THESIS

Characteristics of a Regulating Pole Synchronous Converter.

by

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CHARACTERISTICS OF A REGULATING POLE SYNCHRONOUS CONVERTER.

I. Introduction.

Toward the latter part of the College Year of 1913-14, the Department of Electrical Engineering was augmented by the arrival of a General Electric Double Current Generator, or Regulating Pole Synchronous Converter. Because it was such a small machine, and also because it was designed for 50 cycle current instead of a standard frequency, the regular factory tests were omitted. It was therefore desirable to run such tests as would disclose its characteristics and action under various conditions.

II. Description of the Converter.

In general the construction of a synchronous converter is similar to that of a direct current generator, with the addition of collector rings connected to the armature winding at equal distances around the armature. There are, however, several important details in which the construction of a synchronous converter differs from that of a direct current generator, notably in the arrangement of the armature winding, the shape of the pole tips, and, in the case of the regulating pole type, a complete auxiliary set of poles, narrower than the ordinary shunt field poles, and set between them in the frame.

Like all synchronous converters, it is equipped with a device for automatically opening the direct current circuit in case the speed becomes too high. This safety device (or speed-limiting switch, as it is generally called) consists of a switch which is operated by a centrifugal governor. The centrifugal weight is mounted on the shaft and revolves with it, while the switch is stationary and is mounted on the commutator end bearing-block. The switch can be adjusted to operate at any predetermined speed. Under normal operating conditions, the circuit of the emergency trip coil on the line circuit-breaker is open, but should the speed of the converter increase to the predetermined setting, the switch will close, thus tripping the line circuit-breaker.

The machine is also supplied with a four-pole, double-throw, field break-up switch for the shunt field. See Fig.III also diagram of field connections, Fig. Blue Print in Lab. This switch serves two purposes; it opens the field in several places to reduce the strain on the insulation, caused by the high potential induced in the fields during alternating-current starting, and it provides a means of obtaining the proper polarity. The switch is normally in the "up" position. The "down" position is used for reversing the polarity of the machine when it builds up wrong after alternating-current starting. When the switch is in the "down" position, the direction of the field is opposite to that induced by the alternating-current which causes the armature to "slip", thus reversing the polarity. When the polarity has been corrected, the switch is thrown to the operating position.

The machine has six collector rings, and may therefore be used on a line supplying six-phase alternating-current. The current most generally available, as in the present case, is three-phase which may be used with equal advantage.

Concerning frequency, this machine is built for 50 cycle current, while the standard form of synchronous converter is for 25 cycle or 60 cycle current.

The ratio of conversion between the alternating- and direct-current voltages is practically fixed, in ordinary synchronous converters by the design of the machine, except for a very slight modification of the ratio of pole arc to pole pitch, and cannot be materially changed by altering the shunt field strength. In the machine under test, however, the conversion ratio may be changed over a wide range by means of the Regulating Field, as will be explained later.

The synchronous converter possesses the same characteristics regarding power-factor as a synchronous motor; that is, for each load there is a certain field strength necessary to give unity power-factor input, and any variation from this field strength produces wattless current, the wattless component lagging if the machine is under-excited, and leading if over-excited. The best operating condition is obtained with unity power-factor input at the average load, because this condition gives the lowest heating in the armature and therefore the smallest loss.

The I^2R loss in a synchronous converter due to the energy current is materially less than in a direct current generator, owing tothe neutralizing effects of the motor and generator currents. The I^2R loss due to the wattless component of the current resulting from lagging or leading power-factor is, however, the same as in an alternating current generator.

Therefore a synchronous converter should be operated as near unity power-factor as possible. A compound wound converter, like the one under test, will operate at unity power-factor at only one load value for each adjustment of the shunt field. If the load varies, the field current should be adjusted unity power-factor at the average load.

III. Theory of The Regulating Pole.

The extensive use of synchronous converters, especially with electric lighting and power plants, frequently necessitates a variable ratio between the alternating current and direct current voltages.

Before the advent of the regulating pole converter the variation of conversion ratio from alternating current to direct current bus-bars had been obtained by means of auxiliary apparatus such as induction regulators, or voltage-varying dial switches connected to the taps of the transformer windings. These devices, however, are expensive and require attention.

To simplify the wiring arrangements and reduce the c cost of auxiliary devices, the General Electric Company has developed a regulating pole synchronous converter, the machine under test being the smallest commercial unit of this type built. In this machine, as in all others of modern design, the field structure is divided into two parts - a main pole and a regulating pole. The ratio between voltages on the direct current and alternating current sides may be readily varied by varying the excitation of the regulating poles, the only auxiliary apparatus required being a field rheostat for controlling the exciting current in the regulating field.

Consider a machine with a field structure like that shown in Fig. 1, resembling a machine with commutating poles, but with the brushes so set that one of the regulating poles adds its flux to that of one main pole, cutting the conductors between two direct current brushes. The regulating pole is shown with a width 20 percent of that of the main pole. To obtain definite figures it will be assumed that the machine at normal speed, with the main poles excited to normal, but no excitation on the regulating poles, gives 100 volts D. C. Then with each regulating pole excited to the same amount as the main poles and with a corresponding polarity, the D.C. voltage will rise to 120 volts, at the same speed, since the total flux cutting the conductors in one direction between brushes has been increased 20 percent. If the excitation of the regulating poles is reversed and increased to the same density as the main poles, the D. C. voltage will fall to 80 volts, since the regulating poles are opposing the main poles.

If new the machine is a converter, this variation of D.C. volts may be accomplished without altering the A.C.

voltage,provided the main field excitation remains the same. Fig. 2 shows the A.C. voltage developed in the armature winding by the two sets of poles. The horizontal line OA represents the A.C. voltage generated by the main poles,regulating poles unexcited,when delivering 100 volts D.C. For a six-phase converter OA is about 72 volts diametrical. If the regulating poles are excited to full strength to bring the D.C. volts up to 120,the A.C. voltage generated by the regulating poles will be 90 degrees out of phase with that generated by the main poles,since they are equally spaced between the main poles, and will be about 15 volts as shown by AB. This gives a resultant A.C. voltage OB equal to 73.6 . If the regulating poles are reversed to full strength to cut the D.C. voltage to 80,the A.C. voltage will again be 73.6 . It is therefore evident that with constant field the D.C. voltage may vary from 120 to 80 while the A.C. voltage varies from 72 to 73.6 volts.

The A.C. volts can be kept constant through the full range of D.C. volts by changing the main field so as always to give an equal and opposite flux change to that of the regulating filed. A constant total flux may thus be obtained equal to the radius of the circle BAC, Fig. 2 ; OA,the main field strength,will equal OB when the regulating field is unexcited,and it is then that 100 volts only can be obtained. This method of operation gives unity power-factor with constant e.m.f. of 73.6 volts A.C,and a

D.C. voltage range of 80 to 120 volts.

In practice, machines are not built as indicated diagramatically; that is, with regulating poles midway between the main poles, because a better construction is obtained by placing the regulating pole closer to the corresponding main pole, see Fig. 3, The effect on the D. C. Voltage remains unchanged except for magnetic leakage from the main pole to the regulating pole when the latter is opposed to the former. The effect on the A.C. voltage is somewhat altered. Fig 4 shows the effect on the A.C. voltage of varying the regulating field strength of a machine similar to Fig. 3, from a density equal to that in the main poles to the same amount reversed, main field excitation constant. The D.C. voltage in this case varies from 30 percent above that produced by the main field alone to 30 percent below, or from 130 to 70 volts, while the A.C. voltage varies from 80 to 70 volts. The A.C. voltage may be held constant by strengthening the main field as the regulating field is reversed and vice versa. This range, however, is seldom required. Assume therefore that the range is 90 to 125 volts, and that at the highest voltage both main and regulating fields have the same density, thus giving practically a continuous pole face of uniform flux intensity. The diagram of A.C. component voltages to give constant A.C. resultant voltage across the rings for this case is shown in Fig. 5. At 125 volts D.C. the main field produces an A.C. voltage OA, and the regulating field a voltage AB, with a resultant OB equal to about 78.5 volts A.C. At 107.5 volts D.C. the main field produces an A.C. voltage OA_1 and a regulating field voltage A_1B_1 giving a resultant A.C. voltage OB_1 equal to 78.5 volts. Similarly at 90 volts D.C. the main field produces an A.C. voltage OA_2, and the regulating field, now reversed, produces the voltage A_2B_2 giving the resultant OB_2 again equal to 78.5 volts. It will be noted that theoretically the main field strength must be increased about 15 percent above its value at 125 volts D.C. in order to keep the D.C. voltage at 90 volts.

IV. The Tests.

1. Measures taken to prevent hunting.

When the machine was set up and tried out it was found impossible to load it with more than 25 amperes, and even at this load it would sometimes fall out of step. Knowing the rated load to be 75 amperes, there was obviously something wrong. The first step taken to get rid of the hunting was to substitute heavy conductors (0000 stranded cable) from the secondaries of the transformers to the converter. This helped a great deal. The next step was to allow more transformer capacity, and accordingly two banks of transformers were paralleled. Each bank was connected ΔY, the Y being connected to the machine. Then the Induction Regulator was placed in the circuit between the transformer secondaries and the machine to maintain constant voltage. This also reduced the hunting. Separate excitation was then adopted as a further aid in the desired direction,and was used throughout the tests. Self excitation may,however,be employed.

As a result of these additions and considerable running under load the machine was made to carry 112.5 amperes or 150 percent of rated load without falling out of step.

It may be noted that during the heat run,as well as at other times after continued running under load,all hunting ceased;the meter needles holding a set deflection, and the machine operating without the characteristic pulses.

Before proceeding with the testing of the synchronous converter it was necessary to determine the A.C. voltage for best operation. This was limited to some extent by the available taps on the transformers used. Three complete tests were run at 70, 80, and 90 volts respectively, between the incoming three-phase lines;and it was determined that the best operation was approximately 80 volts. Other tests showed the correct voltage for best operation to be 78.5 volts. See page 55.

2. Resistances.

The resistances of the various windings were measured, several readings being taken with each method at the "cold" and "hot" temperatures. The following is a list of measurements and method employed:

	Wheatstone Bridge (Leeds & Northrup Potentiometer No. 9678.)		Vm. - - Am.	
	Cold	Hot	Cold	Hot
Synchronous Converter Armature	0.050	0.063	0.055	
Shunt Field	13.255	14.905	13.280	14.650
Series Field	0.016	0.018	0.017	
Reg. Field	18.507	19.805	18.520	19.400

3. The Voltage Ratios.

In order to determine whether the various taps had been brought out correctly, and were connected to their proper rings, readings of voltages between each ring were taken. The voltage between phases balanced up exactly as shown below. As will be seen from the data and diagram, the machine is connected"double delta"on the circular D.C. winding, so that three phase current may be applied. One delta is between rings 1-3-5, and the other is between 2-4-6

With the line voltage held at 78.5 volts applied, with 1.0 power factor, regulating field neutral,and 107.5 volts on the direct current side,carrying no load,the following voltages were obtained:

Between Rings	Voltage	Between Rings	Voltage
1 - 2	48	2 - 6	80
1 - 3	80	3 - 4	48
1 - 4	93	3 - 5	80
1 - 5	80	3 - 6	93
1 - 6	48	4 - 5	48
2 - 3	48	4 - 6	80
2 - 4	80	5 - 6	48
2 - 5	93		

With the A.C. line voltage held at 78.5 volts applied, 73.0 amperes A.C. with 1.0 power factor, and regulating field neutral, and 97.5 volts on the direct current side, carrying full load of 75 amperes D.C., the following voltages were obtained:

Between Rings	Voltage	Between Rings	Voltage
1 - 2	48	2 - 6	78.0
1 - 3	79	3 - 4	48.0
1 - 4	91.5	3 - 5	79.0
1 - 5	79	3 - 6	91.5
1 - 6	48	4 - 5	48
2 - 3	48	4 - 6	78
2 - 4	78	5 - 6	48
2 - 5	91.5		

See page 54.		Meters		Cap.
Line	78.5 v. A.C.	Weston	11583	150 v.
	97.5 v. D.C.	"	6427	150 v.
	73.0 a. A.C.	"	7970	150 a.
	75.0 a. D.C.	G. E.	252432	150 a.

The ratio of A. C. volts to D. C. volts is:

No Load.			Full Load.		
3 Phase A.C.	D.C.	Ratio	A.C.	D.C.	Ratio
83.5	123.0	67.9	83.5	114.0	73.2
78.5	115.0	68.0	75.0	103.0	73.0
79.0	113.4	69.0	78.5	107.5	73.0

The ratio of A. C. to D. C. currents is:

A. C.	D. C.	Ratio.
73	75	97.5

4. Core Loss Test --- Open Circuit.

The method employed for these tests was the "belted core loss method," which separates the core loss from the bearing friction, brush friction and windage. A small direct current motor was used to drive the machine under test, as a generator, at its rated speed. The rating was as follows: General Electric Continuous Current Motor, Shunt Wound, No. 340759, Speed 1650, Volts 115, H.P. 3, amperes 23.9; operated with a 4" and a 9 1/2" pulley onto a 7" pulley on the converter. The motor was operated with good commutation and a fixed setting of the brushes through the range of load required for the core loss test. The motor was operated above and below its rated speed in order to get a check on the test and on the motor losses. The belt tension was maintained just sufficient to overcome slipping, in order not to increase the bearing friction unnecessarily. The driving motor was wired so that readings could be taken of armature volts and amperes, and speed. A reading was taken on the motor corresponding to normal speed of the machine under test. The synchronous converter was wired with its field separately excited and provision made for reading armature volts,(and current in the Short Circuit Core Loss Test) also field volts and amperes. Several readings were taken of the armature resistance, both cold and hot, so as to determine the I^2R loss in the motor.

The test was then carried on as follows: the field of the driving motor was adjusted to about normal value, and excited from a source of constant voltage, so that it could be held constant throughout the test. The speed of the driving motor was regulated by varying the voltage applied to the armature. The motor was allowed to run the converter for a sufficient time to bring the friction to a constant value as determined by constant motor input, and no field on the converter. Readings were then taken of the input to the motor with the converter unexcited and all brushes down on the commutator of the converter. The difference between these two sets of readings gave the brush friction. Starting with zero field on the converter, observations of the input to the motor were made at various values of the field current up to that giving 125 percent mean normal load voltage. Correcting the motor input at these various field strengths by subtracting the I^2R loss of the armature of the driving motor, and the power input to the driving motor for zero field on the converter, the core loss at the various field strengths is found.

In order to insure constancy of friction losses during the test, readings of motor input for zero field were repeated during and after the test. Readings were also taken at the end of the test with normal voltage field current and with brushes raised from the commutator, for comparison with the reading in which the same field current was used with the brushes on the commutator, and with the set of readings giving the brush friction. The speed was held constant throughout the test by means of a Schuchardt und Schutte Tachometer, and a Hartmann and Kempf Frequencymeter. The brush tension was 0.8 lb. per brush.

The corrections for losses were made as indicated above, and the corresponding values of watts loss in the core were obtained. See pages 34-5 for data obtained, and also page 57 for curve. It will be observed that the motor was run at two different speeds, one above rating, viz. 2625 R.P.M., and one below, at 1115 R.P.M. The former was merely a check on the latter, as at the former speed belt slipping could not be avoided. As seen from the curves, the difference of the losses is constant throughout the test. The converter was run at its rated speed (1500 R.P.M.), the two motor speeds being caused by the ratios of pulleys used.

The tests are interesting as they show the effect on the results of the speed of the driving motor, and the slip of the belt. Curve "A" shows the relation between the direct current volts and the core loss at the check speed. Curve "B" shows the relation between the same two quantities at the test speed. Curve "A" is consistent with this, since at the check speed the losses are greater.

In order to obtain definite information concerning the core loss in the synchronous converter, use is made of mathematics and a formula is deduced. The curve "B" of page 57 is parabolic in form. It therefore follows some definite parabolic law, and it only remains to discover a formula expressing the correct relation between core loss and direct current volts. If the volts are squared and a curve plotted with these as ordinates, and watts loss as abscissae, we obtain a straight line, see page 56. Now using the equation of the parabola

$$X = a + by^2$$

and using any two points on the straight line, a formula may be obtained expressing the desired relation. Taking points (5045, 275) and (16190, 991) and substituting

$$\begin{array}{r} 275 = a + 5045b \\ 991 = a + 16190b \\ \hline 716 = 11145b \end{array}$$

therefore $b = 0.06424$
$a = -49.0$

Therefore $X = 0.06424y^2 - 49.0$

where X = core loss of synchronous converter in watts.
y = direct current volts generated.

The above formula was tested throughout the range plotted, and the maximum error was 0.3 percent, an error almost entirely personal, as another trial was 0.09 percent of the experimental value obtained. It will be seen that the core loss of the converter may be readily calculated for any value of the direct current volts generated.

5. Short Circuit Core Loss.

Synchronous alternating machines generally have loss measurements taken, not only on open circuit, but also on short circuit. In the latter case, the increase in power supplied by the driving motor over that required by the friction loss is plotted as ordinates against the armature amperes as abscissae. The curve obtained is similar in character to the open circuited core loss curve. Observations were made with the short circuited armature current up to 260 percent of its normal full load current. See pages 36 and 57.

6. Friction and Windage.

The friction and windage losses in the synchronous converter were found when driven by the small direct current motor used in the core loss test.

The brush friction is determined by finding the difference in driving motor amperes with brushes down and brushes up, and multiplying by the voltage. The friction and windage loss equals the difference in driving motor current with all brushes on the commutator up and with the belt off. See page 36.

7. Saturation - No Load - - Full Load.

The saturation test was made in order to ascertain the characteristics of the magnetic circuit. The "motor saturation" method was used. The machine was operated as a motor with no load and then with full load. The energy was supplied from the City, stepped down through the two banks of transformers, previously mentioned and led through the regulator to the converter. After the machine had attained synchronous speed, the field, already weak, was increased in small steps; but as the speed was independent of the motor field, the machine was regulated for minimum input current at each voltage. Readings were taken of armature volts and amperes, and also field volts and amperes.

The curves, see page 58, show the saturation or magnetization of the converter. As this magnetomotive force, which is caused by the ampere-turns of the field windings, acts over the reluctance of the magnetic paths, it produces a magnetic flux. The electromotive force is generated by varying this flux. The M.M.F. $=\frac{4\pi}{10}At$, but $\frac{4\pi}{10}t$ is a constant for the machine, therefore the field current is a measure of the M.M.F. Also the E.M.F. generated $=\frac{2\phi Nnp}{(60\times10^8)c}$ and as all but ϕ are constant at synchronous speed, the E.M.F. is a measure of the flux. For this reason the saturation curve may be drawn, taking the field current and the armature volts as coordinates.

8. Synchronous Impedance.

Synchronous Impedance was taken to determine the field current necessary to produce a given armature current when the machine is running short-circuited. The armature was first short-circuited through an ammeter, and then, with the machine running at synchronous speed and a weak field current, the current in each phase was read. The field current was gradually increased until 200 percent normal armature current was reached. Readings were also taken of armature volts and field volts, also current and speed.

The armature current in a polyphase machine produces a M.M.F. which remains constant for a given current,its angular position depending upon the power factor. It also produces a C.E.M.F. of self-induction, due to its stray field excitation. These two forces change the voltage directly as the current, that is, the change produced is directly proportional to the current. In as much as the resistance drop is also directly proportional to the current, the total change due to these forces may be expressed as a constant multiplied by the current. This constant is called the "Synchronous Impedance" of the machine; and as the line E.M.F. equals the induced E.M.F. minus the impedance E.M.F. IZ, we have $E_1 = E_m - IZ$. When the machine is short circuited, the terminal volts are zero, therefore $E_1 = E_g - IZ = 0$ or $E_g = IZ$. The current values obtained on short cirtuit and the voltage were plotted with the corresponding field excitation. Values of I & E for corresponding field excitation were thus obtained from which values of Z were taken; these were averaged, and as a result the value of 0.4258 ohm for "Synchronous Impedance" resulted.

However, Hay, in his "Alternating Currents" page 152 says: "The $\frac{\text{voltmeter reading in open circuit}}{\text{ammeter reading in short circuit}}$ = the impedance of the apparatus, which may be assumed constant under all conditions of load". This gives the value $\frac{21.5}{50} = 0.43$ ohm Synchronous Impedance.

9. Phase Characteristics.

In taking the phase characteristic curves to determine the field current for minimum input at a given load, the synchronous converter was operated as a motor from the regular source of alternating current, having a frequency and voltage desired at the point of minimum input. Starting with a weak field the armature volts and amperes, and the field volts and amperes were read. The field was increased by small steps up to and beyond the point of minimum input armature current. On a no-load phase characteristic curve, the watts input at the lowest point should check very closely with the sum of the core loss, friction and windage losses, since the power factor is unity on synchronous motors at this point. This was found to be the case. The first value being obtained as follows: $73.0 \times 9.8 \times 1.73 = 1.238$ kw. and the second value, see page

35, $85.4 \times 14.8 = 1.263$ kw. With a weak field the current is lagging, and with a strong field it is leading. Two no-load and two full-load phase characteristics were taken; see page Curve 1 was taken with the desired voltage at the point of minimum input. If this had been held constant throughout the run the left half of the curve would have been drawn at a less oblique angle, while that to the right would have tended more to the vertical - in no way affecting the minimum current input, however. Curve 4 shows the effect of holding 70 volts impressed on the machine. Curve 2 was taken holding A.C. volts constant and varying the main field only. Curve 3 was taken at the lowest limit of direct current volts, holding the A. C. and D. C. volts constant and adjusting the D. C. line current to that value which gives the rated output for the mid-voltage with zero auxiliary field.

10. Running Light Test.

The running light test was made to determine the shunt field excitation at the impressed D.C. voltage, and is taken on the synchronous converter with the machine running from the D.C. side. The D.C. voltage is held constant, while the shunt field is varied until rated speed is obtained. The input to the field and armature is then taken. See I page41 also page60.

Another test was made running light from the D.C. side, holding speed and shunt field current obtained from test. See II page 41 also page 60.

Another test was made holding speed constant and varying the shunt field. See III page42 also page60. The curves show the relation of D.C. and A.C. voltages to field current; and it may be seen that the A.C. voltage corresponding to D.C. mid-voltage of 107.5 is 77.5 volts. It was found in operating from the A.C. side that 78.5 volts impressed were necessary to hold the D.C. mid-voltage at 107.5 volts. This difference is probably due to experimental error, and the field current corresponding to 78.5 volts A.C. may be taken as correct.

11. Efficiency by Separate Losses.

The efficiency of the synchronous converter was calculated by the "separate loss" method at unity power factor. The losses were calculated at no-load and at each quarter load up to 50 percent over-load. The core loss, brush friction, friction and windage, resistance and temperature were previously obtained, and with these and the constance of the machine, the efficiencies were calculated.

The recorded values include the loss due to the regulating field and the shunt field, which are separately excited. However, the energy should be charged up against the converter as auxiliary to its operation. See pages 43 and 61.

12. Starting Tests.

Synchronous converters are designed to be started by one of the following methods:

1. Small induction motor.
2. From the alternating current side as an induction motor.
3. From the direct current side as a shunt motor.
4. From an auto-starter.
5. From normal-voltage tap of transformer by throwing the converter on the line through reactance coils.

The first three of these methods were used, as the others were not available.

1. In order to observe the volts and amperes necessary to start the machine, using the General Electric 10 H.P. Induction Motor mounted with it (see illustrations), it was necessary to use 3 phase energy from the Westinghouse Rotary Converter No. 629991. The volts and amperes necessary to start the machine were observed, but readings at synchronous speed could not be obtained because of 60 cycle supply.

2. The starting of the converter from the A.C. side

is similar to the starting of any synchronous motor, except that the field is left open-circuited, otherwise there would be destructive flashing at the commutator. In this condition there is generated in the field a very high voltage which would be liable to break down the insulation. To avoid this the field is "sectionalized", each section being connected independently to a double-throw break-up switch mounted on the frame of the converter as described in Section II. The switch is left open on starting and as soon as the machine has reached synchronous speed it is closed. If the direction of the D.C. voltage is wrong, the switch is closed in the "down" position until the right polarity obtains, when it is put in the "up" position.

3. The test as a shunt motor allowed the energy used at synchronous speed to be observed. The energy required to start by the three methods is as follows: 1. By induction motor 4.85 kw. 2. From A.C. side 5.77 kw. 3. From D.C. side 0.091 kw.

13. Voltage regulation with Regulating Field.

Having considered the principle of the regulating field(Sec. III) its operation is of interest and accordingly two tests were made taking the nine positions of the rheostat arm as indicated on the data sheet, under the following four conditions:

No Load Unity Power Factor.
Full Load " " "
No Load Constant Shunt Field.
Full Load " " "

The results of these tests agreed very closely as shown on page 62. As will be seen from the curves, extremes of the voltage range for no load are 133 volts and 55 volts, or a difference of 78 volts produced entirely by the regulating field; while those for full load, of 75 amperes, are 125 and 54 respectively.

The regulation, or range obtained by the regulating poles, of the synchronous converter is, therefore:

$$\text{No Load}\quad \begin{array}{r} 133 \\ 55 \\ \hline 78 \end{array}\ \text{volts} \qquad\qquad \text{Full Load}\quad \begin{array}{r} 125 \\ 54 \\ \hline 71 \end{array}\ \text{volts}$$

The regulation of the synchronous converter from the A.I.E.E. standardization Rules 1914 - Sec. 285, is found from the data and curves to be

$$\begin{array}{lr} \text{Terminal voltage no load} & 107.5 \\ \text{" " full "} & 95.5 \\ \hline \text{Regulation} & 12.0\ \text{volts} \end{array}$$

$$\text{Or}\qquad \text{Regulation}\quad \frac{12.0\ \ 100}{107.5} = 11.15\%$$

14. Normal Load Heat Run.

One of the most important tests of a converter is the heat run. It is made to determine the performance of the machine under operating conditions, the temperature rise of the various parts, and the location of any hot spots that might develope with continued running.

The normal load of 75 amperes was put on the machine, running as a straight rotary, for seven hours before the temperatures became constant. After four and one half hours the converter showed fewer signs of hunting, and at five hours no hunting was observed. This condition lasted until the end of the run.

15. Polarity Reversal In Synchronous Converters.

In the Electrical World, Vol. 65, page 210 there is an article by E.R.Shepherd, which sets forth some experiments made on the reversing switch in the field circuit. The purpose of the study is to determine just what takes place in the converter when the field switch is changed from "up" to "down" position. As the present machine was equipped with such a switch, it was desired to duplicate the experiment as far as possible. Accordingly the machine was synchronized by means of the induction motor, The stroboscopic disc showed that it came up to speed and locked in step. With the field switch open the volt meter read 97 volts, and the compass showed the poles alternately N and S. On closing the field switch in the "up" position the E.M.F. increased to 112. There was no shift of the armature as shown by the disc. On closing the switch "down" (reversing the main field), the D.C. armature voltage reversed to 10, and did disc showed a slip of half a pole in the direction opposite to armature rotation. On opening the switch the armature slipped another half pole and the voltage came up to 110 volts with poles reversed. With the switch in the "down" position the brushes were shifted along the commutator causing violent sparking, but it was not shifted enough to cause it to fall out of step.

As a result of the test it was determined that the "up" position was that designed for running. The "down" position is made use of when in starting up from the A.C. side as an induction motor and phasing in, the wrong polarity is given the D.C. voltage.

16. Oscillograph Curves.

The Oscillograph was used to show the character of the voltage and current waves in the line feeding the synchronous converter. A series of curves were traced showing the waves at the extreme positions of the regulating field rheostat, and under three conditions, viz: No load, constant shunt field; Full load, constant shunt field; and No load unity power factor. They were taken on the load side of the transformers, which were connected ΔY . The curves obtained showed plainly the harmonics in the line and distortion of the current, caused by the tendency of the converter to hunt.

V. Conclusions.

The foregoing experiments have brought out the characteristics of the regulating pole synchronous converter under test, and of this type of machine in general. The disadvantages of the machine are: its tendency to hunt, and its large losses. Its advantages are: its wide range of application, eg. as a synchronous converter, as a double-current generator, as an A.C. or D.C. generator, and as an A.C. or D.C. motor; and its voltage regulation by means of the regulating poles. With the tendency to hunt entirely eliminated by proper connections to the energy supply, it should prove a useful piece of laboratory apparatus.

VI. Data Sheets, Illustrations, Diagrams and Curves.

Operation of Synchronous Converter.

Reg. field neutral. Shunt field separately excited.

A.C.		Obs.	Obs.	D.C.		Field
Volts	Amps.	K.W.	P.F.	Volts	Amps.	Amps.
90	13.5	1.9	1.00	127.0	0	4.95
90	23.0	3.2	.93	126.5	10	4.95
90	33.5	4.6	.90	125.5	20	4.95
90	42.5	5.7	.88	124.5	30	4.95
90	54.0	7.1	.87	123.0	40	4.95
90	66.0	8.3	.87	122.0	50	4.95
90	76.5	9.4	.87	121.5	60	4.95
90	87.0	10.6	.87	120.0	70	4.95
90	98.0	11.7	.87	119.0	80	4.95
90	109.0	13.0	.88	118.0	90	4.95
80	21.0	1.8	1.00	109.0	0	3.9
80	28.0	2.9	.99	107.5	10	3.9
80	34.0	4.3	.98	106.0	20	3.9
80	41.0	5.3	.97	105.0	30	3.9
80	49.0	6.2	.96	103.0	40	3.9
80	60.0	7.6	.95	101.0	50	3.9
80	62.5	8.3	.95	100.5	60	3.9
80	78.0	10.5	.96	99.0	70	3.9

Operation of Synchronous Converter con.

A.C.		Obs.	Obs.	D.C.		Field
Volts	Amps.	K.W.	P.F.	Volts	Amps.	Amps.
80	83.0	11.2	.98	98.0	75	3.9
80	89.0	12.0	.99	97.5	80	3.9
80	97.0	13.2	.99	96.5	90	3.9
70	14.0	1.7	1.00	92.7	0	2.8
70	23.0	2.7	.98	92.0	10	2.8
70	30.0	3.6	.97	91.0	20	2.8
70	37.5	4.4	.97	89.5	30	2.8
70	45.0	5.4	.97	88.3	40	2.8
70	54.0	6.4	.95	87.3	50	2.8
70	61.0	7.3	.96	85.0	60	2.8
70	69.0	8.3	.97	84.0	70	2.8
70	77.0	9.3	.96	82.2	80	2.8
70	83.0	10.0	.97	81.0	90	2.8

Core Loss Tests.

Reg. field unexcited. 4" motor pulley. Motor field current 0.32 amp. Speed 1500 R.P.M.

Motor			Converter		
Volts	Amps.	Field Volts.	A.C. Volts	D.C. Volts.	Field Amps.
147.0	7.6	72.0	37.0	51.0	1.07
147.0	8.1	72.0	46.0	63.0	1.50
147.0	8.9	72.0	54.6	76.0	2.00
147.5	9.7	72.0	63.0	87.4	2.50
147.5	10.5	71.9	69.0	96.0	3.00
147.5	11.2	71.9	74.0	103.8	3.40
148.0	11.8	71.9	79.3	110.6	4.00
148.0	12.3	71.9	83.0	116.0	4.50
148.0	12.8	71.8	87.3	122.9	5.00
149.0	13.5	71.8	91.0	127.9	5.50
149.0	14.3	71.8	94.7	134.0	6.50
10498 Meters.	37604	5374	11583	6427	2844

With no field excitation on converter

147.0 6.2

	Loss		D.C.	
$147.0 \times (7.6 - 6.2) = 205.5$	watts.	51.0	Volts.	2600 Volts^2
$149.0 \times (8.1 - 6.2) = 1208.0$	watts.	134.0	Volts.	17960 Volts^2

Core Loss Tests.

Reg. field unexcited. 9 1/2" motor pulley. Motor field current 0.50 amp. Speed 1500 R.P.M.

Motor			Converter		
Volts	Amps.	Field Volts	A.C. Volts	D.C. Volts	Field Amps.
81.9	9.1	122.0	30.0	38.0	1.0
84.3	11.3	122.0	53.1	71.0	2.0
85.1	13.9	122.2	67.5	91.8	3.0
85.4	14.8	122.5	71.9	98.1	3.4
86.2	16.0	122.6	77.0	106.4	4.0
87.0	18.0	121.9	84.5	118.0	5.0
87.5	19.8	121.4	90.8	127.2	6.0
89.5	22.0	121.0	97.0	137.4	7.35
10498 Meters.	37604	5374	11583	6427	2844

With no field excitation on converter

81.9 8.0

	Loss		D.C.	
81.9 × (9.1–8.0) = 89.8	watts.	38.0	Volts	1442 Volts^2
89.5 × (22.0–8.0)=1197	watts.	137.4	Volts	18890 Volts^2

Short Circuit Core Loss.

Reg. field unexcited. 9 1/2" motor pulley. Motor field current 0.50 amp. Speed 1500 R.P.M.

Motor			Converter				
Volts	Amps.	Field Volts	A.C. Volts	A.C. Amps.	D.C. Volts	Field Amps.	Loss K.W.
83.0	9.3	115.0	2.4	15.0	-	0	0.1079
84.9	14.3	114.8	10.0	61.2	-	0.82	0.535
86.2	19.6	114.2	11.5	89.0	17.5	1.22	1.000
86.0	26.8	106.0	13.0	112.0	21.0	1.48	1.618
85.8	27.3	113.3	15.0	112.5	22.0	1.60	1.655
85.3	33.5	113.4	18.0	130.0	24.5	1.80	2.175

Friction and Windage.

Motor					
Volts	Amps.	Field Amps.	Pulley in.	Field Volts	Remarks
147.0	6.20	0.32	4	72.0	No field on converter.
148.0	3.80	0.32	4	72.0	All brushes up.
142.5	2.60	0.32	4	72.0	Motor only.
81.9	8.00	0.50	9 1/2	122.0	No field.
81.0	5.40	0.50	9 1/2	121.4	D.C. brushes up.
80.0	3.80	0.50	9 1/2	121.6	All brushes up.
81.0	1.60	0.50	9 1/2	121.7	Motor only.

Saturation (No Load and Full Load).

Constant speed. Impressed voltage varied. Field current adjusted for minimum current demand per voltage.

	A.C. Volts	D.C. Volts	D.C. Amps.	Field Volts	Field Amps.
No Load	23.4	37.5		11.0	0.8
	41.9	62.2		20.5	1.5
	53.2	76.0		27.0	2.0
	62.2	89.2		34.0	2.5
	68.1	97.6		41.1	3.0
	74.3	106.6		48.2	3.5
	79.2	113.4		55.7	4.0
	83.9	119.7		63.0	4.5
	87.3	125.0		70.5	5.0
	91.2	131.3		81.2	5.5
	94.0	134.0		88.0	6.0
	89.0	127.2		74.0	5.0
	82.2	117.2		60.0	4.0
	72.1	103.2		44.8	3.0
	58.1	83.1		30.0	2.0
	31.6	52.2		15.0	1.0
Full Load	33.0	44.0	75.0	33.8	2.35
	47.2	68.5	75.0	43.4	3.0
	55.9	82.2	75.0	51.0	3.5
	62.0	91.8	75.0	58.1	4.0

Saturation (No Load and Full Load).

Full Load A.C. Volts	D.C. Volts	D.C. Amps.	Field Volts	Field Amps.
67.8	102.0	75.0	66.3	4.50
73.0	109.6	75.0	75.0	5.00
60.0	88.8	75.0	55.2	3.65
51.0	75.8	75.0	46.3	3.10
42.5	56.0	75.0	37.0	2.45
34.0	46.0	75.0	33.0	2.20
26.0	34.0	75.0	30.0	2.00

Synchronous Impedance.

Speed 1500 R.P.M.

Short A.C. Circuit Amps.	Open Circuit Volts	Field Amps.	Field Volts
45	19.0	0.593	8.0
50	21.5	0.671	9.0
55	24.0	0.750	10.0
60	26.0	0.82	11.0
65	28.0	0.90	12.0
70	30.0	0.97	13.0
75	32.0	1.04	14.0
80	34.0	1.12	15.0
85	35.8	1.20	16.0
90	37.5	1.27	17.0
95	40.0	1.34	18.0
100	42.5	1.42	19.0
10942	6427	456	27904

Phase Characteristics.

No Load.	A.C. Volts	Amps.	Obs. P.F.	Obs. K.W.	Field Volts	Field Amps.	D.C. Volts	
I.	65.0	52.0	.63	3.7	14.5	1.00	93.5	
	69.8	29.0	.90	3.0	29.0	2.00	98.0	
	73.0	9.8	1.00	1.3	43.5	3.00	102.0	
	74.8	11.5	.95	1.45	49.0	3.39	102.6	
	76.9	21.5	.84	2.4	59.0	4.00	104.9	
	79.0	39.5	.67	3.6	72.5	5.00	107.9	
	81.0	58.0	.60	5.0	88.5	6.00	110.0	
	1557 Meters.	10942	114058	65139	5374	456	6427	
							D.C. Volts	Amps
II.	68.7	89.0	.93	9.8	14.5	1.00	84.0	75.0
	73.0	79.0	.95	9.5	28.0	2.00	88.0	75.0
	75.0	69.5	1.00	9.0	44.0	3.00	89.5	75.0
	75.0	74.0	.88	8.4	59.0	4.00	87.0	75.0
	75.0	85.0	.72	8.0	73.3	5.00	87.5	75.0
III.	70.0	71.8	.99	8.6	30.0	2.05	83.0	75.0
	70.0	69.5	.96	8.1	44.0	3.00	81.5	75.0
	70.0	70.0	1.00	8.0	34.5	3.40	80.6	75.0
	70.0	81.5	.77	7.6	59.5	4.05	80.0	75.0
	70.0	99.0	.36	4.3	-	0	-	-

Phase Characteristics.

	A.C.		Obs.	Obs.	Field		D.C.	
	Volts	Amps.	P.F.	K.W.	Volts	Amps.	Volts	Amps.
IV.	70	98.0	.70	8.3	6.0	0.50	90	62.5
	70	73.3	.82	7.2	14.0	1.00	90	44.8
	70	42.5	.85	4.4	28.0	2.00	90	30.0
	70	27.0	.96	3.1	43.0	3.00	90	19.0
	70	44.0	.35	1.8	58.0	4.00	90	12.0
	70	60.0	.10	0.7	67.0	4.60	90	4.0
V.	70	73.0	.05	4.5	73.0	5.10	90.0	0
	70	41.5	.45	2.3	58.5	4.00	91.3	0
	70	15.0	.88	1.6	44.0	3.00	92.5	0
	70	13.0	1.00	1.6	41.0	2.80	92.8	0
	70	31.3	.60	2.3	29.5	2.00	94.8	0
	70	67.5	.39	3.2	14.5	1.00	98.0	0

Running Light Test.

Impressed volts 100.0

	Shunt Field	Arm. Amps.	R.P.M. Speed
I.	8.0	9.5	1015
	7.5	9.5	1040
	7.0	9.5	1070
	6.5	9.5	1100
	6.0	9.5	1140
	5.5	9.5	1150
	5.0	9.5	1200
	4.5	10.2	1275
	4.0	10.5	1330
	3.5	10.6	1415
	3.0	10.8	1500
	2.5	11.3	1650

	D.C.		A.C.		Field	
	Volts	Amps.	Volts	Amps.	Amps.	Speed
II.	98.4	11.5	69.2	0	3.39	1400
	102.0	11.3	71.9	0	3.39	1450
	107.0	11.0	75.0	0	3.39	1500
	110.3	12.0	77.3	0	3.39	1550
	113.0	12.3	79.5	0	3.39	1600

Running Light Test.

	D.C.		A.C.		Field	
	Volts	Amps.	Volts	Amps.	Amps.	Speed
III.	92.3	12.5	66.8	0	2.75	1500
	97.2	12.9	70.0	0	3.00	1500
	103.5	13.0	74.3	0	3.50	1500
	108.0	13.1	77.5	0	3.75	1500
	111.9	13.2	79.9	0	4.00	1500
	114.0	13.4	80.9	0	4.30	1500
	122.4	13.9	87.0	0	5.05	1500
	130.9	14.0	92.3	0	6.00	1500
	137.0	14.1	96.7	0	7.00	1500
	141.0	14.2	98.9	0	7.60	1500

Calculations of Efficiency.

Percent of Rated Load	25	50	75	100	125	150
Line Amperes	18.75	37.50	56.30	75.00	93.75	112.5
Shunt Field Amperes	3.8	3.8	3.8	3.8	3.8	3.8
Armature Amperes	22.55	41.3	60.1	78.8	97.55	116.3
Terminal Volts	90.0	90.0	90.0	90.0	90.0	90.0
Armature Drop	0.725	1.45	2.18	2.90	3.63	4.35
Series Field Drop	0.235	0.47	0.705	0.94	1.175	1.41
Brush Drop	1.85	1.37	1.55	1.74	1.925	2.11
Total Induced Volts	92.81	93.29	94.44	95.58	96.73	97.97
Core Loss	0.535	0.540	0.550	0.560	0.580	0.595
Armature I^2R Loss	0.019	0.063	0.134	0.228	0.352	0.501
Series Field Loss	0.006	0.020	0.043	0.074	0.114	0.162
Shunt Field Loss	0.342	0.342	0.342	0.342	0.342	0.342
Regulating Field Loss	0.076	0.076	0.076	0.076	0.076	0.076
Brush Loss	0.053	0.112	0.187	0.272	0.375	0.490
Brush Friction	0.251	0.251	0.251	0.251	0.251	0.251
Friction and Windage	0.275	0.275	0.275	0.275	0.275	0.275
Total Losses	1.557	1.675	1.858	2.078	2.365	2.692
Kilowatt Output	1.69	3.38	5.06	6.75	8.44	10.12
Kilowatt Input	3.24	5.05	6.92	8.82	10.80	12.81
Efficiency in Percent	53.0	67.0	73.0	77.0	78.0	79.0

Starting Tests.

I. With Small Induction Motor.	A.C. Volts	Amps.	P.F.
	31.0	92.5	.98
	30.0	93.0	.97
	31.0	92.0	.98
	31.0	92.0	.98

II. A.C. Side as Ind. Motor.	Volts	Amps.
	23.0	140.0
	23.5	140.0
	23.0	145.0
	23.0	146.0

III. D.C. Side	D.C.	
as Shunt	6.0	18.0
Motor.	5.0	20.0
Sh. F. 1.5a.	5.0	19.0
	4.0	12.0
	3.5	14.0
Sh. F. 3.8a.	3.5	15.0
	4.5	14.0
Sh. F. 3.9a.	4.0	16.0

At synchronous speed:

V.	A.
114.2	12.0
114.0	12.0

Voltage Regulation with Regulating Poles.

Osc.	A.C.		Sh.Field	Reg. Field		D.C.		Reg.
No.	Amps.	P.F.	Volts	Volts	Amps.	Volts	Amps.	Field
1.	9.0	1.00	54.5	122.0	0.42	107.5	0	↓
2.	11.0	.83	54.5	121.5	0.52	112.0	0	↘
3.	18.5	.50	55.5	121.2	0.91	116.8	0	→
4.	43.0	.24	55.2	120.8	2.14	125.0	0	↗
5.	83.0	.02	55.0	120.0	5.85	133.0	0	↑
6.	9.4	.93	55.6	121.0	0.53	102.1	0	↙
7.	11.3	.75	55.6	120.9	0.88	96.8	0	←
8.	16.7	.58	55.5	120.3	2.12	77.8	0	↖

Voltage Regulation with Regulating Poles, and Oscillograph Data.

Osc. No.	A.C. Amps.	P.F.	Sh.Field Volts	Reg. Volts	Field Amps.	D.C. Volts	D.C. Amps.	Reg. Field
9.	13.4	.77	55.2	119.5	5.95	55.0	0	↑

Above data taken at No Load, constant shunt field; A.C. volts 78.5; shunt field amperes 3.8

Data below taken at Full Load constant shunt field; A.C. volts 78.5; shunt field amperes 3.8

10.	65.0	.99	55.5	129.3	0.45	94.0	75	↓
11.	69.0	1.00	55.2	129.0	0.58	99.5	75	↘
12.	75.5	.94	55.1	128.8	0.98	113.0	75	→
13.	96.0	1.00	55.1	128.0	2.28	114.0	75	↗
14.	Too much load for transformers.							
15.	63.0	1.00	55.2	128.8	0.59	90.0	75	↙
16.	63.0	.99	55.2	128.3	0.93	85.0	75	←
17.	57.5	.95	57.0	128.0	2.26	70.0	75	↖
18.	54.0	.85	56.8	126.9	6.18	52.0	75	↑

Data below taken at No Load 1.0 power factor; A.C. volts 78.5;

		Sh.Field						
		Volts	Amps.					
19.	9.0	22.3	1.52	127.5	6.10	128.0	0	↑
20.	10.5	32.3	2.25	128.0	2.22	126.0	0	↗
21.	9.5	45.0	3.12	127.8	0.98	118.5	0	→
22.	9.0	49.0	3.37	127.8	0.58	114.3	0	↘
23.	10.0	54.0	3.70	127.5	0.45	109.5	0	↓
24.	10.0	58.4	3.95	127.2	0.58	100.0	0	↙
25.	9.0	61.0	4.10	126.0	0.97	93.0	0	←

Voltage Regulation with Regulating Poles, and Oscillograph Data.

Osc.	A.C.	Shunt	Field	Reg.	Field	D.C.		Reg.
No.	Amps.	Volts	Amps.	Volts	Amps.	Volts	Amps.	Field
26.	9.0	63.5	4.38	125.4	2.22	77.5	0	↖
27.	10.5	60.5	4.05	124.2	6.24	56.0	0	↑

Data below taken at Full Load 1.0 power factor; A.C. volts 78.5

	69.0	51.0	3.55	129.1	0.53	96.5	75	↓
	72.0	43.5	3.00	128.0	0.65	102.0	75	↘
	73.5	38.0	2.65	128.1	1.15	106.0	75	→
	79.0	20.0	1.40	128.2	1.80	116.0	75	↗
	83.0	13.0	0.95	128.5	3.10	119.0	75	↑
	66.5	54.0	3.80	128.8	0.60	91.0	75	↙
	64.5	56.8	4.00	128.7	0.92	86.5	75	←
	57.5	66.0	4.60	128.0	2.00	75.0	75	↖
	49.0	72.5	4.80	127.8	6.65	57.0	75	↖

Normal Load Heat Run.

Power Factor 1.0 A.C. Volts 78.5 D.C. Amps. 75.0

Time	A.C. Amps.	Cal. K.W.	D.C. Volts	Shunt Volts	Field Amps.	Temperatures 1. F.	2. C.	3. C.	4. F.
12:10						70.9	24.0	23.0	73.3
12:40	15.6	2.12	109.5	62.0	3.90	77.0	44.0	29.0	94.5
1:00	73.0	9.91	98.0	62.0	3.90	77.6	49.0	31.8	101.5
1:30	72.5	9.85	99.0	62.0	3.90	78.0	53.0	35.1	107.1
2:00	72.5	9.85	99.0	62.0	3.90	78.3	55.0	37.8	111.3
									C
2:30	74.0	10.00	99.0	62.0	3.90	77.0	58.0	39.9	46.3
3:00	73.0	9.91	99.0	62.0	3.90	80.1	60.0	42.0	50.4
3:30	73.0	9.91	99.0	62.0	3.90	78.0	61.0	42.6	51.7
4:00	73.0	9.91	99.0	62.0	3.95	75.8	63.0	43.0	52.8
4:30	73.0	9.91	99.0	62.0	3.95	76.5	63.7	44.0	52.9
5:00	72.5	9.50	98.0	62.0	3.95	76.5	64.9	46.0	53.4
5:30	73.0	9.91	99.0	62.5	3.95	77.6	65.0	47.1	54.0
6:00	71.5	9.70	98.0	62.0	3.95	77.3	65.8	47.0	54.3
6:30	71.5	9.70	99.0	62.5	3.95	76.1	66.0	47.0	54.8
7:00	71.5	9.70	99.0	62.5	3.95	76.0	66.1	47.1	55.0
7:30	71.5	9.70	99.0	62.5	3.95	75.9	66.1	47.0	55.1
8:00	71.5	9.70	99.0	62.5	3.95	76.0	66.1	47.0	55.2

Normal Load Heat Run.

Temperatures.

Time	5. C	6. C	7. C	8. C
2:30	38.8	25.0	33.0	
3:00	40.7	25.0	35.2	
3:30	41.9	24.9	35.5	
4:00	42.8	24.8	37.5	
4:30	43.3	24.6	38.5	
5:00	43.8	24.7	39.5	
5:30	44.2	24.6	39.8	
6:00	44.7	24.3	40.0	50.0
6:30	45.0	24.2	40.2	52.4
7:00	45.2	24.0	40.4	52.5
7:30	45.2	24.0	40.5	52.5

Temperatures:

1. Room.

2. Shunt Field Pole Face.

3. Regulating Pole.

4. Shunt Field.

5. Bearing.

6. Room.

7. Frame.

8. Transformers.

VI. Illustrations, Diagrams, and Curves.

Illustrations.

1. Shows Regulating Field Rheostat.
2. General Layout.
3. Shows Terminal Board with Four-Pole Field Break-up Switch.
4. Shows Speed Limit Device, Regulating and Shunt Field Poles, and Induction Voltage Regulator.

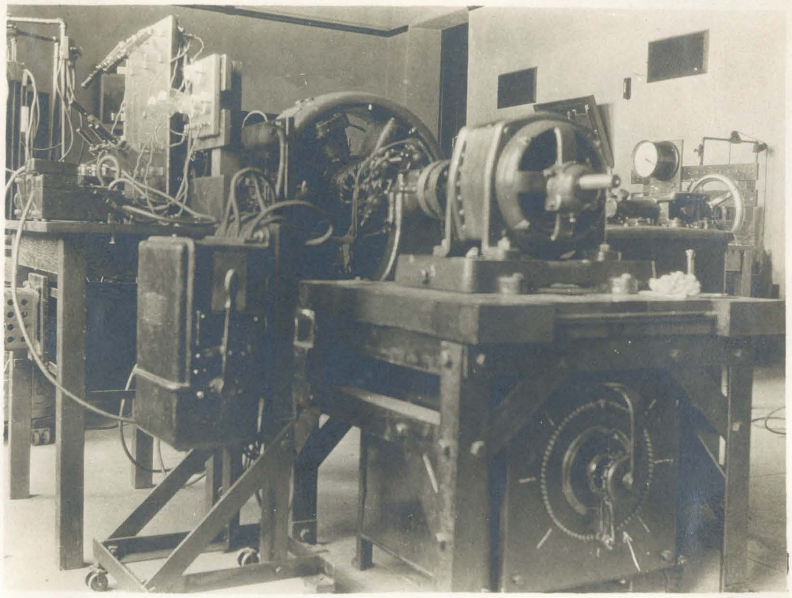


Fig. I.

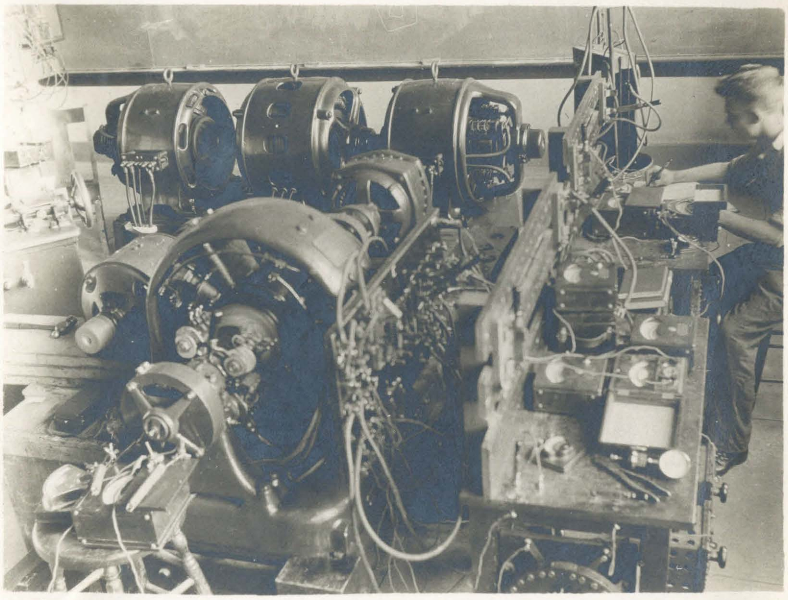


Fig. II.

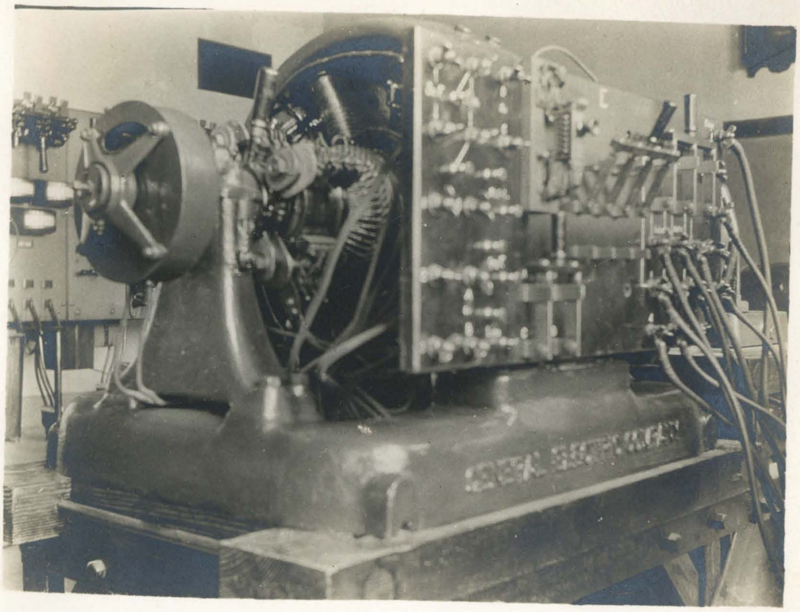


Fig. III.

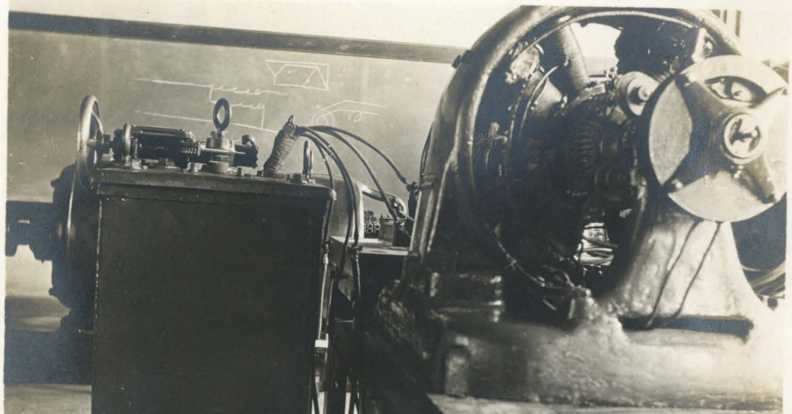
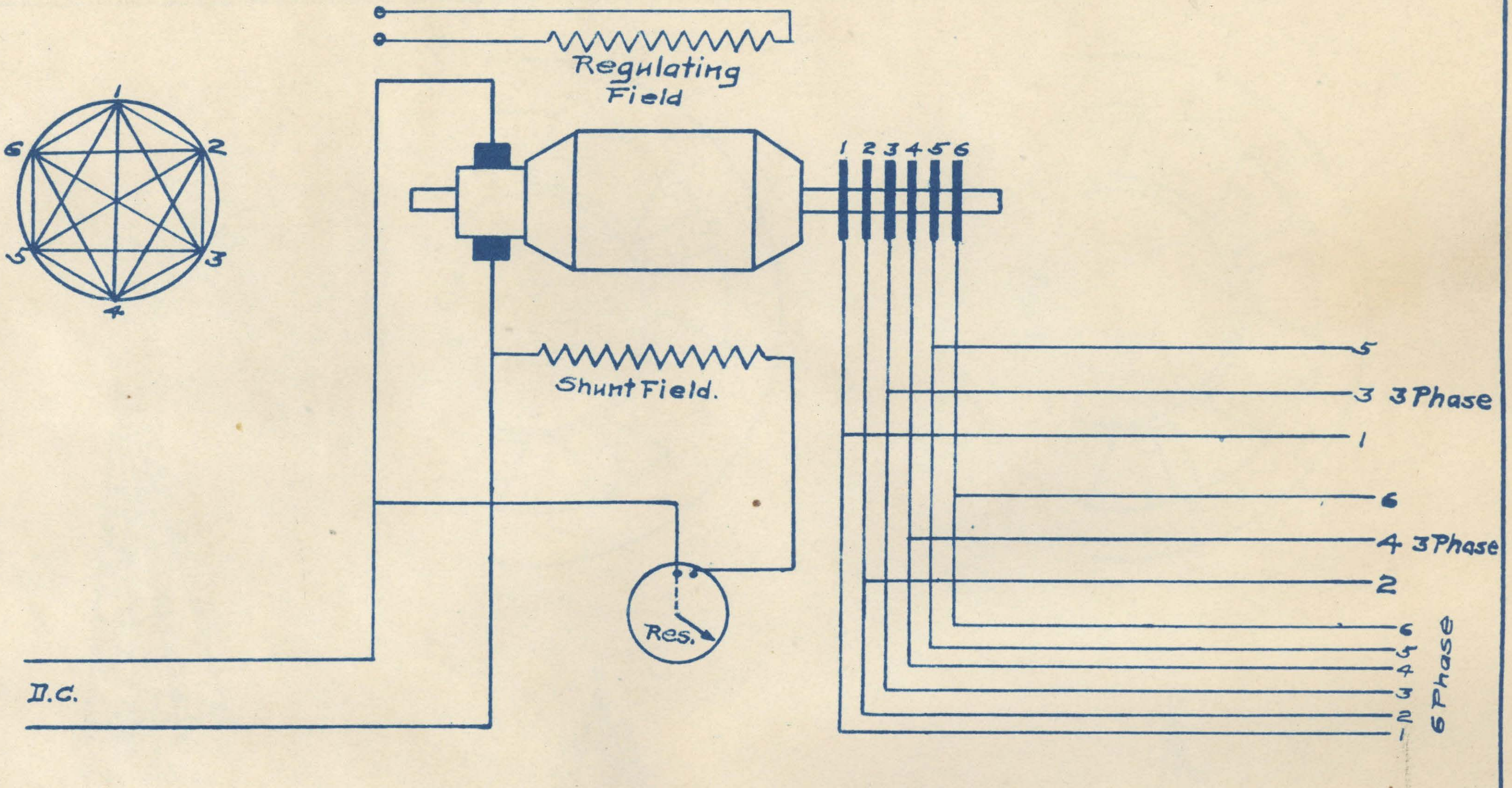


Fig. IV.



1 Phase A.C. Volts = 70.7% D.C. Volts.
3 " " " = 61.2% D.C. " .
6 " " " = 35.3% D.C. " .

Thesis.

Diagram of Connections.
G.E. Regulating Pole
Synchronous Converter.
No. 695701.

W. M. Holmes.

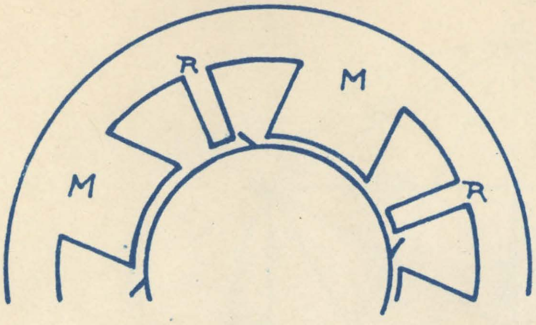


Fig. 1.

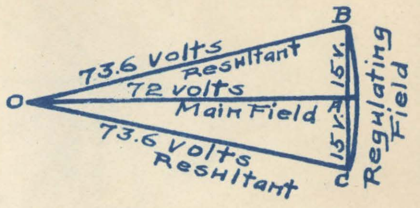


Fig. 2.

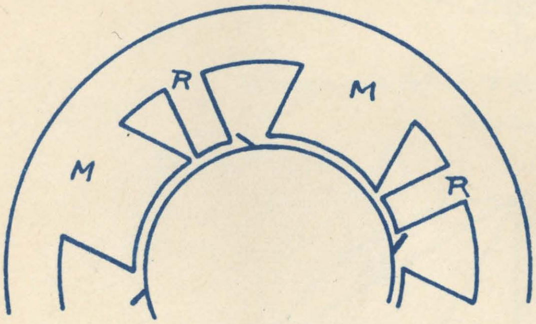


Fig. 3.

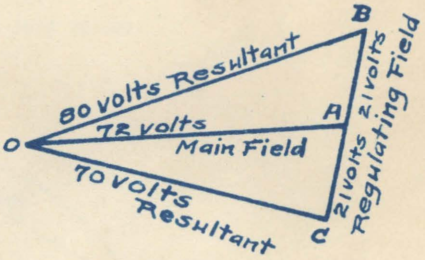


Fig. 4.

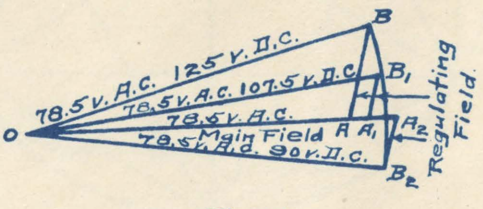


Fig. 5.

Theory of the Regulating Pole.

The Voltage Ratios.

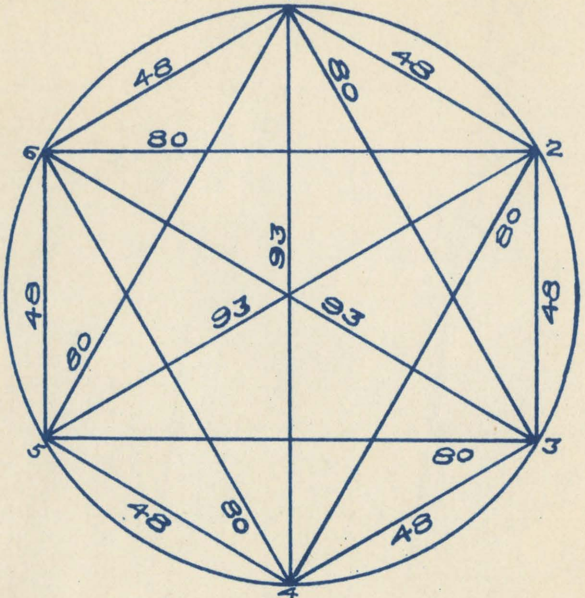


Fig. 6

Diagram of Voltages on A.C. Side
No load.

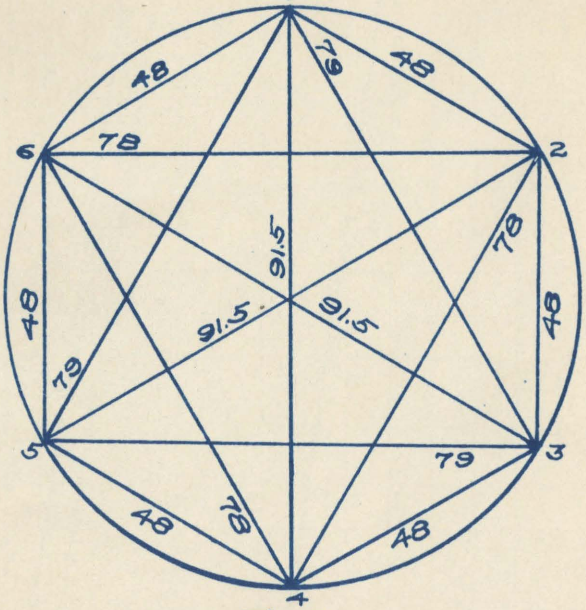
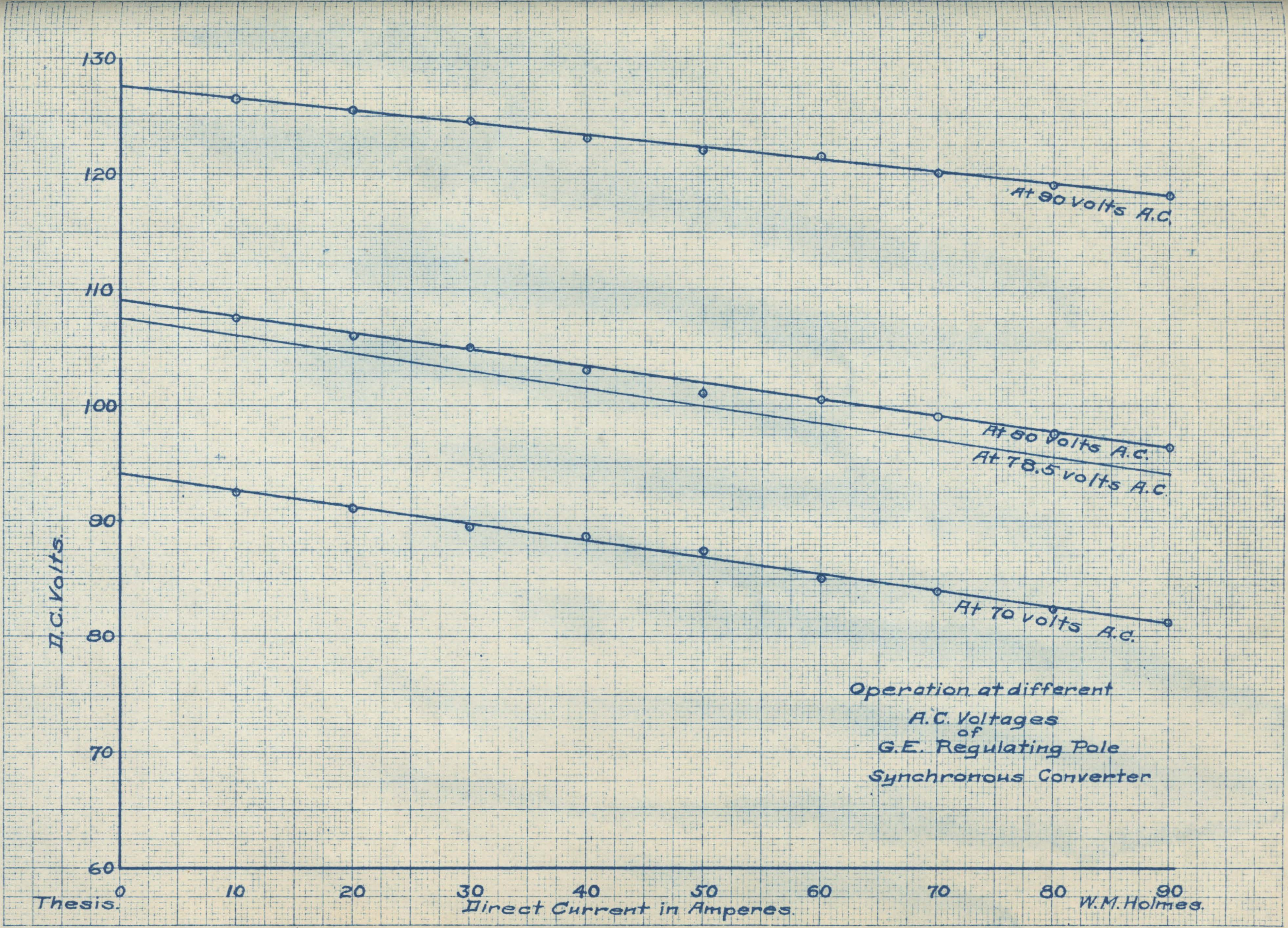


Fig. 7.

Diagram of Voltages on A.C. Side
Full load. 75 A.



Operation at different
A.C. Voltages
of
G.E. Regulating Pole
Synchronous Converter

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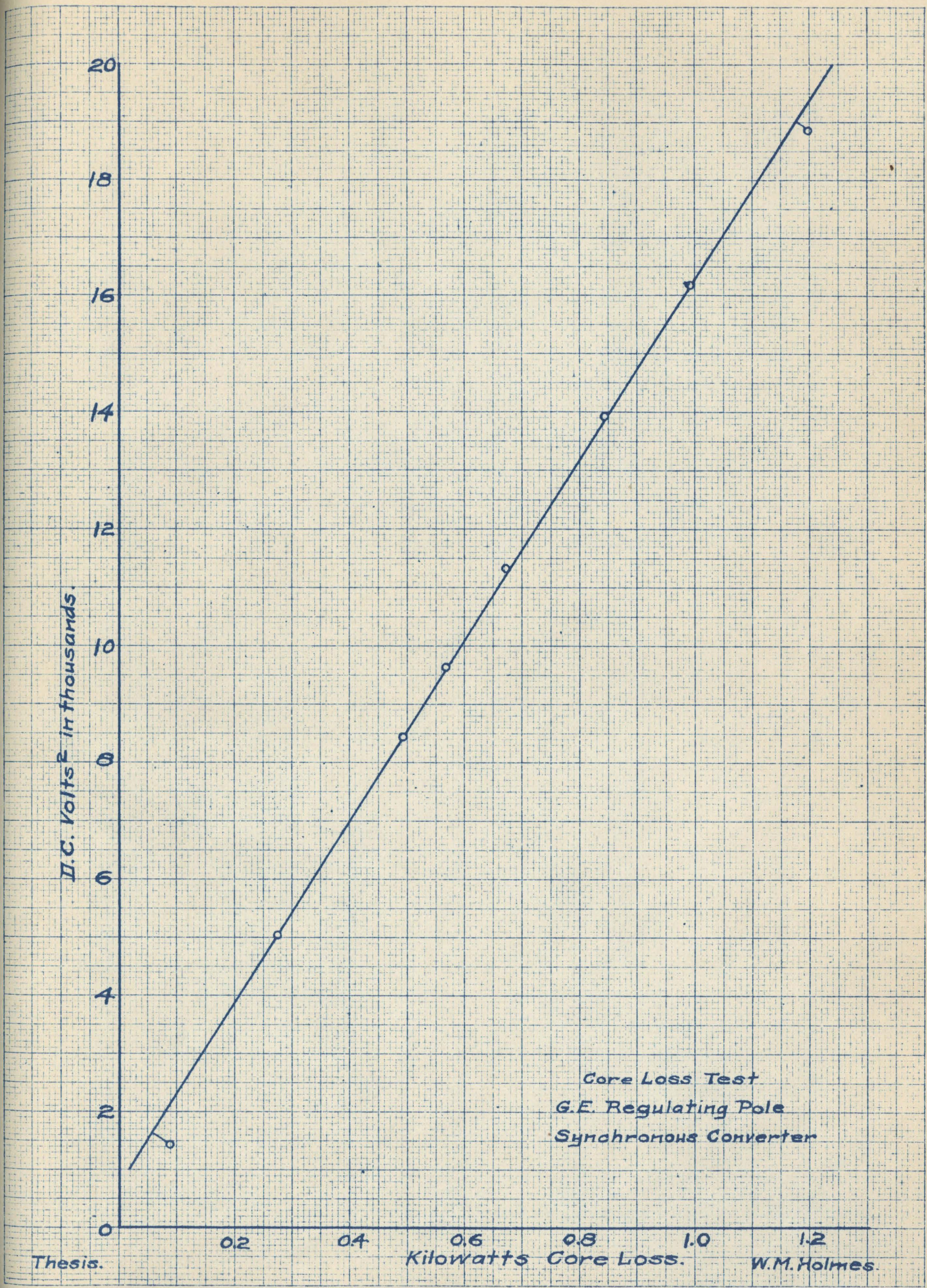

Core Loss Test
G.E. Regulating Pole
Synchronous Converter

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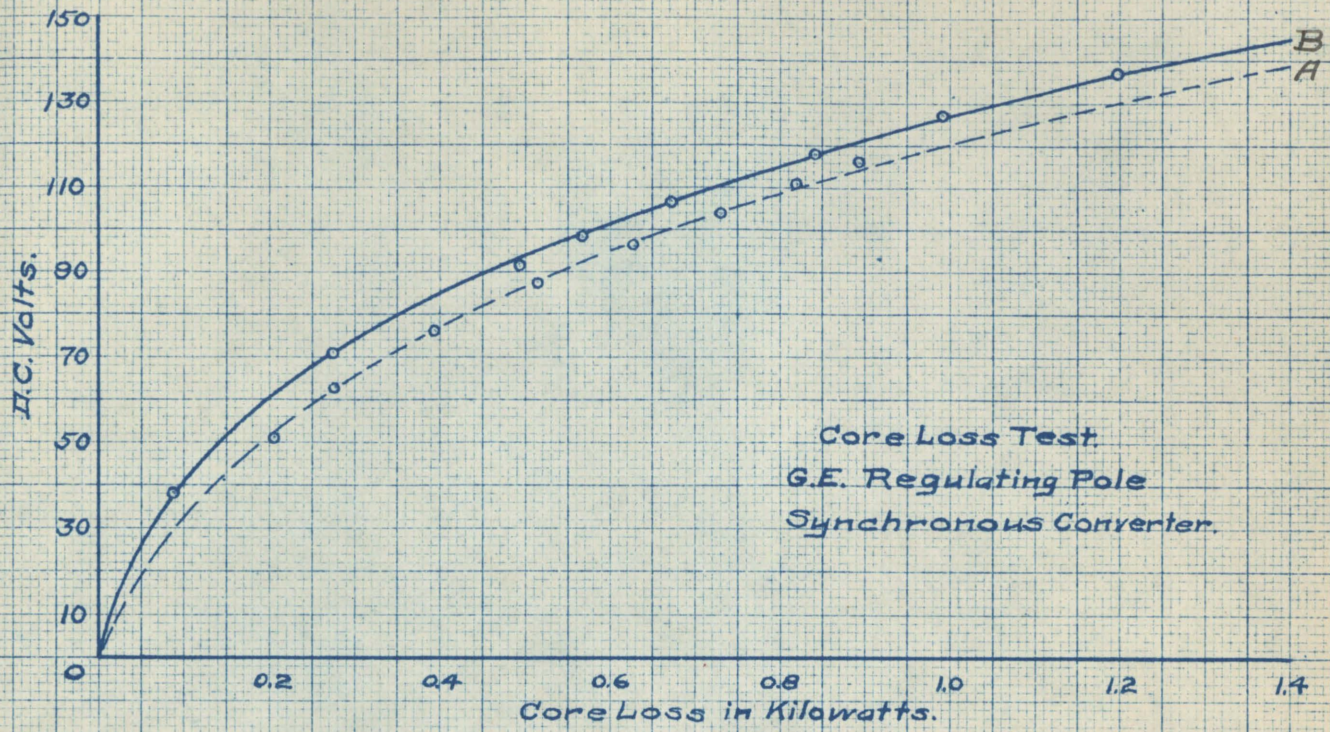

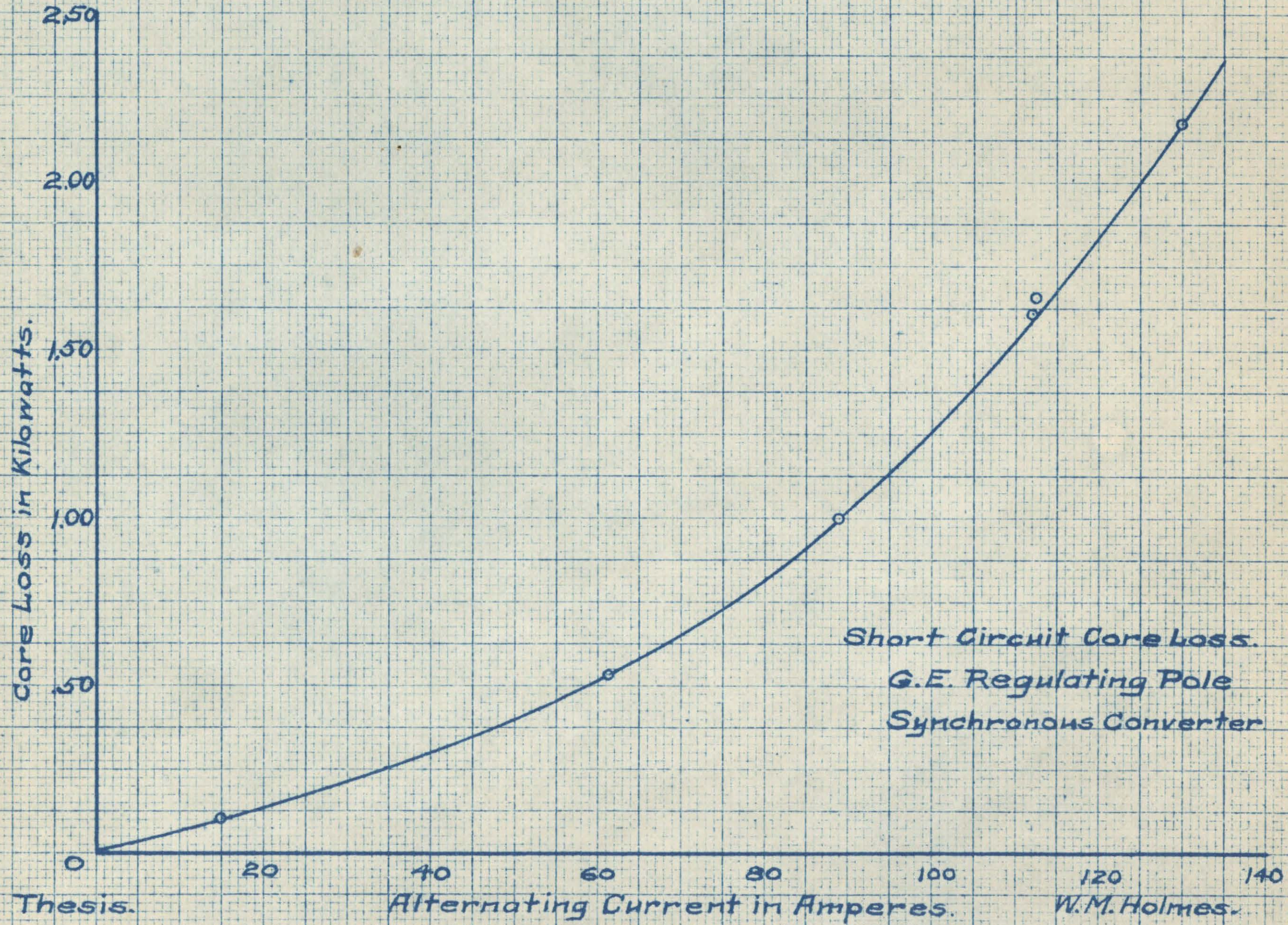

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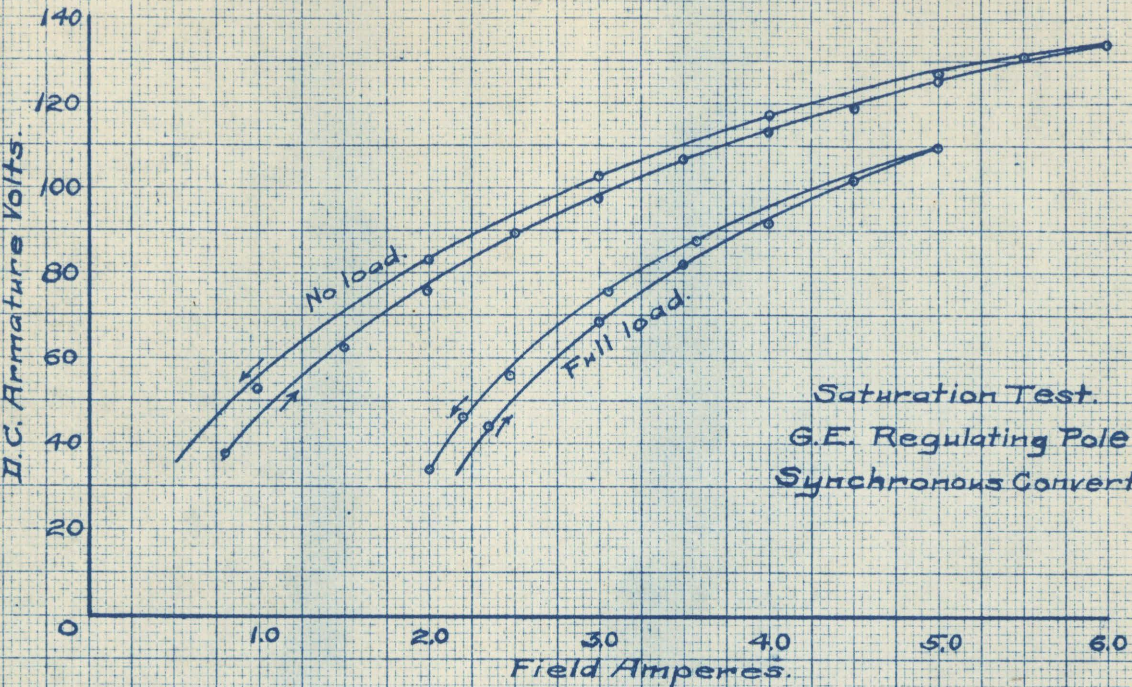
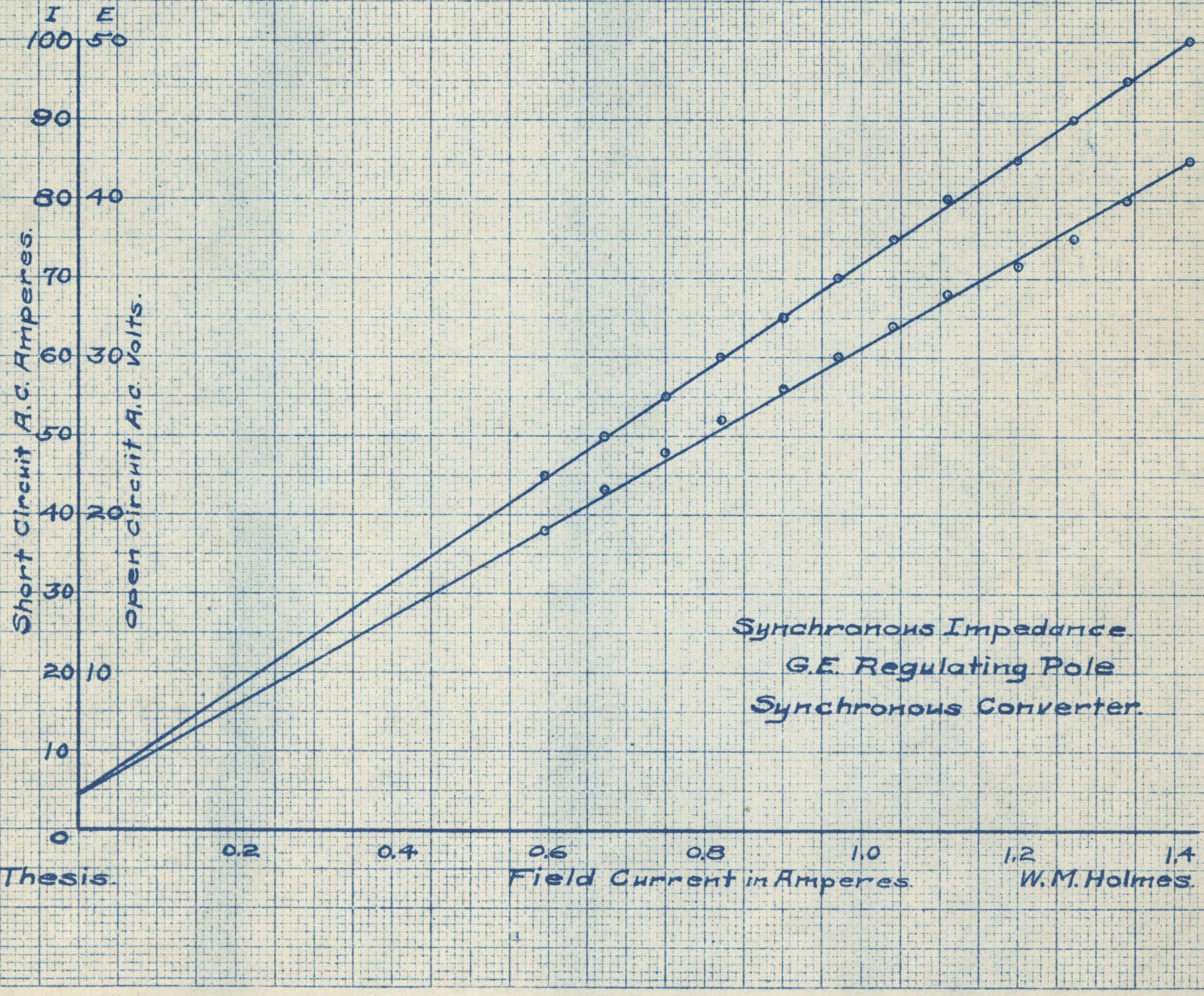
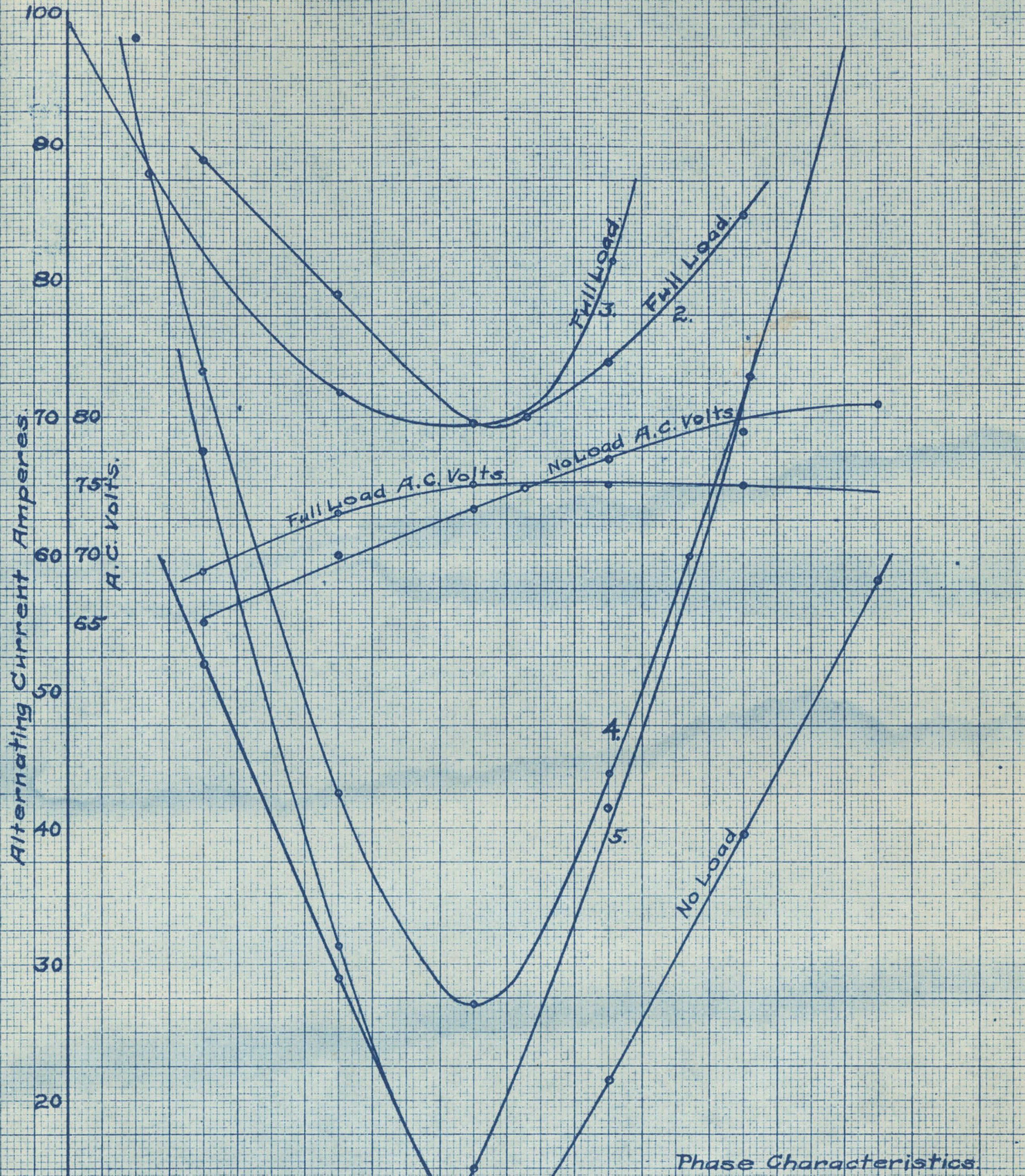


Saturation Test.
G.E. Regulating Pole
Synchronous Converter.



Synchronous Impedance.
G.E. Regulating Pole
Synchronous Converter.

Thesis. W.M. Holmes.



Phase Characteristics.
G.E. Regulating Pole
Synchronous Converter.

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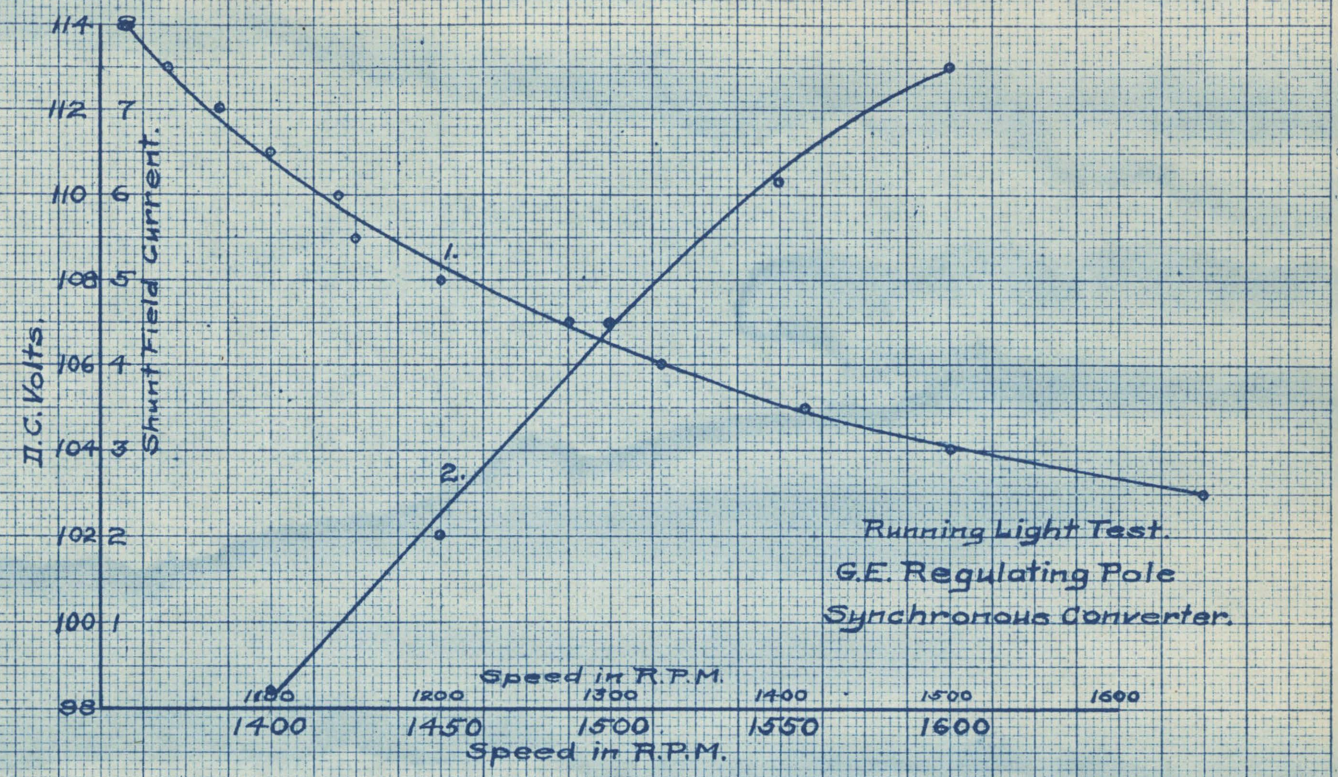
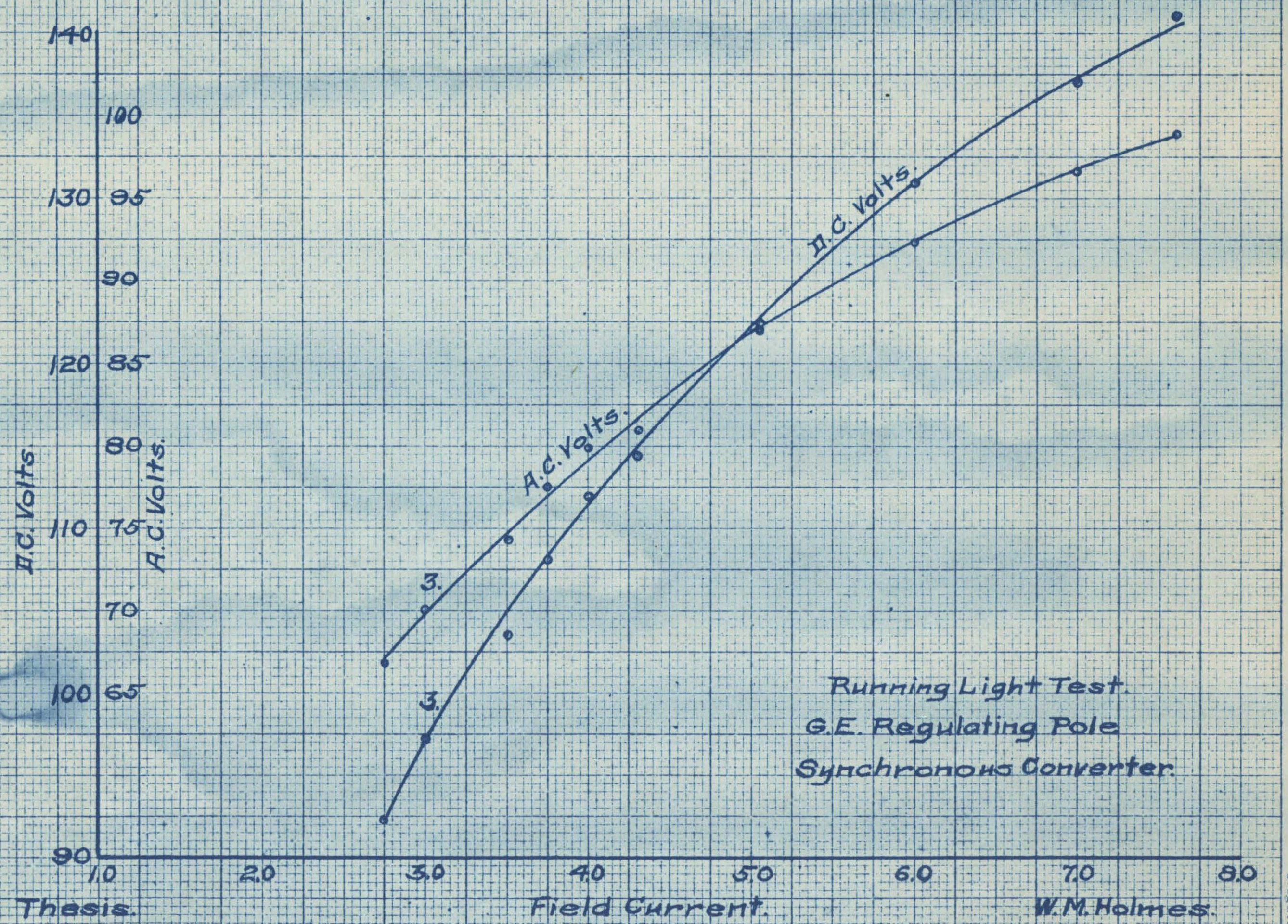
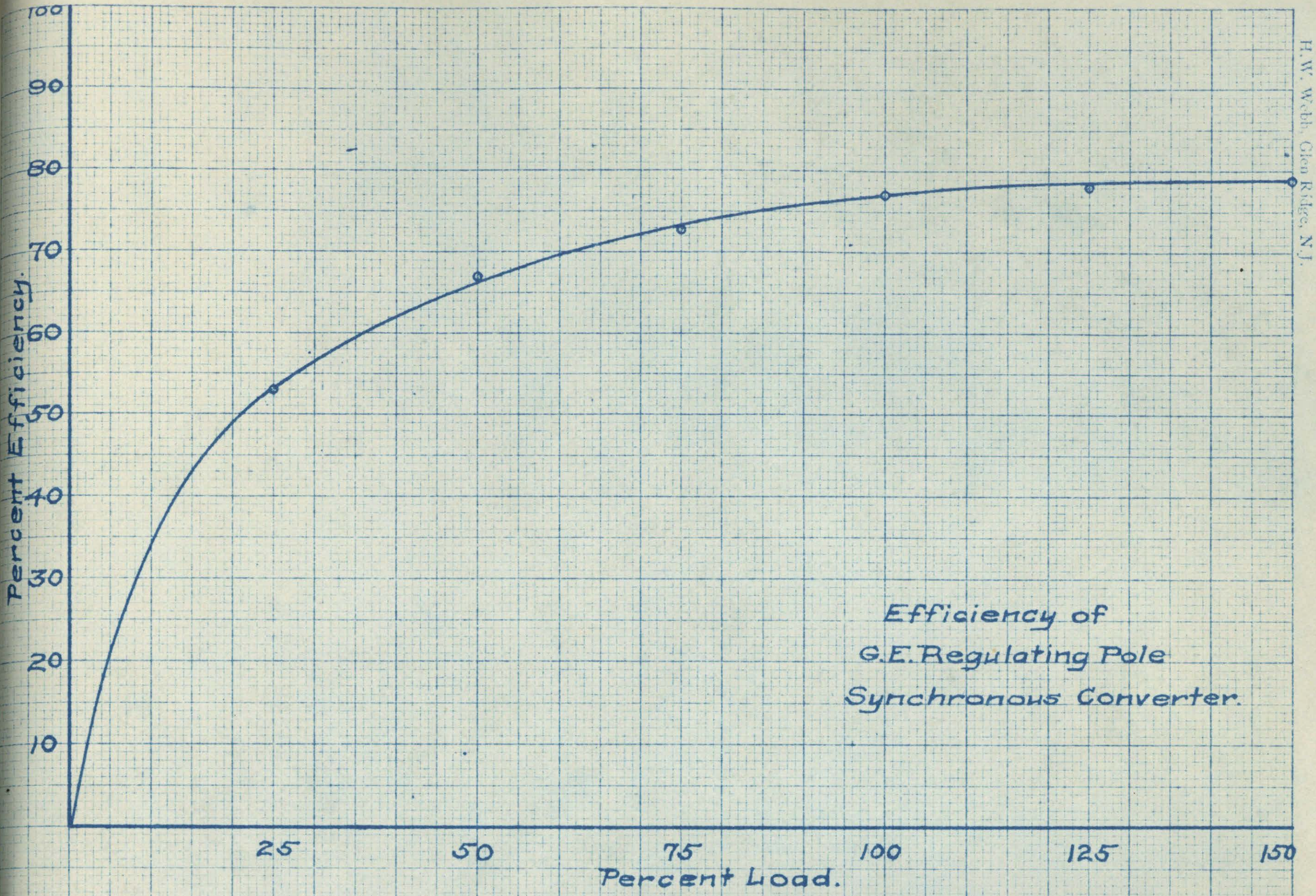
H. W. Webb, Glen Ridge, N.J.

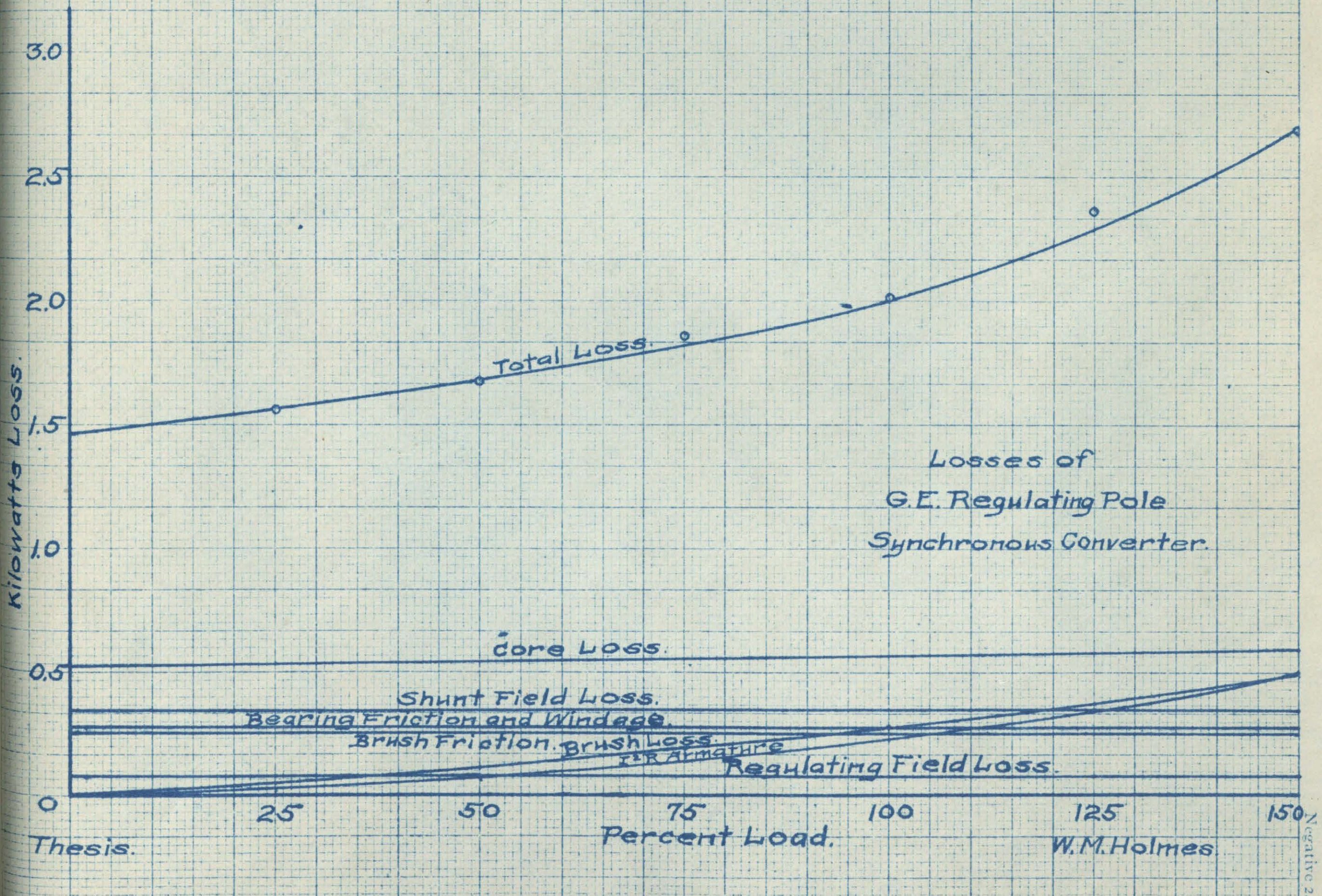
Negative 2.





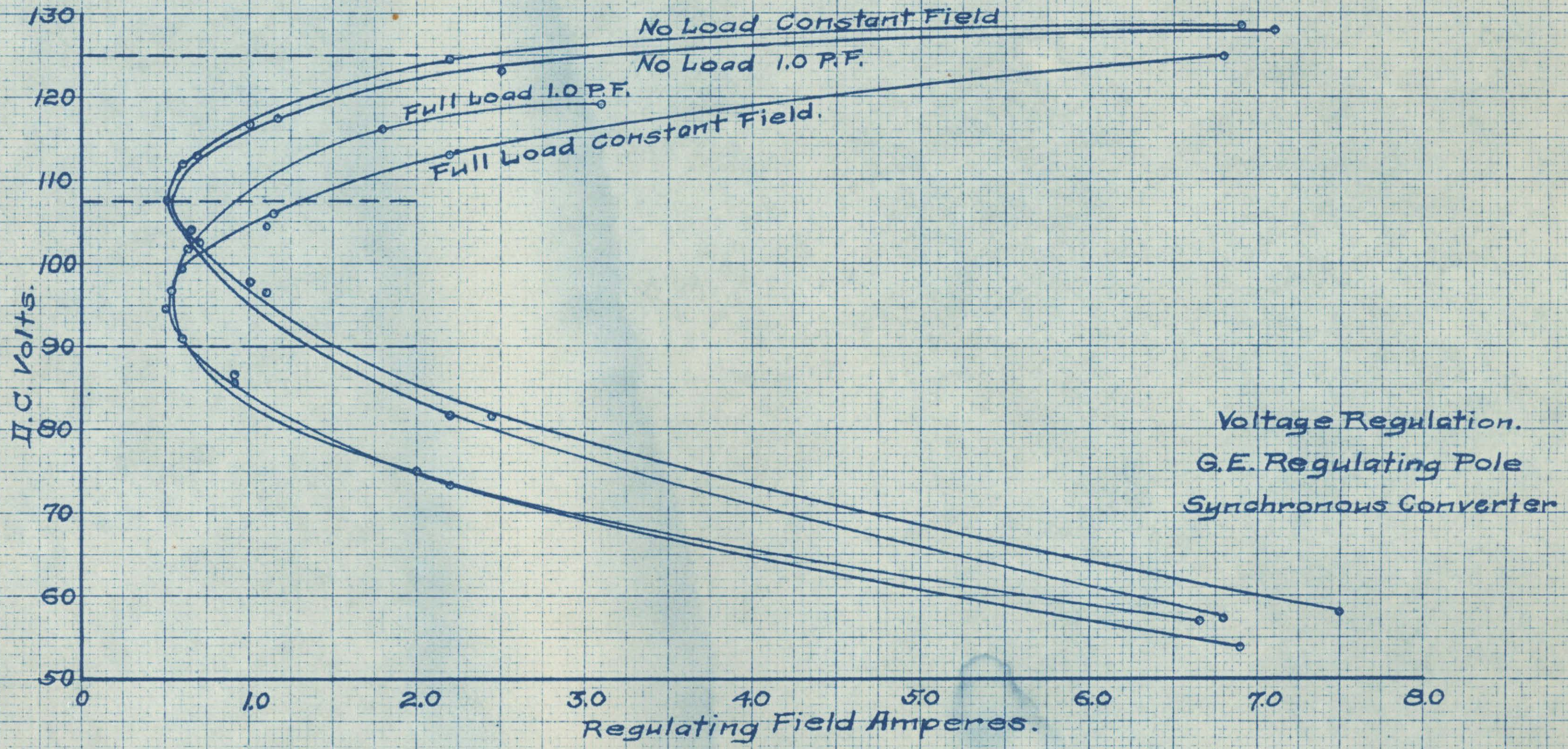
Thesis. W.M.Holmes.





Thesis.

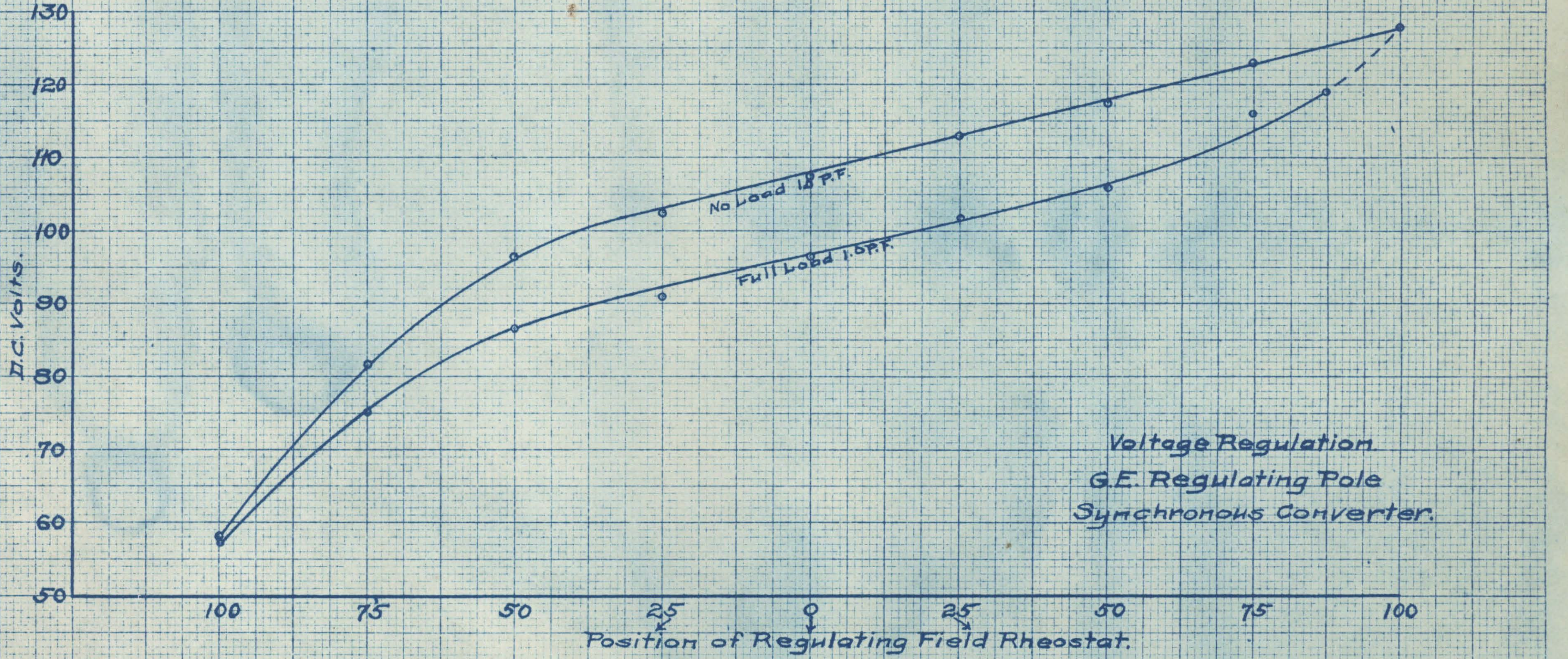
W.M.Holmes.



Voltage Regulation.
G.E. Regulating Pole
Synchronous Converter

Thesis.

W.M. Holmes.

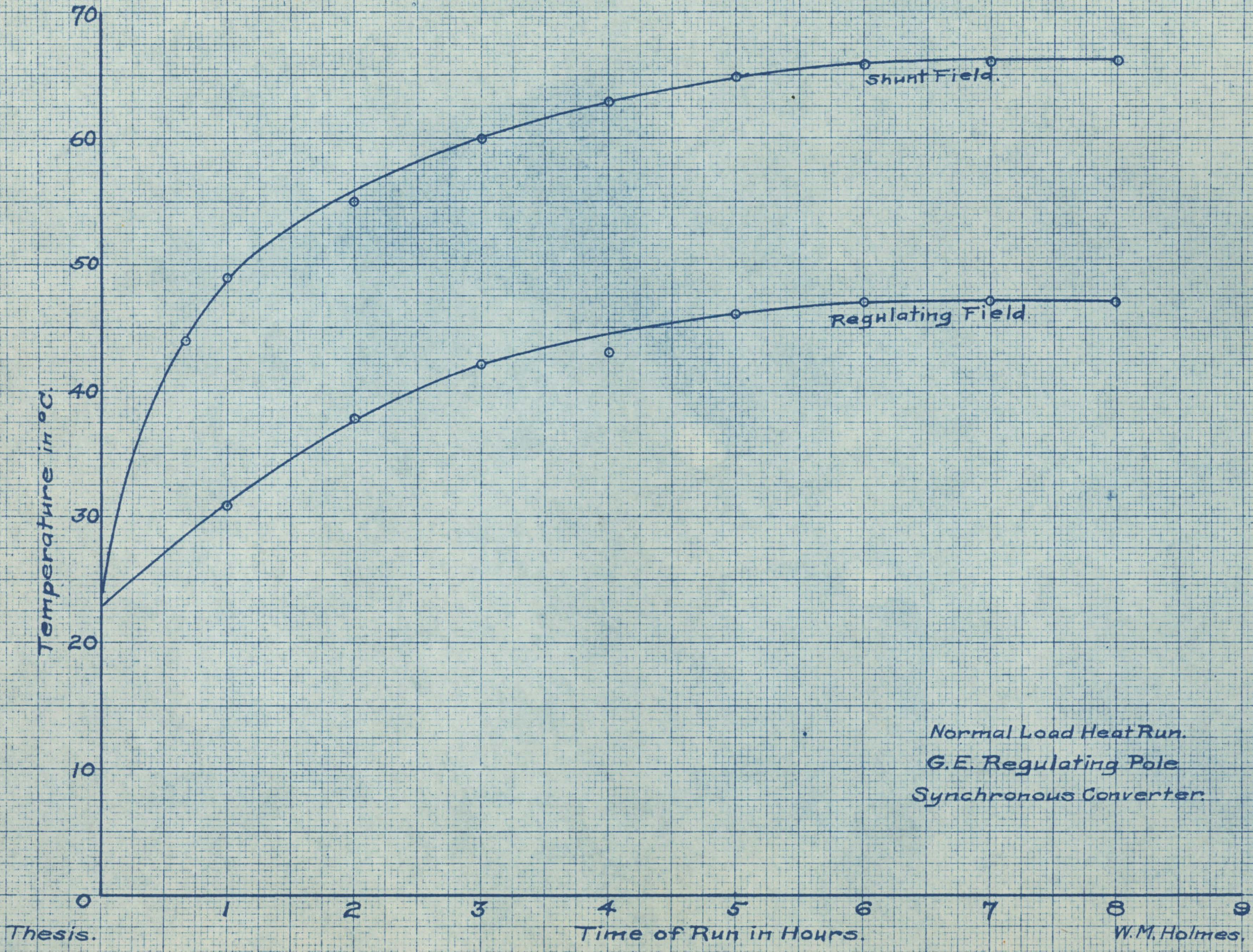


Voltage Regulation.
G.E. Regulating Pole
Synchronous Converter.

Thesis.

W.M. Holmes.

H.W. Webb, Glen Ridge, N.J.
Negative 2.



Normal Load Heat Run.
G.E. Regulating Pole
Synchronous Converter.

Thesis.

W.M. Holmes.

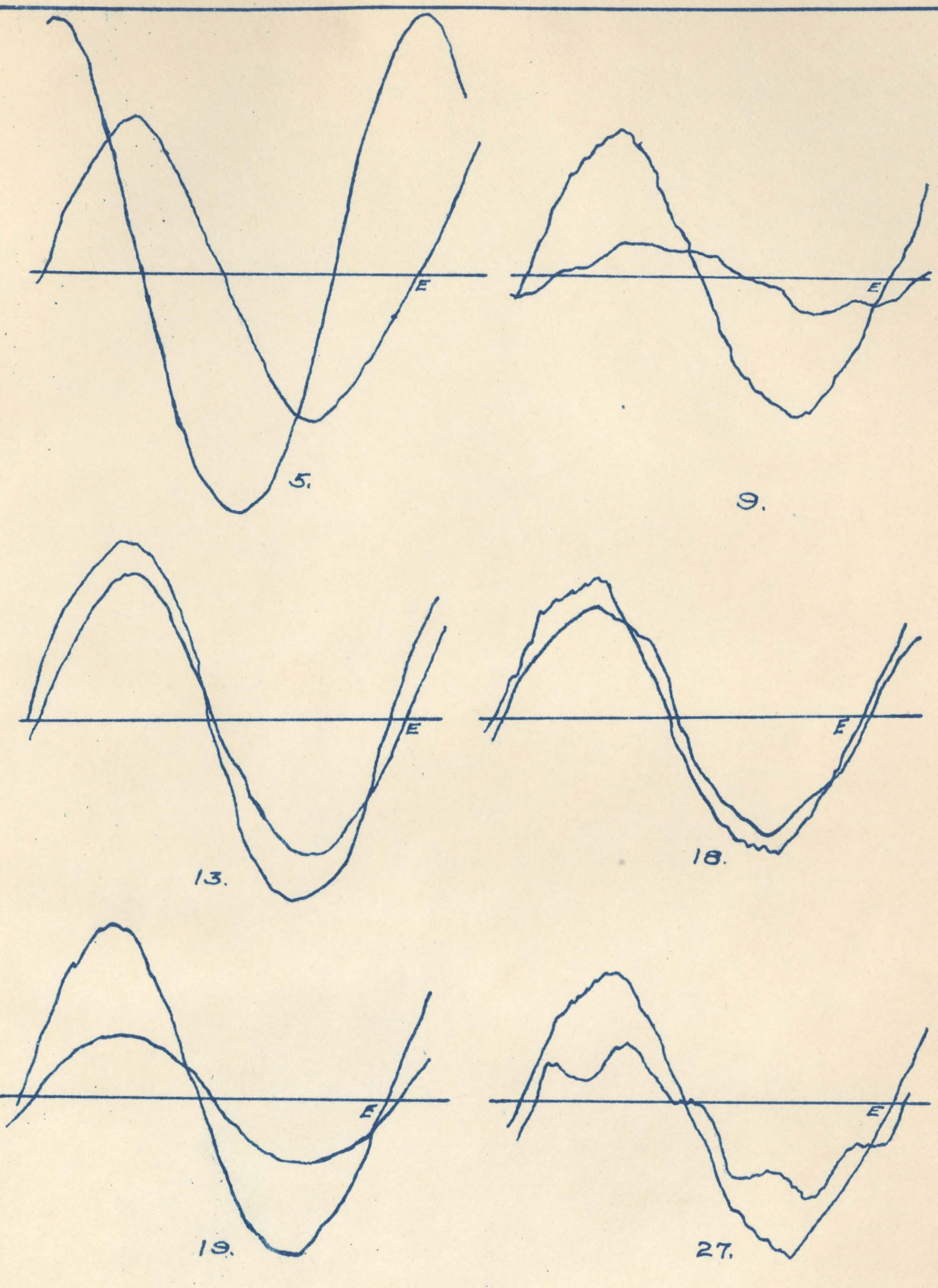


Fig. 8.
Oscillograph Curves.

Thesis W.M.Holmes.