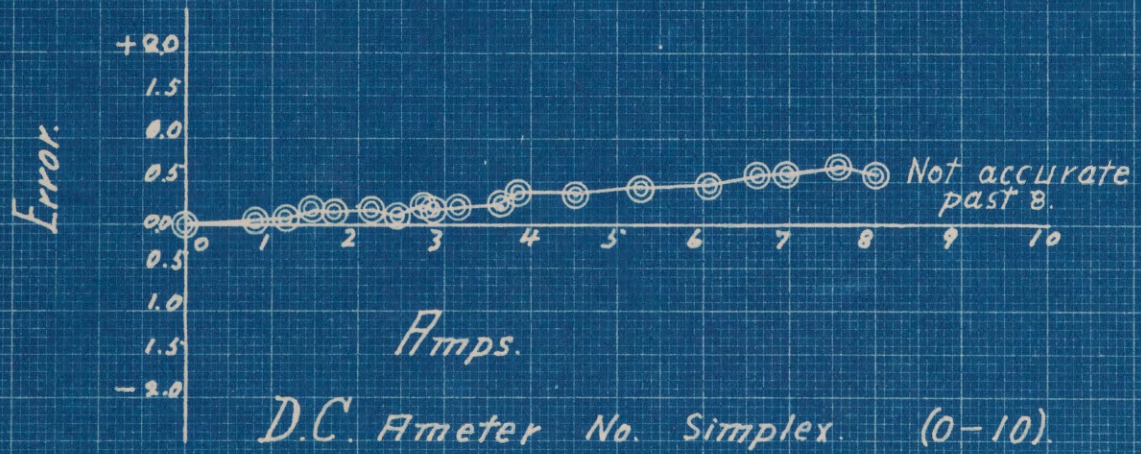
#5




Amps.

A.C. Ameter No. 17396. (0–5).

8th Instrument.



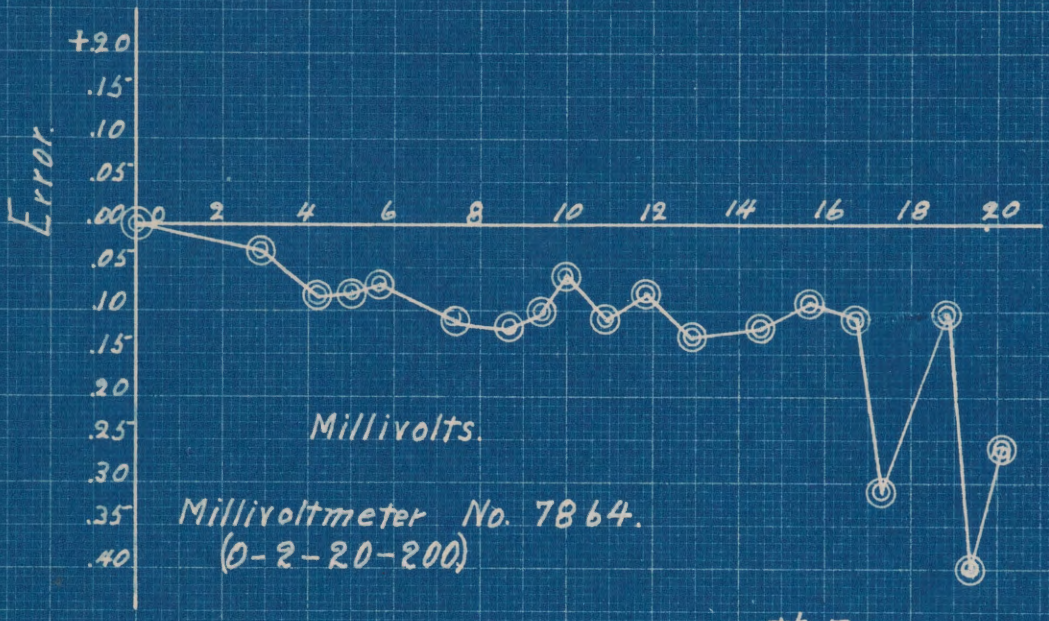

Amps.

D.C. Ameter No. Simplex. (0–10).

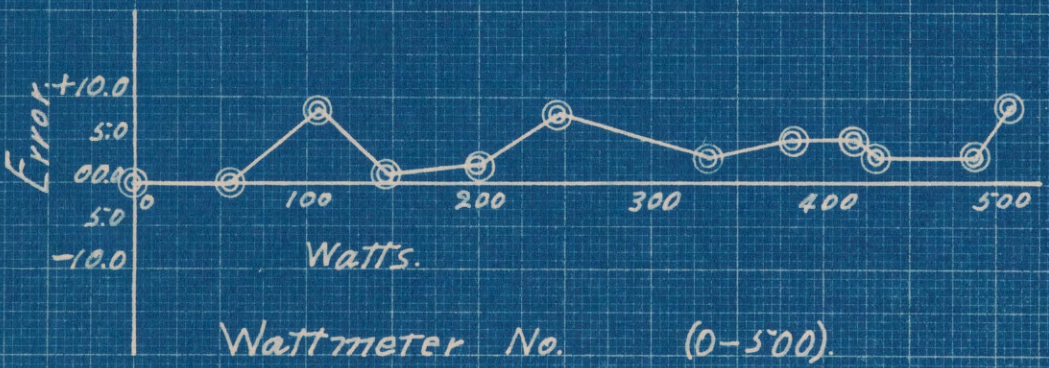
9th Instrument.

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#6.



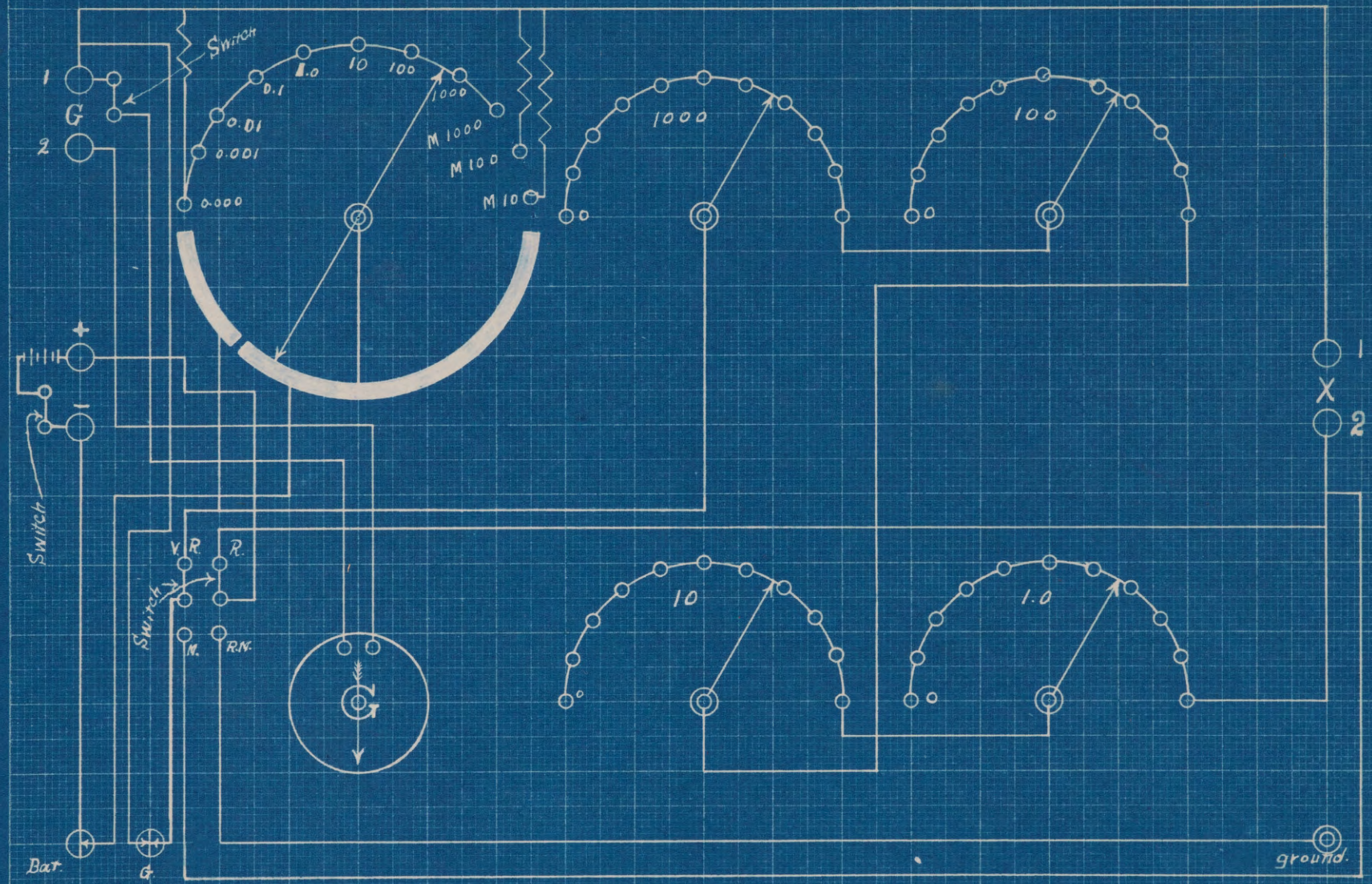

11th Instrument.




Wattmeter No. (0-500).

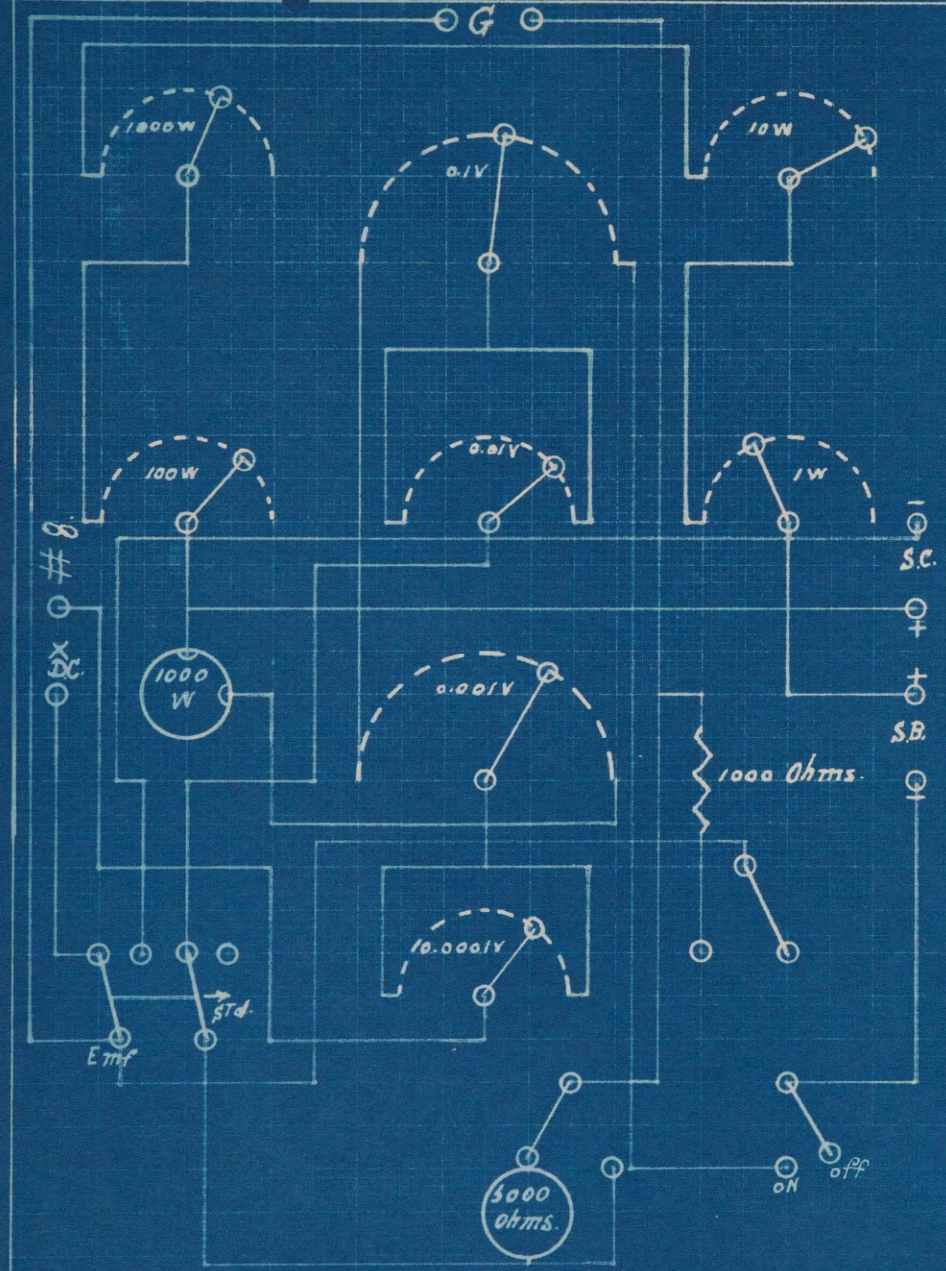
10th Instrument.

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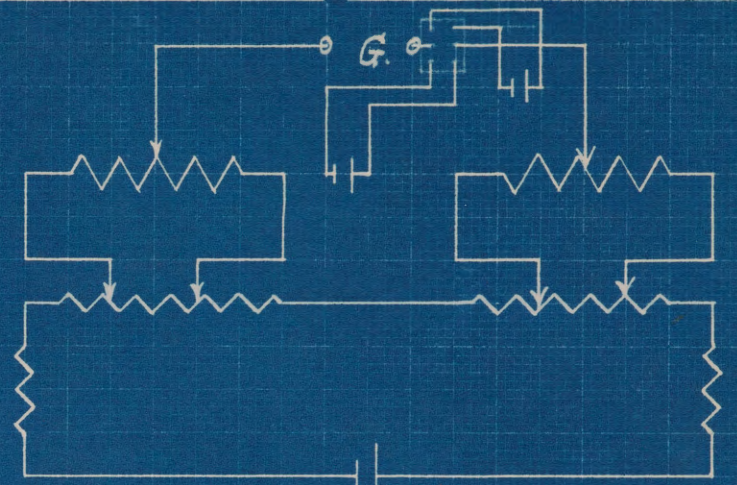



Leads and Northrup dial decade testing set.

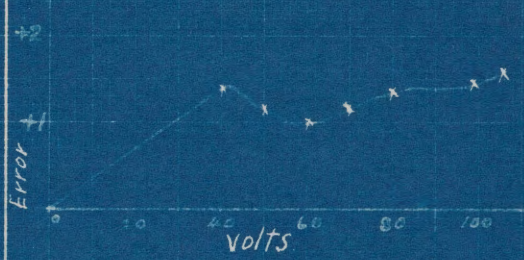
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potentometer wiring 10-20-21



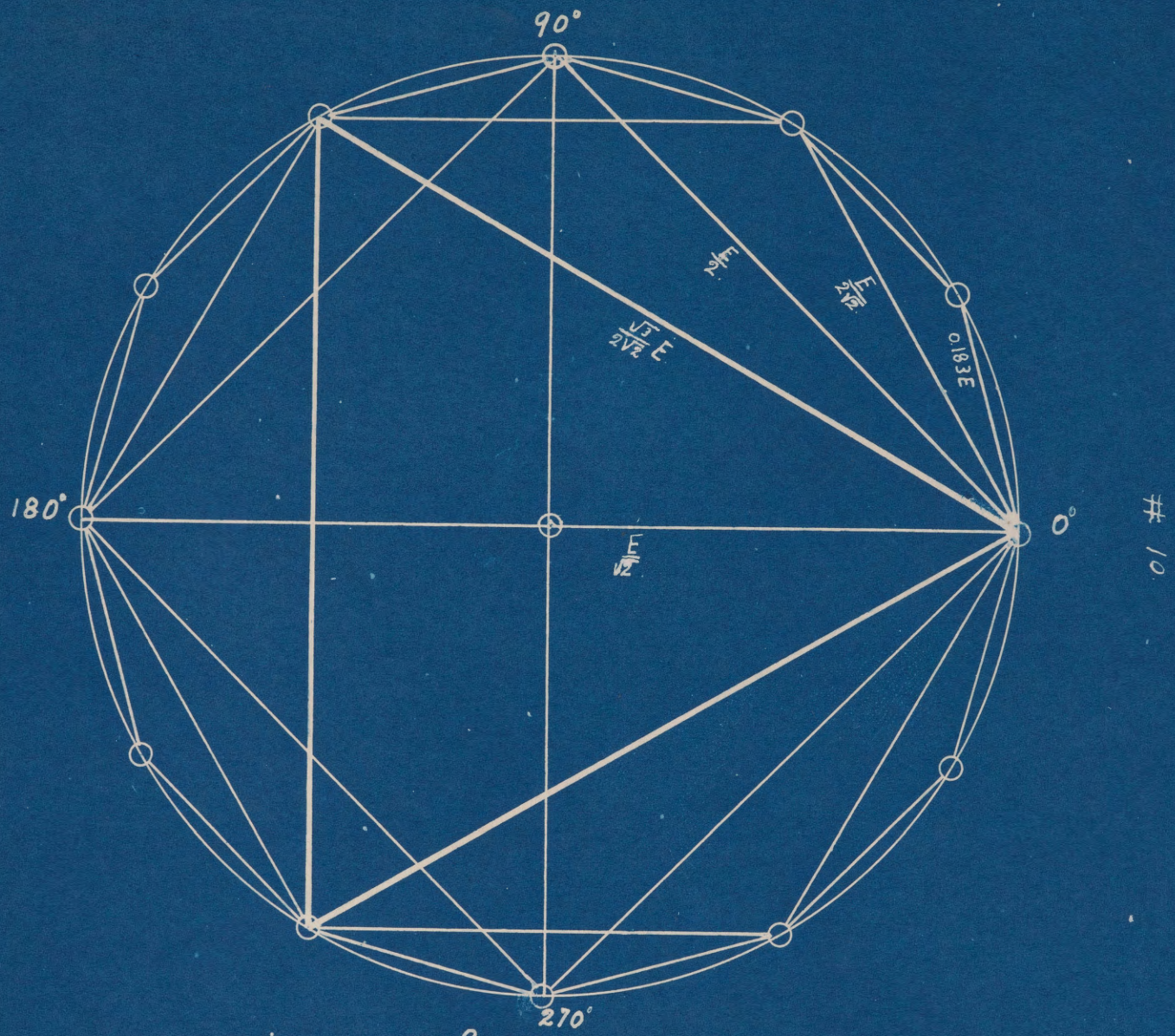

potentometer diagram.




Correction curve for Ayers voltmeter Model 135 Western Electric Co. No 6202.

Instrument used to standardize standard voltmeter.

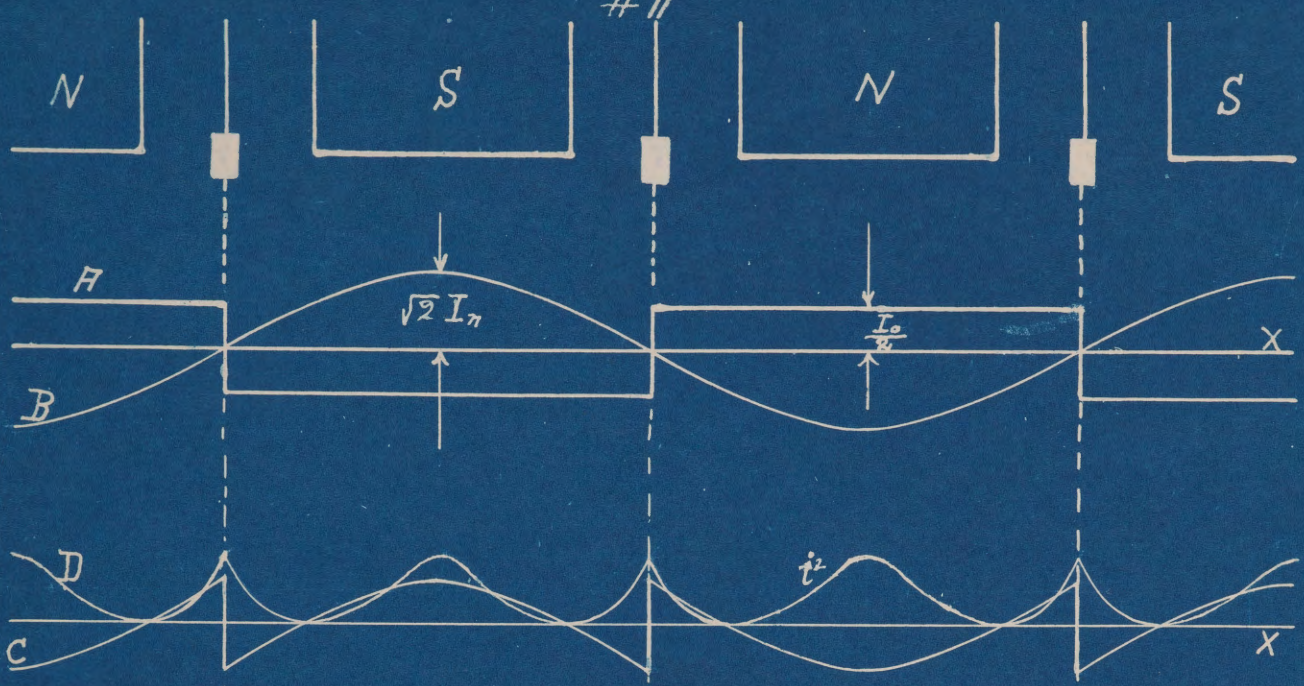
G.R.Bryan.



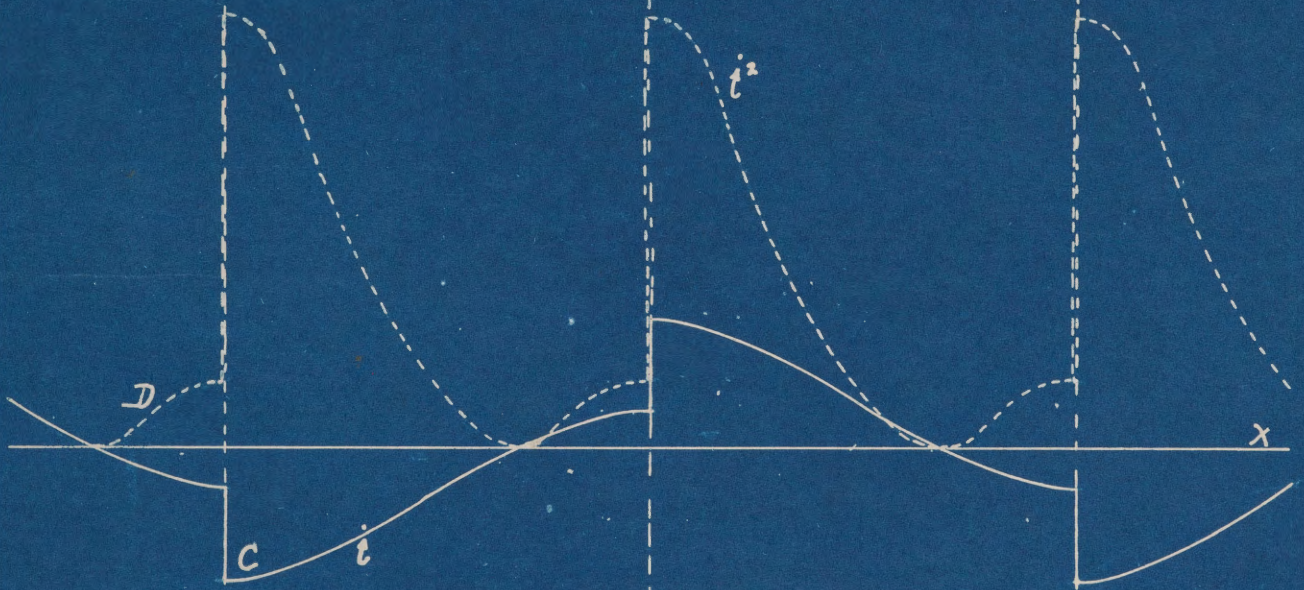

# 10.

Diagram of voltage ratio.

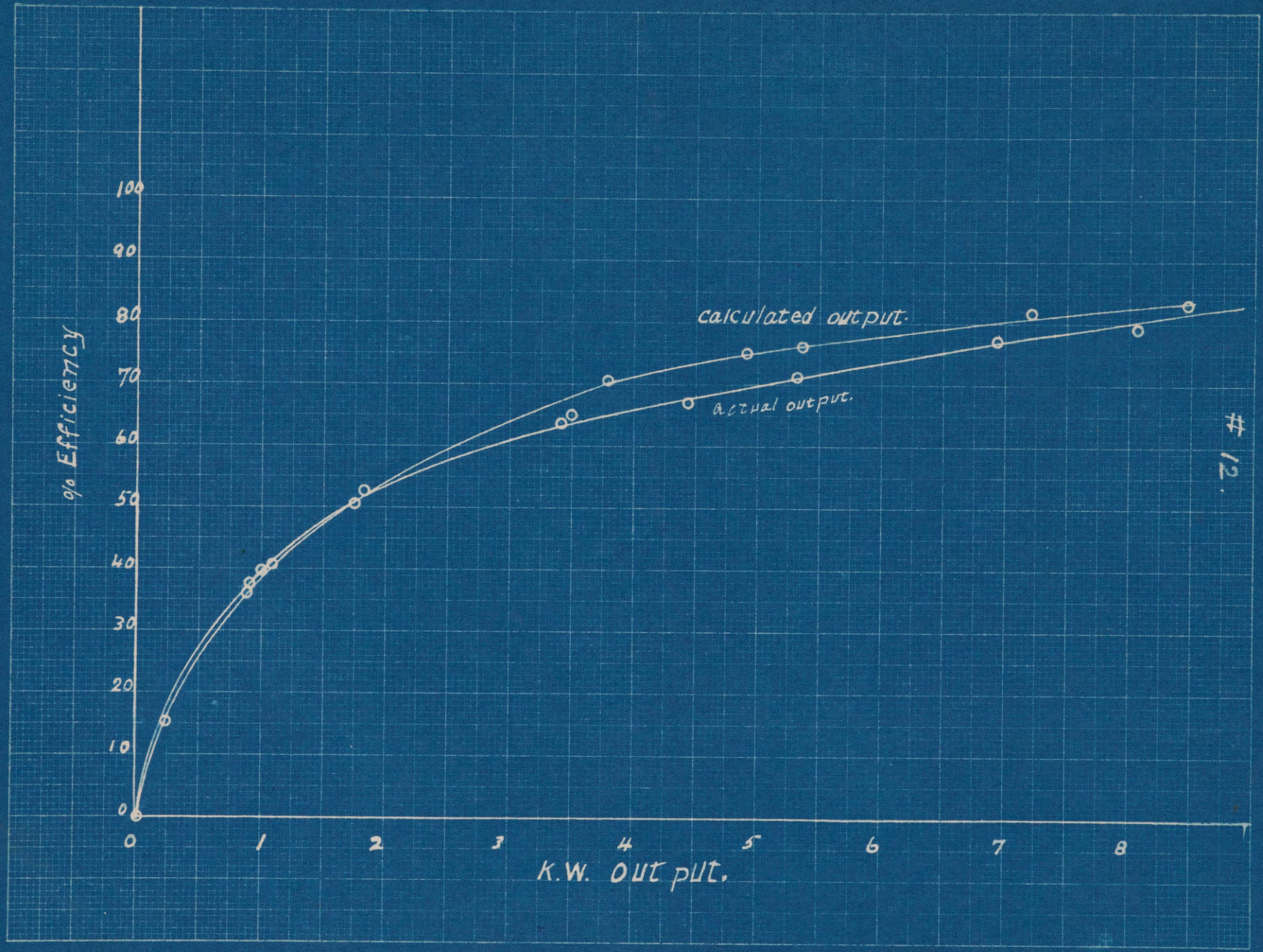
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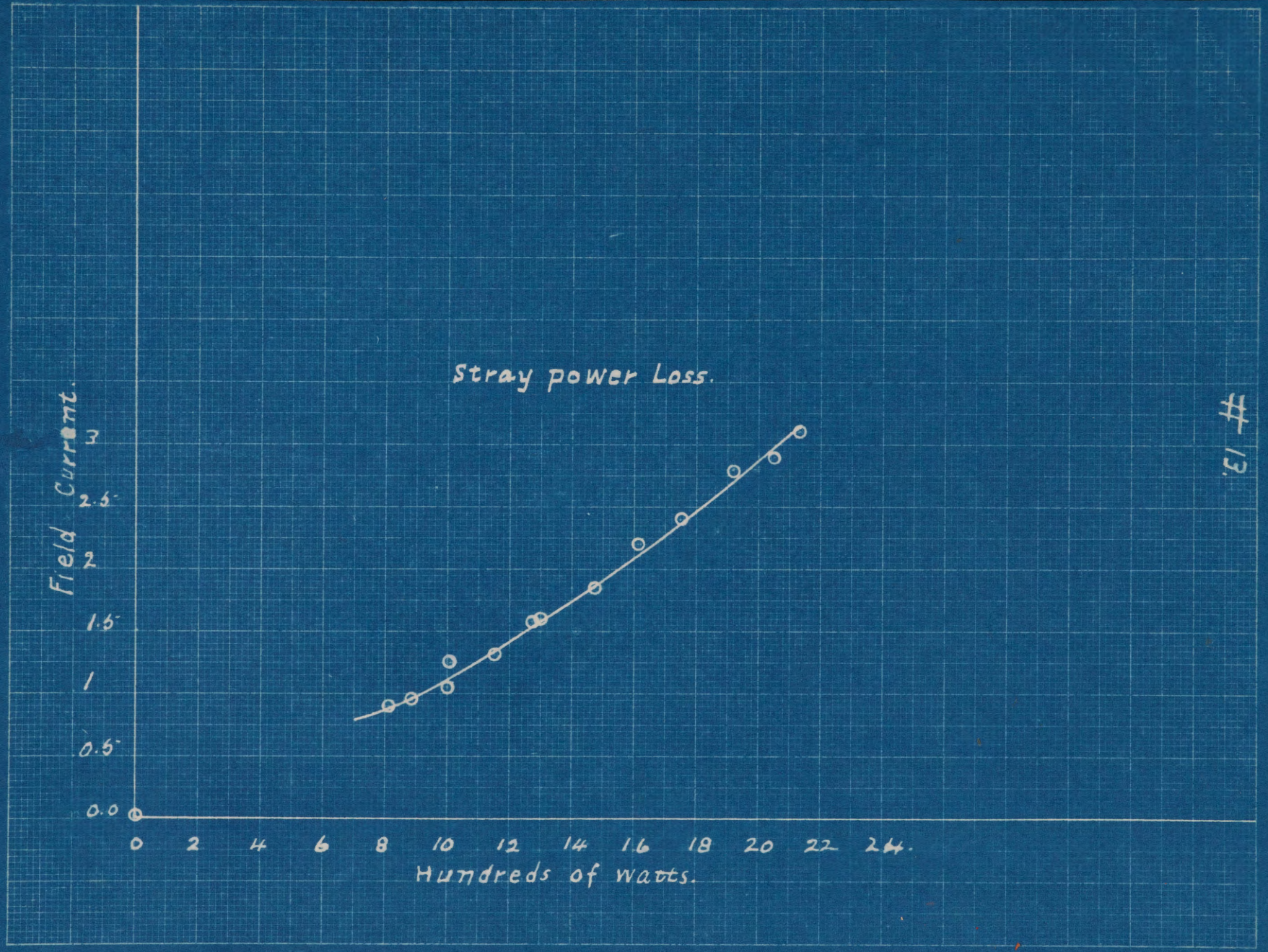

$3\phi$, $\alpha = 0°$. SHOWS I FLOWING THRU CONDUCTOR M.




$3\phi$ $\alpha = \pi/3$. CURVES SHOWING I AT PT. OF CONECTION TO SLIP-RINGS, THEREFORE HEAT LOSS IN CONDUCTOR.

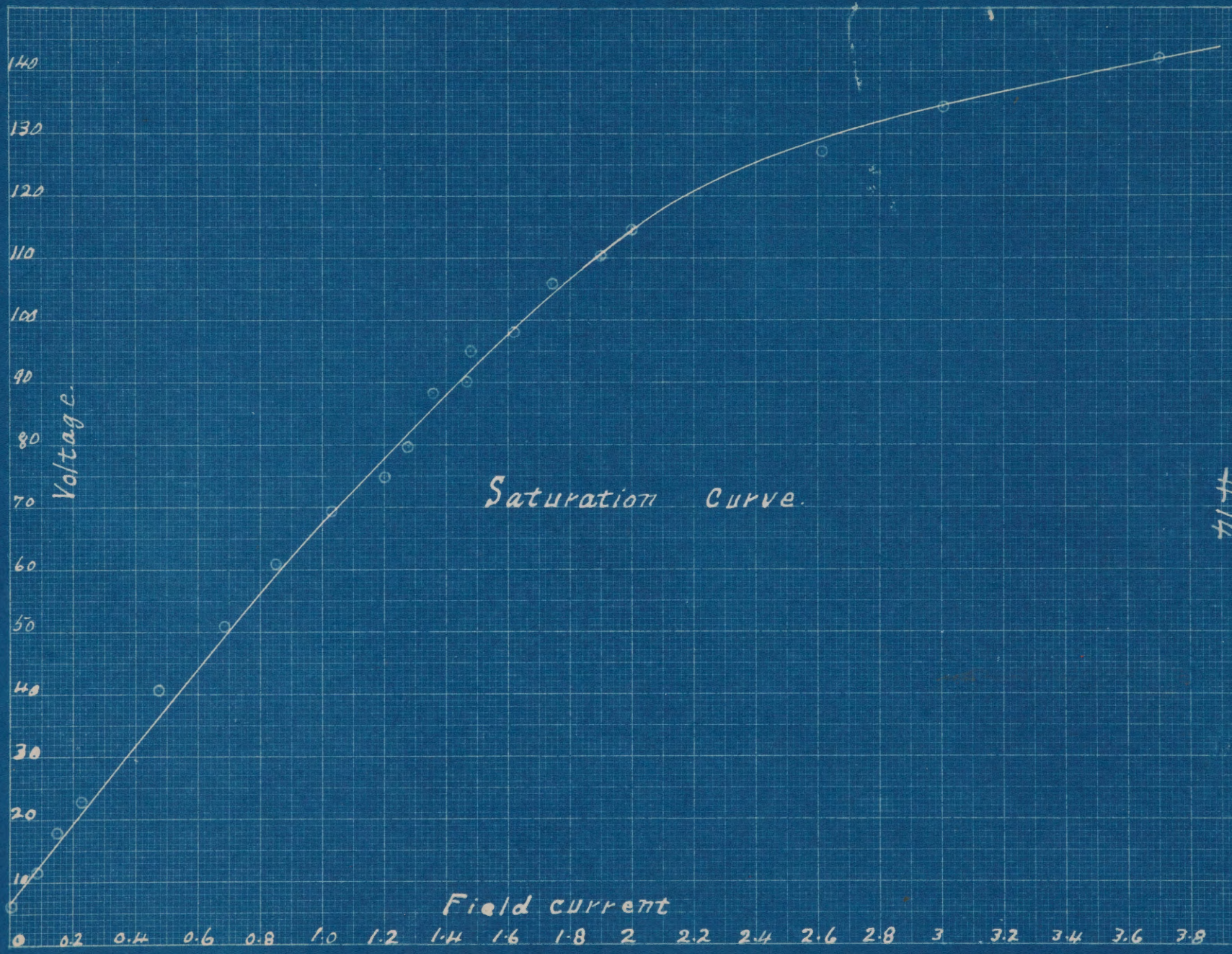



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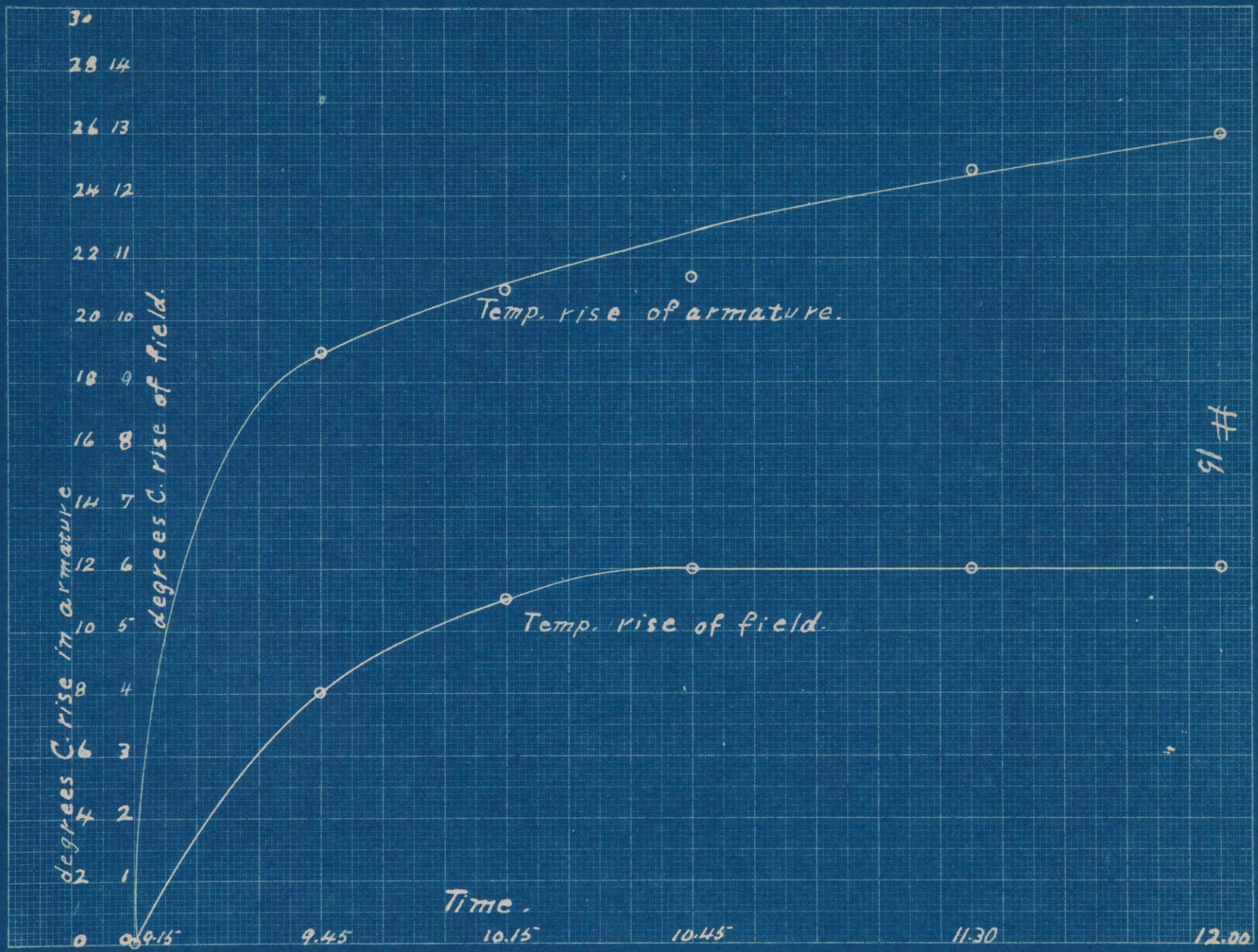



#13

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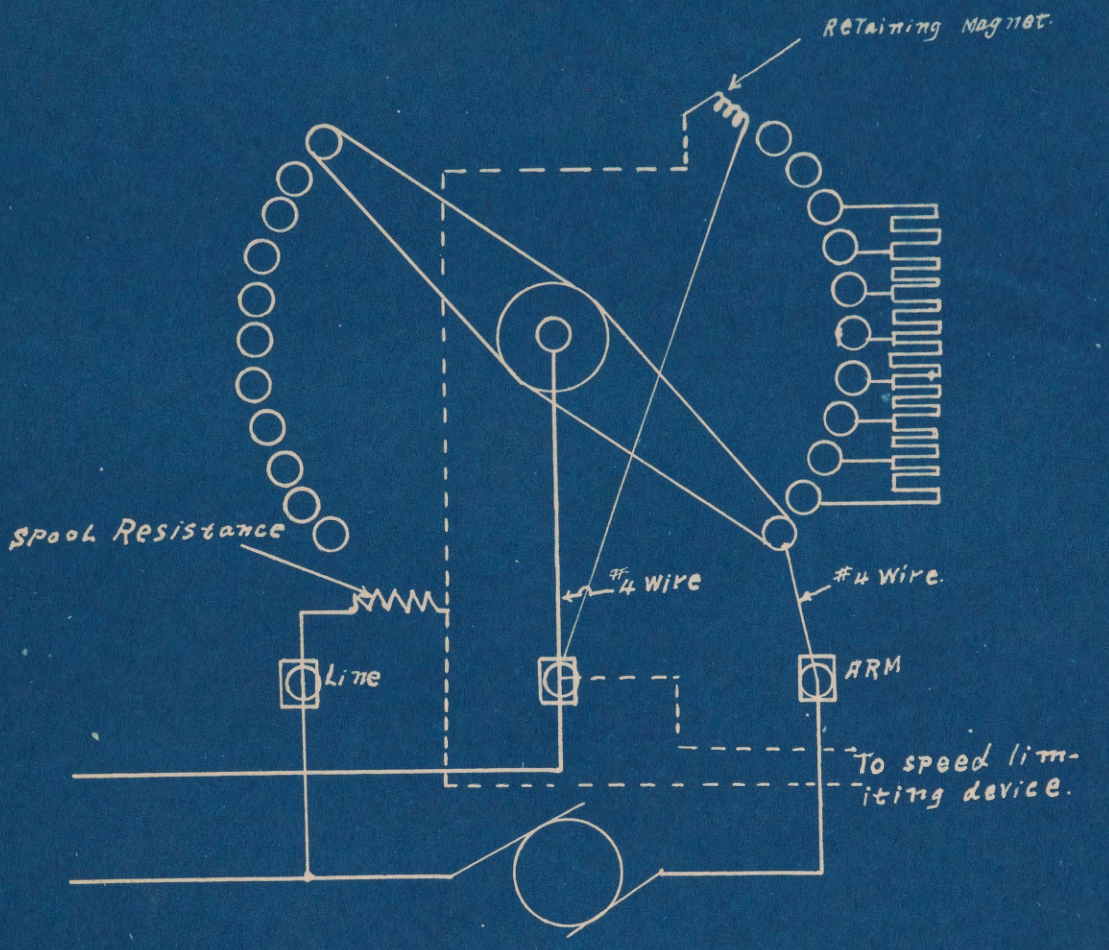



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#16




D.C. Rheo. S A. A.I— 160 volts
connections of starting switch with retaining magnet across the line in series with Resistance
G.E. Co. Schenectady N.Y.

5-9-23. ~~A.R.B.~~ S 5568.