INDUCTIVE and NON-INDUCTIVE

LOAD TESTS on TYPE ATB - FORM E

GENERAL ELECTRIC CO. ALTERNATOR

W. H. Harold

H. A. Burt

R. A. Fulton.

OUTLINE.

Construction

Theory of Alternators

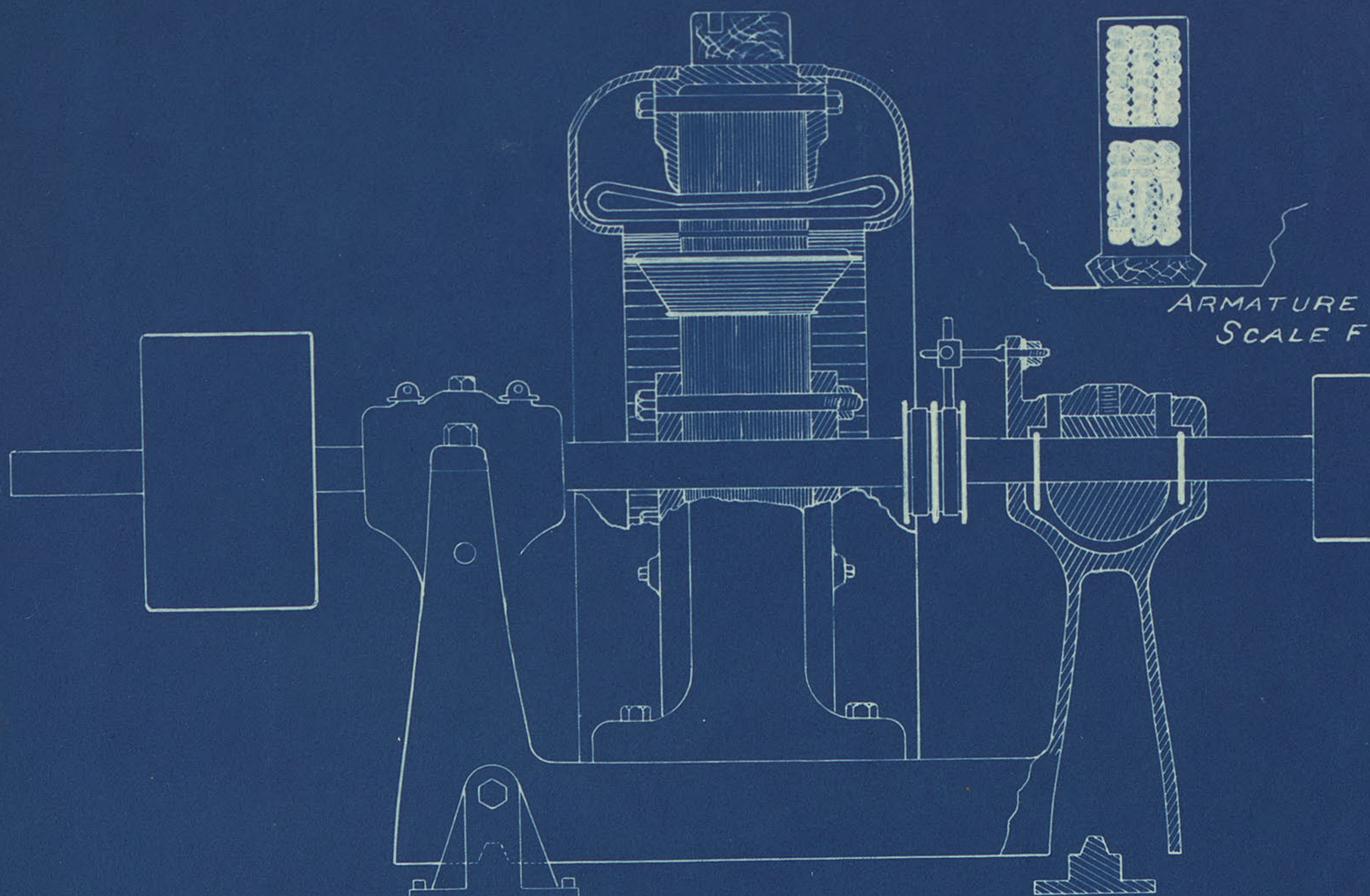
External Characteristic

Saturation curves

Synchronous Impedance

Field Compounding curves

Commercial Efficiency.



ARMATURE SLOT
SCALE FULL SIZE.

G. E. ALTERNATOR
SCALE 2IN=1 FT.

W.H.H.

CONSTRUCTION OF THE ALTERNATOR.

#65466 Type A.T.B. Class 6 - 15 -1200

Full load 69 Amperes 125 Volts Speed 1200.

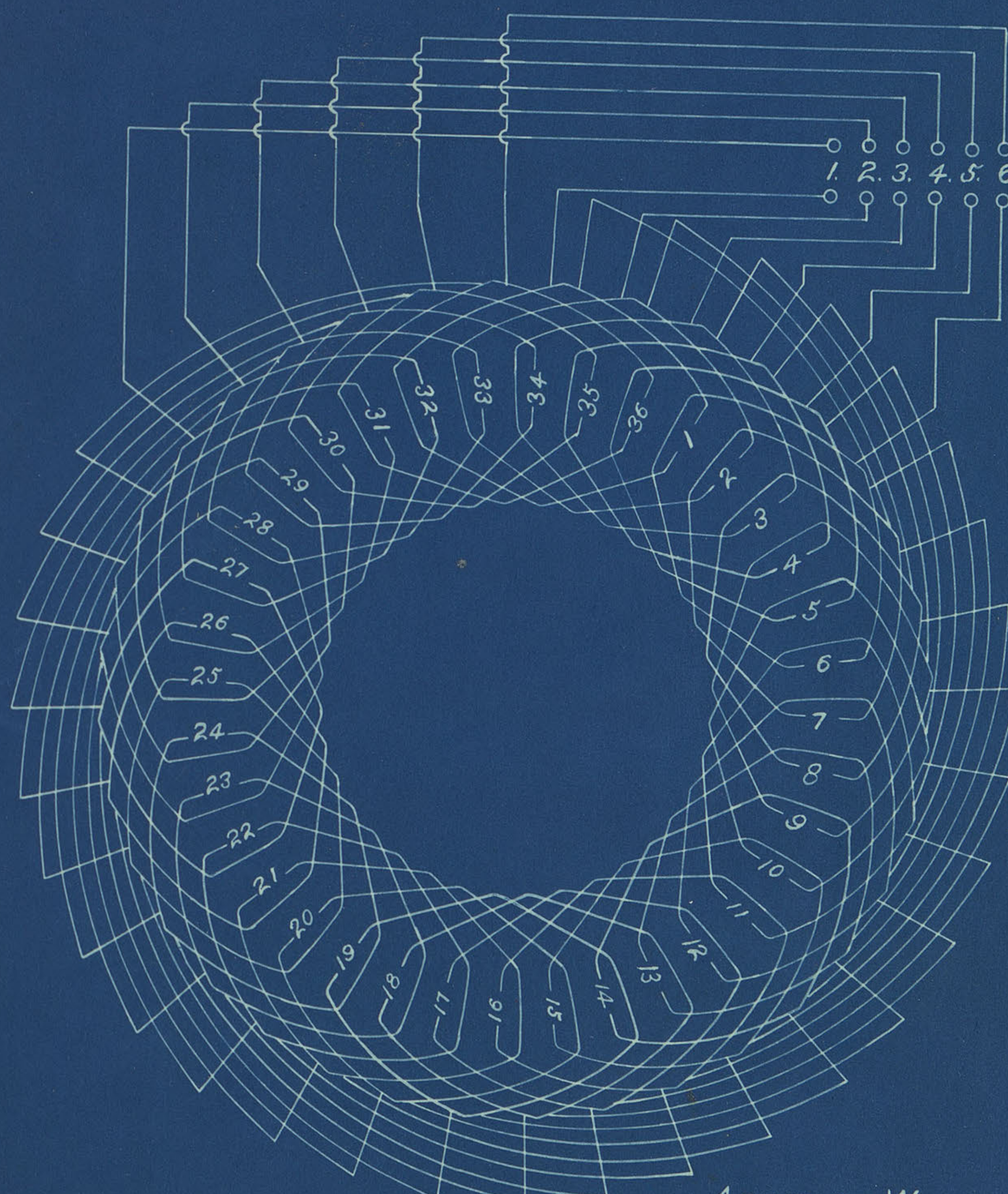
The generator tested for characteristic action under different load conditions is of the revolving field, separately excited, stationary armature type.

The above drawing shows the principal points in the construction of the machine. On the left is the main pulley which is run by the main drive belt; on the right is a smaller one from which a small direct current generator is run for exciting the alternator field. The shaft is lubricated by rings which dip into an oil reservoir. The revolving field receives its exciting current from the exciter through two slip rings. The field spider and pole faces are of laminated steel, that in the pole faces is japanned and that in the spider is not. These laminations are held together by bolts as shown in drawing.

The armature ring is built of japanned laminations which are held together by bolts and clamps. If the laminations should for any reason become loose and cause a disagreeable humming they may readily be tightened.

There are six field coils which are wound as shown; all coils are in series each adjacent one being wound opposite and the terminals brought to the slip rings. One brush on the ring is shown; there are two brushes on each ring.

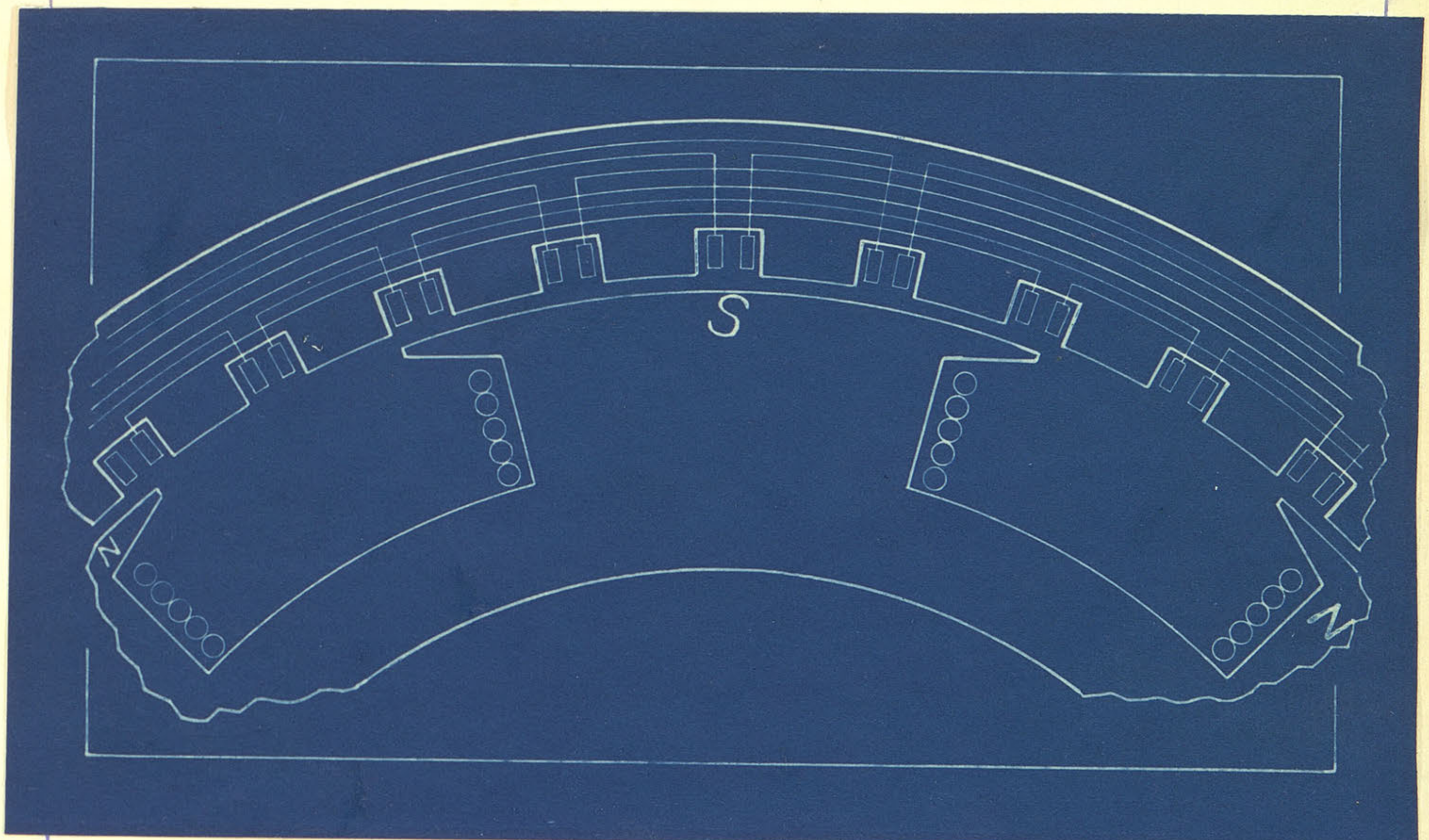
The scheme of an armature slot is shown on drawing and is the construction most commonly employed by modern dynamo builders.



ARMATURE WINDING
FOR
G.E. ALTERNATOR.

W. H. H.

There are two conductors in each slot and each conductor is composed of twenty four small wires.

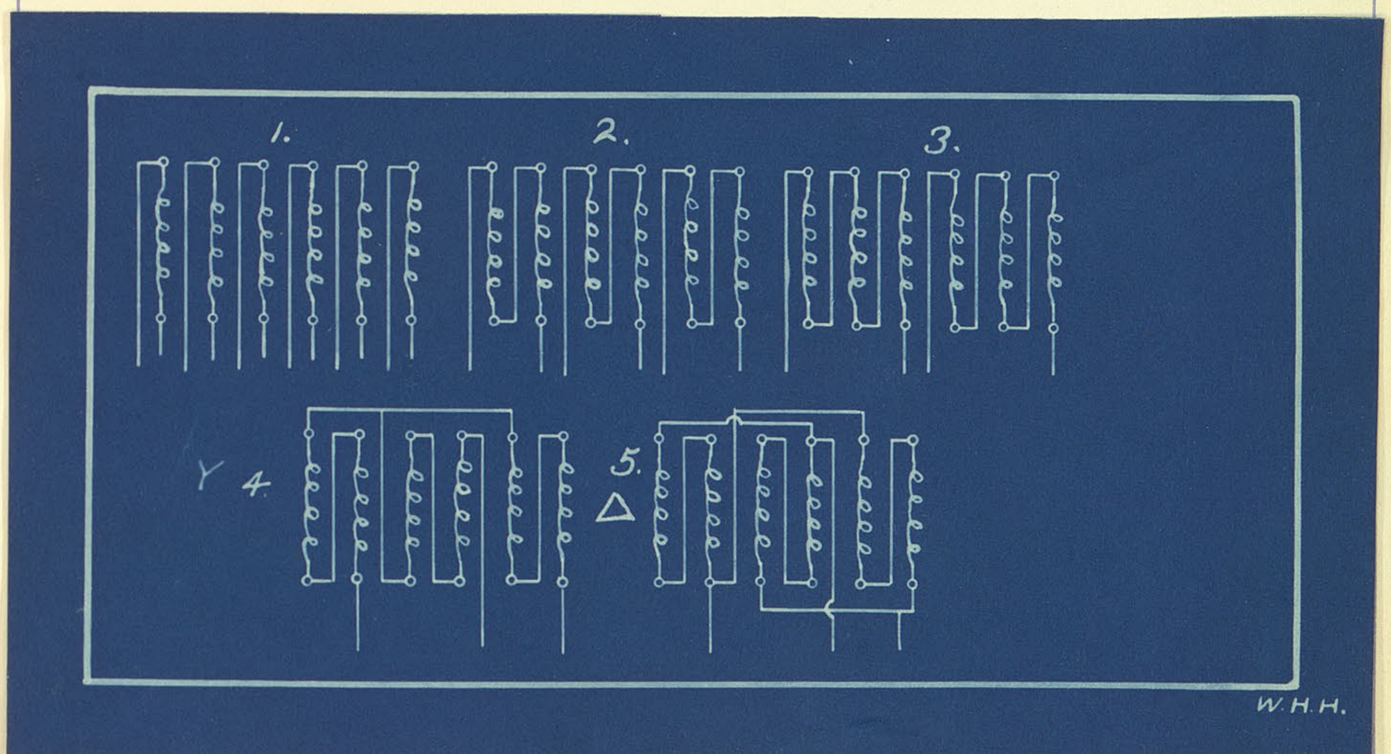


The scheme of armature winding of this machine is as shown above. There are thirty six coils which lie in the thirty six armature slots. Six coils are in series each being in a similar position relative to the poles; thus the armature may be considered as having six single coils. The ends of each coil are brought to the connection block on which the connections for different phase currents are made. This machine is Y connected for three phase current and the terminals are connected thus, considering 1_1 as the lower connection at number 1 and 1^1 as the upper connection;

1_1 to 2' 1' to 3_1

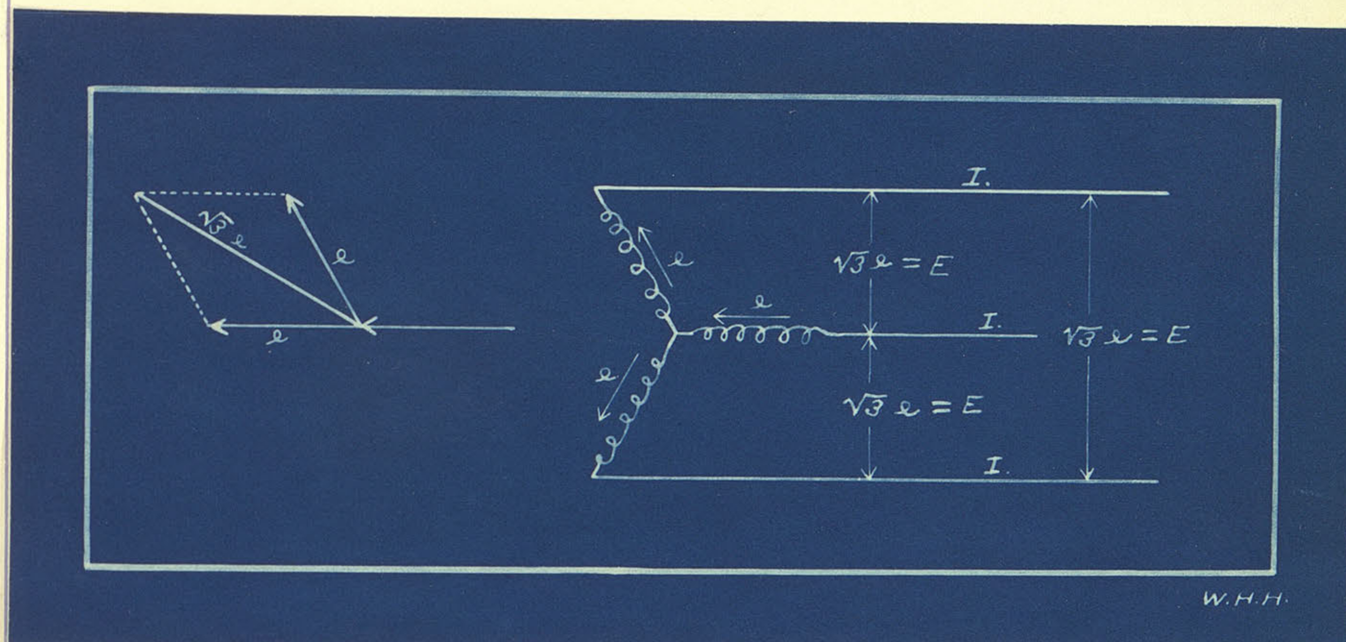
4_1 to 3' 5_1 to 6' and 5' to 3_1

2_1 4' and 6_1 are the leads to the line.



In the above scheme number 1. represents the connections of the alternator for a twelve wire six phase system which give alternating E.M.Fs 60° apart; that is, the maximum E.M.Fs of the coils occur 60° apart. Number 2 represents a three phase six wire connection the maximum E.M.F.s occurring 120° apart. Number 3 represents a four wire two phase connection the maximum E.M.F.s occurring 180° apart. 4 and 5 are three phase three wire Y and Δ connections. In the Y connection one end of each coil is connected to a common point, the three free ends form the line terminals.

In the $\triangle$ connection one end of each coil is connected to one end of the adjacent coil and the line wires go to these three points.



In the above scheme for the Y connection there is supposed to be e effective volts and I amperes generated in each of the three coils.

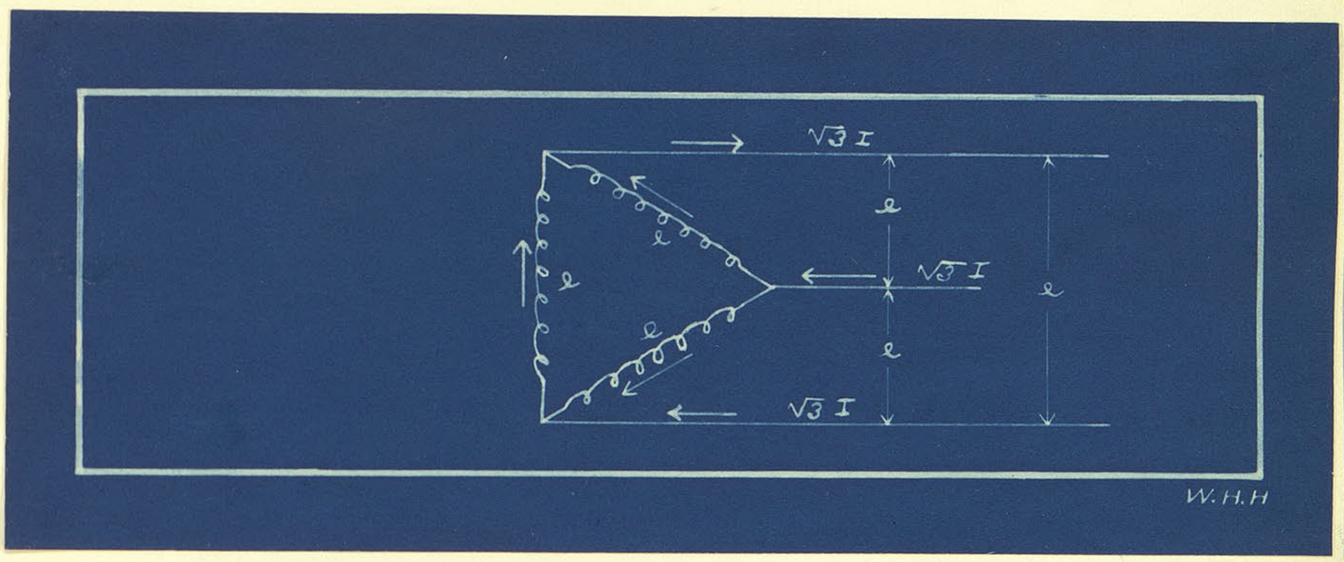
Assume the E.M.F. in each coil to be in the direction shown by the arrows.

Taking leg 1 and 2 we have two E.M.F.s combined at 120°. The resultant is found to be $\sqrt{3}$ e. This is true for any two legs and the pressure between any two line wires is $\sqrt{3}$ e.

Since I amperes is generated in each coil, there will be I amperes flowing on each line.

The full load rating of this machine is 69 amperes at 125 Volts; that is with balanced load of 69 amperes on each line we have a pressure of 125 volts between lines. Since E the voltage between lines is $\sqrt{3}$ e, the voltage e generated in each coil is $\frac{E}{\sqrt{3}} = \frac{125}{1.732} = 72.3$ volts

If the connection of the coils is a Δ connection and



there is e volts and I amperes generated in each coil, the pressure between lines is that of the one coil only and is e volts, while the current in one line is the sum of the currents in the two coils added at 120° and is $\sqrt{3}$ I.

To find the energy in a three phase Y connected balanced system.

Let w = energy in one armature coil.

W = total energy.

e = Volts over each coil.

I = Current in each coil.

Then $w = eI$

$E = e\sqrt{3}$

$$W = 3w = 3\ eI = \frac{3\ EI}{\sqrt{3}}$$

$\therefore W = \sqrt{3}\ EI$ = the total energy in a balanced three phase circuit.

The E.M.F equation of the alternator from which we find the flux.

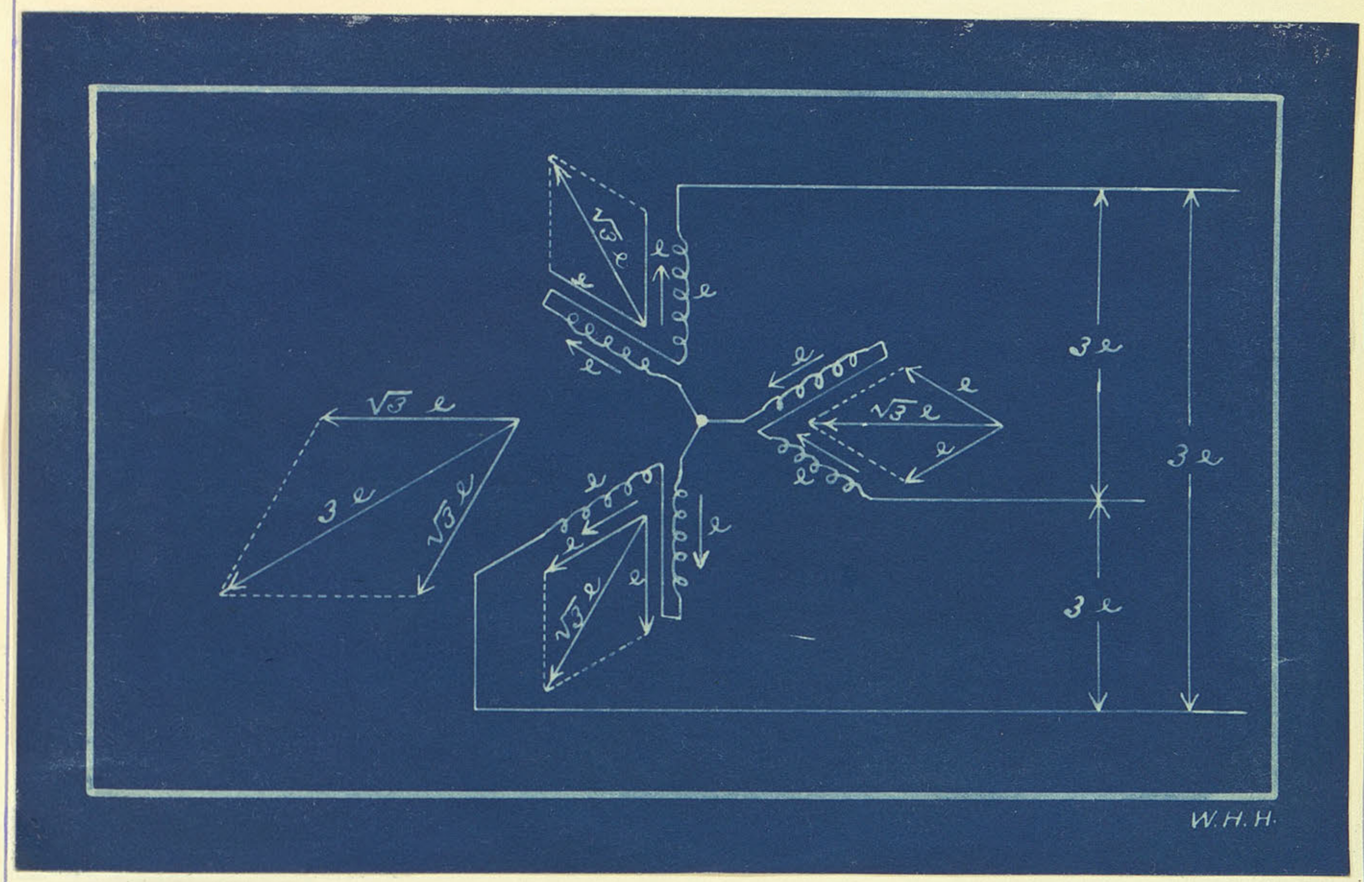
$$110 = \frac{2.22 \times 3 \times 12 \times \text{flux} \times 1200}{10^8 \times 60}$$

In the above equation 110 is the voltage generated at no load, 2.22 is the form factor, 3 is pairs of poles, 12 is the number of inductors in series in each circuit, flux is the flux from one pole, $\frac{1200}{60}$ is revolutions per second and 10^8 the constant to reduce C.g.s. units to volts.

As we have seen from the Y connection for this machine there are two coils in series on each leg of the Y; on one leg are the coils 1_1 to 2' to 1' to 3_1. 2_1 being a terminal of the machine the current may be considered to go into the armature on 2_1 around coil 2 to 2' then to 1_1 around coil 1 to 1' and then to 3_1 the centre point of the Y.

Thus coils 2 and 1 are in series. There are six coils on the machine each sixty degrees apart. Coils 1 and 2 are therefore sixty degrees apart and their E.M.F.s are combined in series at sixty degrees.

Let the E.M.F. of 1 and 2 respectively be e, then combining these in series we get for the E.M.F. in one leg of the Y $\sqrt{3}e$; this is supposed to be going from the centre.



Now take another leg of the Y in which the E.M.F. is supposed to be going toward the centre and by adding its two series coils at 60° we get for the E.M.F. generated $\sqrt{3}e$. Now, by combining the voltage of this leg with the previous one at 120 degrees we get E the voltage between the lines = $\sqrt{3}e + \sqrt{3}e$ added at 60° = 3e.

Therefore we must multiply the right hand side of the E.M.F. equation by 3 to get the E.M.F. between terminals; it then becomes

$$110 = \frac{3 \times 2.22 \times 3 \times 12 \times \text{flux} \times 1200}{10^8 \times 60}$$

From this we find the flux per pole necessary to produce

110 volts.

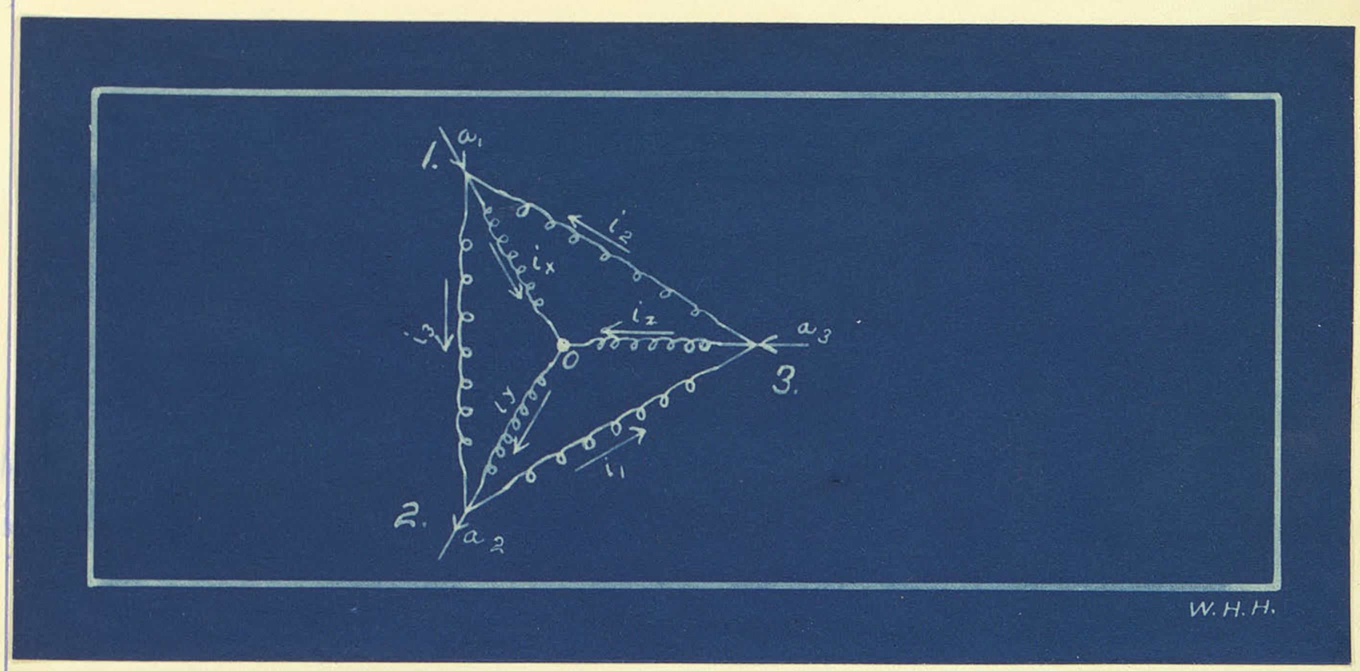
$$\text{flux} = \frac{110 \times 10^8 \times 60}{3 \times 2.22 \times 3 \times 12 \times 1200} = 2293.940$$

If we know the number of ampere turns n on each field pole and the field current i we can find the magneto-motive force which sets up a flux in the magnetic circuit.

$$(\text{M.M.F.} = 4\pi n i)$$

From this and the flux the reluctance of the magnetic circuit at no load, $\frac{\text{M.M.F}}{\text{flux}}$ is found.

To measure the power in a delta or Y connected armature.



Let a_1, a_2, a_3, be instantaneous current in the mains.

Let i_1, i_2, i_3, be the instantaneous current in the delta winding.

Let i_x, i_y, i_z, be instantaneous current in the star connection.

$$\text{Then } a_1 = i_3 - i_2 + i_x$$

$$a_2 = i_1 - i_3 + i_y$$

$$a_3 = i_2 - i_1 + i_z$$

$$a_1 + a_2 + a_3 = i_x + i_y + i_z$$

Let w be instantaneous values of total watts

$$\text{Then } w = v_{1-2}i_3 + v_{2-3}i_1 + v_{3-1}i_2 + v_{0-1}i_x + v_{0-2}i_y + v_{0-3}i_z$$

$$\text{Now } v_{3-1} = - v_{1-2} - v_{2-3}.$$

$$\text{and } i_y = - i_x - i_z$$

$$\text{also } v_{0-1} - v_{0-2} = v_{1-3}$$

$$w = v_{1-2}(i_3 - i_2 + i_x) + v_{3-2}\,(i_2 - i_1 + i_z) \quad (1)$$

and

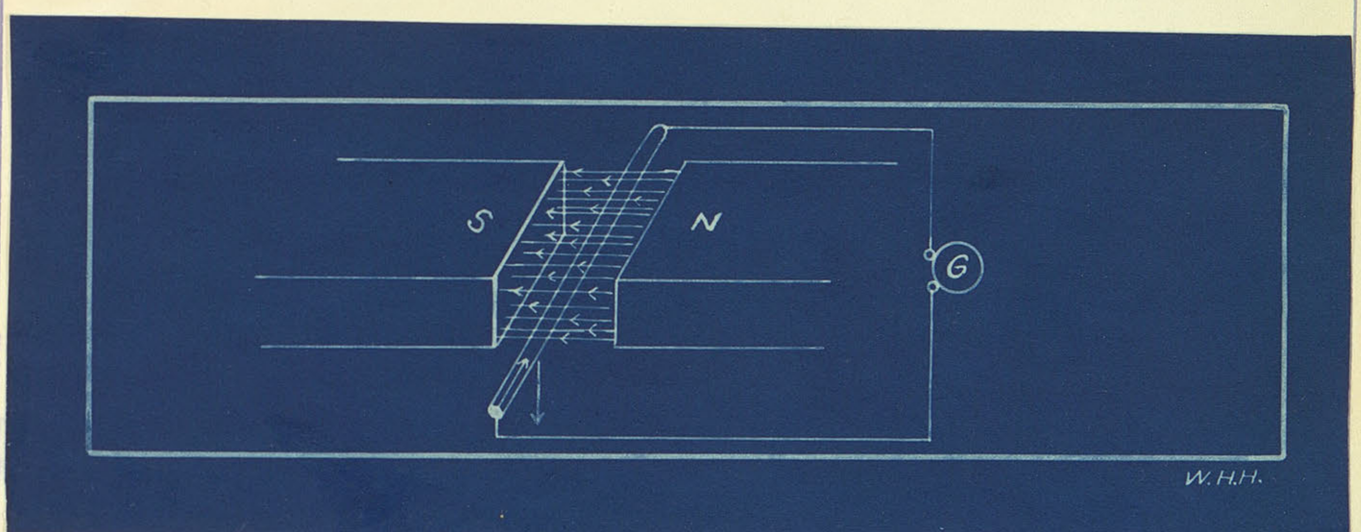
$$\left.\begin{aligned} w &= v_{1-2}a_1 + v_{3-2}a_3 \\ &= v_{2-3}a_2 + v_{1-3}a_1 \\ &= v_{3-1}a_3 + v_{2-1}a_2 \end{aligned}\right) \quad (2)$$

Therefore the total power is thus measured by two wattmeters

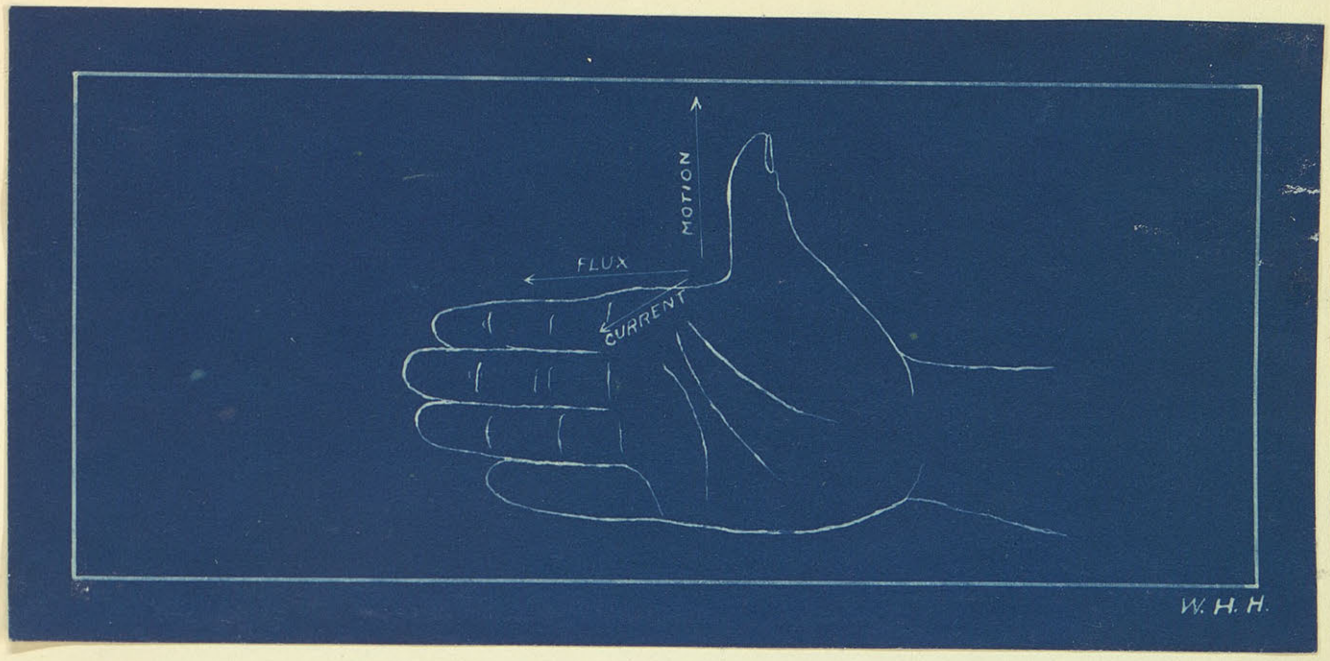
Similarly $w = v_{0-1}a_1 + v_{0-2}a_2 + v_{0-3}a_3$ and three wattmeters are used the potential terminal of one side being brought to 0.

Theory of Alternators:

The alternator, so named because of the alternating E.M.F. which it supplies is an illustration of the principle on which all dynamo electric machinery is based, viz., that whenever a conductor is made to move transversly through a field of magnetic flux in a direction which is not parallel to the direction of the flux, an E.M.F. will be set up within the conductor.



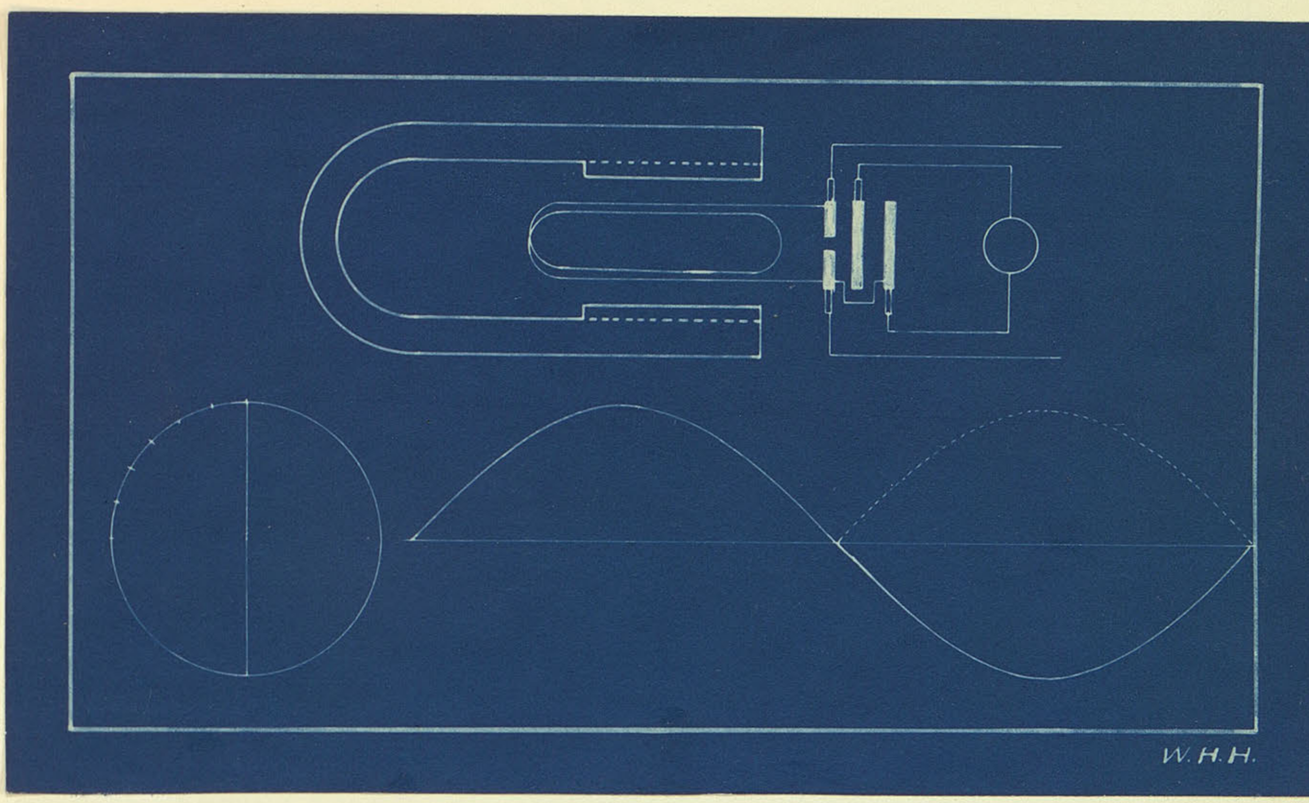
The direction in which this E.M.F. tends to cause an electric current to flow depends upon the direction in which the conductor is moved, and on the direction of the flux. In the above figure we have the two poles of a magnet, marked N and S respectively, indicating the direction of the flux which is assumed to flow from the pole N to the pole S; A conductor A is moving downward in the direction of the arrow M. When the direction of the flux is known, the direction of



the E.M.F. in the cutting conductor may be predetermined by the rule known as the hand rule, illustrated in the above figure.

Turn the right hand so that the thumb points in the direction of the motion of the conductor and hold the first finger at right angles to the thumb as in pointing so that it indicates the direction of the flux. The second finger held at right angles to the first will point in the direction of the induced E.M.F.

Under the conditions indicated in the last figure but one, and according to the hand rule, an E.M.F. will be generated within the conductor tending to produce a current in the direction of the arrow E, and if the two ends of the conductor were connected through a galvanometer the needle would be deflected. If the conductor were moved upward, the needle would be found to deflect in the opposite direction, indicating a current in the opposite direction.

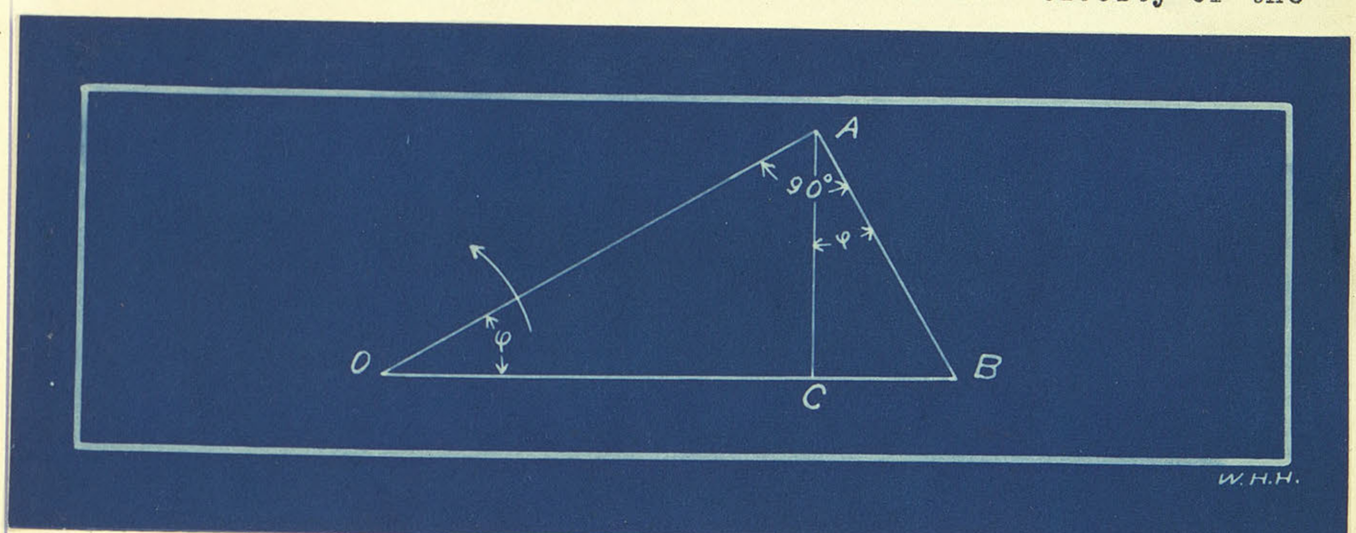


If a coil of wire be rotated about an axis between the poles of a magnet, as in above figure, an E.M.F. will be generated in a definite direction as one half of the coil moves past the N pole and the other half moves past the S pole; and in the opposite direction when the one half moves past the S pole and the other half moves past the N pole; so that during one half of a revolution of the coil, an E.M.F. is generated in one direction and during the other half revolution an E.M.F. is generated in the opposite direction which constitutes two alternat~~or~~IONs per revolution, or one complete cycle (~).

If the two terminals of the coil be connected respectively to the two halves of a split ring provided with brushes which are connected externally through a conductor, a pulsating but unidirectional current will flow.

If, however, the two terminals of the coil be connected to two separate slip rings respectively, provided with brushes, which are connected externally through a conductor, there will still be a pulsating current in the external circuit, no longer unidirectional but alternating in direction. Such a current is known as an alternating current.

The value of the E.M.F. generated at any instant depends upon the speed of rotation, the angular position of the coil, and the strength of the field. In the below figure, O represents a point of rotation, OA the angular position of the coil with respect to OB, and AC, the direction of the magnetic flux. The linear velocity of the



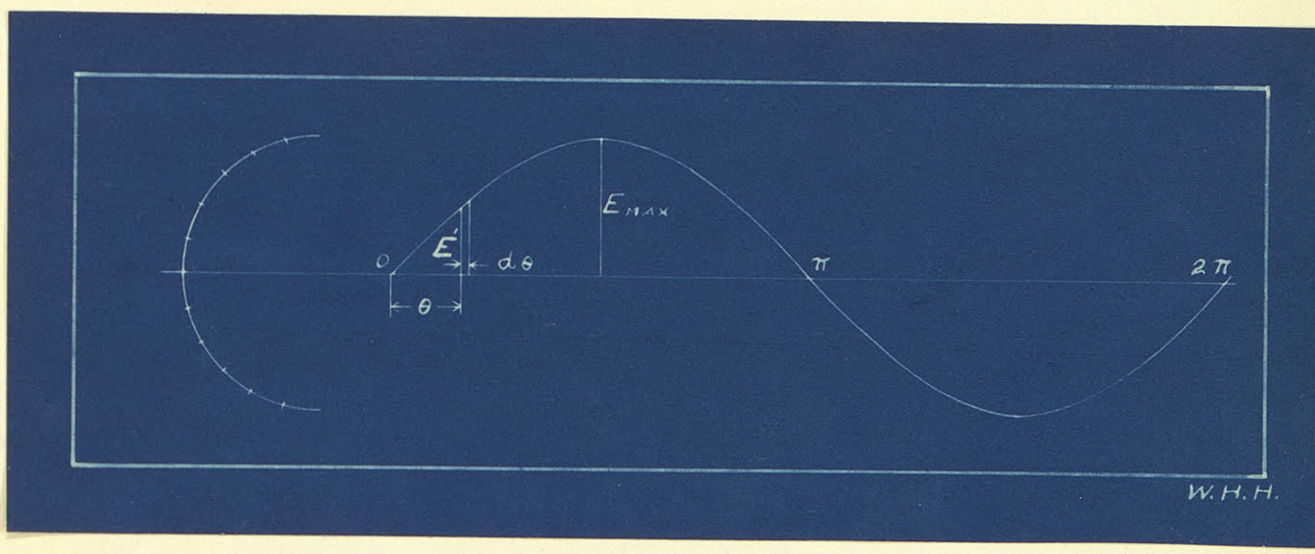
coil at any instant may be resolved into two components; one parallel to the direction of the flux, and the other perpendicular, in which the component perpendicular, BC in above figure, is the one effective in cutting magnetic flux. Denoting angle BAC by θ, we have for the rate of cutting flux,

BC = AB Sin θ, and AC = OA Sin θ, in which OA is proportional to the linear velocity of the coil. Also the maximum cutting of flux, and consequently the maximum E.M.F. is proportional to the linear velocity.

Hence we may write

$$E' = E_{MAX} \sin\theta$$
$$= E_{MAX} \sin 2\pi f t$$

where f is the number of cycles per second and t the time, reckoned from the beginning of a cycle. Plotting E.M.F. as ordinates and $2\pi f t$ as abscissas we obtain the sinusoidal curve. The average



E.M.F. during a half revolution, will be equal to the average ordinate of one lobe of the sine curve.

$$E_{AV} = \int_0^{\pi} \frac{E_{MAX} \sin\theta \, d\theta}{\pi}$$

$$= \frac{E_{MAX}}{\pi} \left(-\cos\theta\right)\Big|_0^{\pi} = \frac{2 E_{MAX}}{\pi}$$

The E.M.F. causing the effective current to flow which is proportional to I'^2, is proportional to E'^2, since $I' = \frac{E'}{R}$ and the value of E_{eff} is equal to the square root of the average squares of the instantaneous values of E.M.F.

$$E_{EFF}^2 = \int_0^{\pi} \frac{E_M^2 \; SIN^2 \theta \, d\theta}{\pi} = \frac{E_M^2}{2}$$

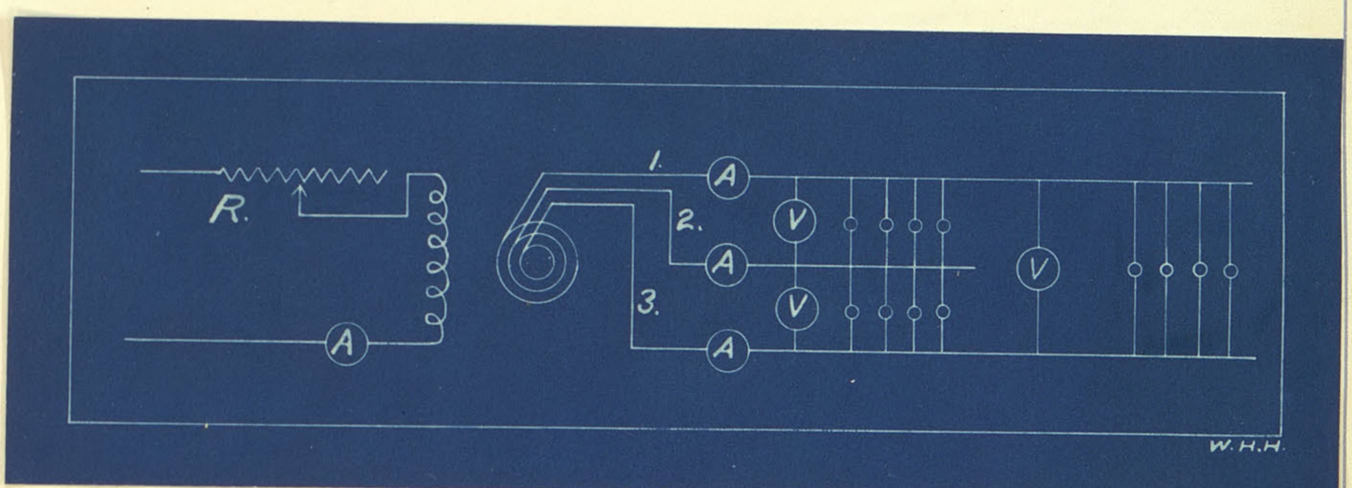
$$E_E = \frac{E_M}{\sqrt{2}}$$

$$\frac{E_E}{E_{AV}} = \frac{\frac{E_M}{\sqrt{2}}}{\frac{2E_M}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1.11$$

which is a factor in the formula for the E.M.F. of an alternator.

EXTERNAL CHARACTERISTIC.

The C.W.Motor was belted to the G.E. alternator, and to the Westinghouse dynamo, which was used as an exciter. Three banks of lamps were connected between the leads of the alternator with a Thompson (0-100) A.C. Ammeter in each line and a Thompson (0-130) A.C. Voltmeter connected between each two lines. The alternator was run at constant normal speed (1200 R.P.M.) and excited by varying the voltage of the exciter, until 110 volts pressure was generated on open circuit. The load switch was then closed and an incandescent lamp load which was increased step by step, from zero up to full load, simultaneous readings of load, volts and amperes were taken while speed and excitation were kept constant.



An external characteristic curve shows the relation of volts and armature current, at constant field excitation. The variation of volts during a change of load current depends on the effect of the armature resistance, armature inductance, amd armature reaction on the field flux.

External Characteristics, 1200 R.P.M.

Volts (1-3)	Volts (2-3)	Volts (1-2)	Amp's 1	Amp's 2	Amp's 3
112.0	112.0	110.0	0.	0.	0.
109.5	109.5	107.5	9.0	10.0	10.0
105.0	104.3	103.0	16.0	17.0	16.8
99.0	98.2	96.5	24.0	26.0	25.8
95.0	95.0	93.0	28.5	31.0	30.5
86.0	85.0	84.5	35.0	37.0	36.9
80.5	79.3	78.5	38.0	40.5	40.0
71.0	69.9	69.0	42.0	44.5	44.0
64.0	62.8	62.0	44.0	46.5	46.3
58.0	57.1	56.5	45.9	48.0	47.9

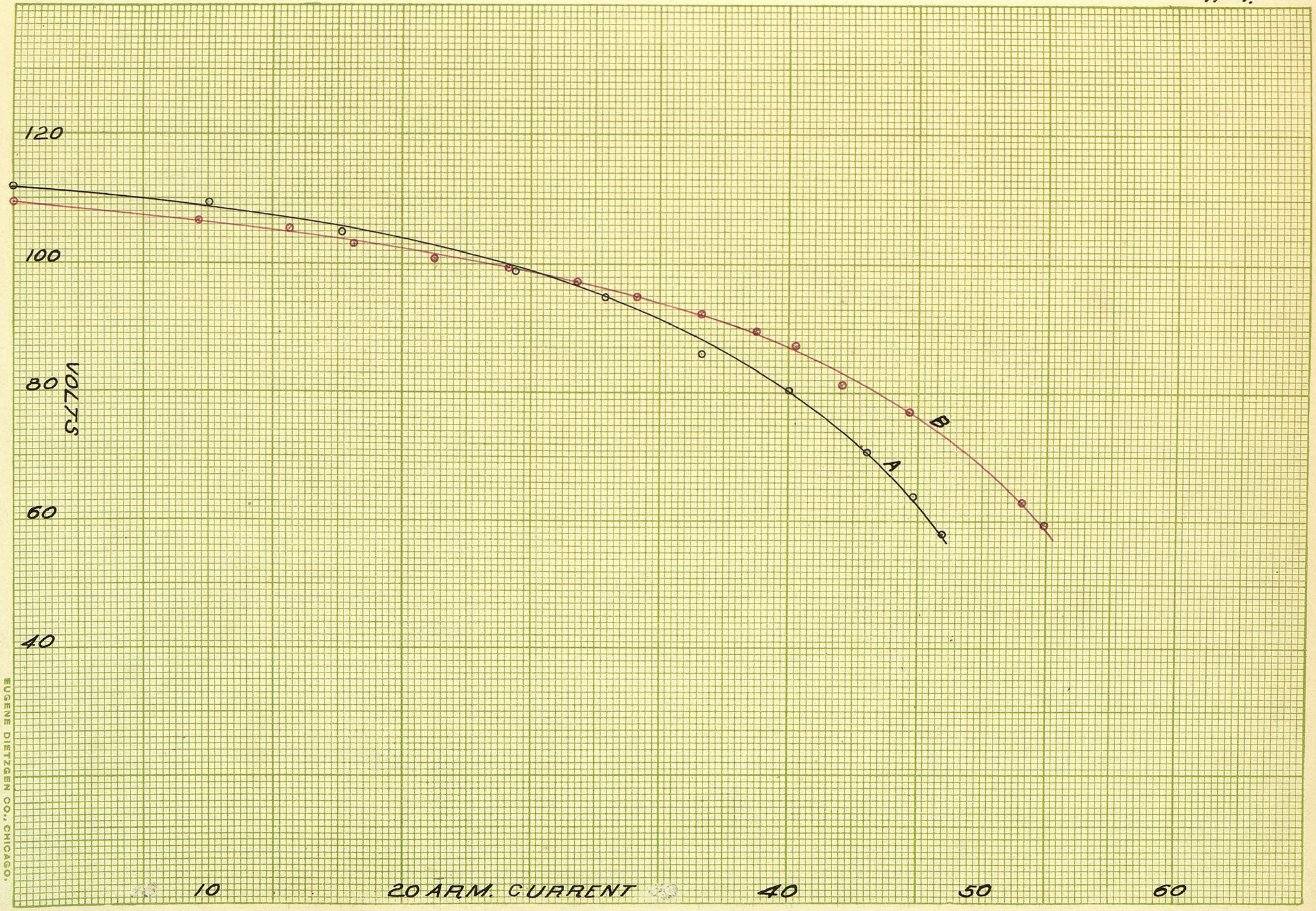
External Characteristic, Unbalanced Load, 1200 R.P.M.

Volts (2-3)	Volts (1-2)	Volts (1-3)	Amp's 1	Amp's 2	Amp's 3
114.0	110.0	111.0	0.	0.	0.
104.0	107.0	110.0	11.0	10.0	13.0
101.3	104.0	107.0	15.0	13.0	25.4
91.0	101.0	104.0	20.0	17.0	31.7
86.0	99.0	101.5	24.8	19.8	37.8
80.5	97.0	98.0	28.6	22.0	42.8
74.5	93.5	93.0	32.0	23.6	46.7
69.5	90.0	89.0	34.5	25.0	49.3
64.0	87.0	85.0	37.0	27.0	52.0
60.7	83.0	80.0	38.5	26.5	53.0
57.3	80.0	77.0	40.3	27.2	54.6

External Characteristic, 900 R.P.M.

Volts	Amp. Fld.	Amp. Arm.
109.5	3.1	0
107.5	"	-
106.7	"	9.5
105.5	"	14.1
103.0	"	17.5
101.0	"	21.7
99.5	"	25.5
97.2	"	29.0
95.0	"	32.2
92.5	"	35.6
89.7	"	38.3
87.2	"	40.4
81.2	"	42.7
77.0	"	46.2
73	"	52.3
69.5	"	53.2

1.



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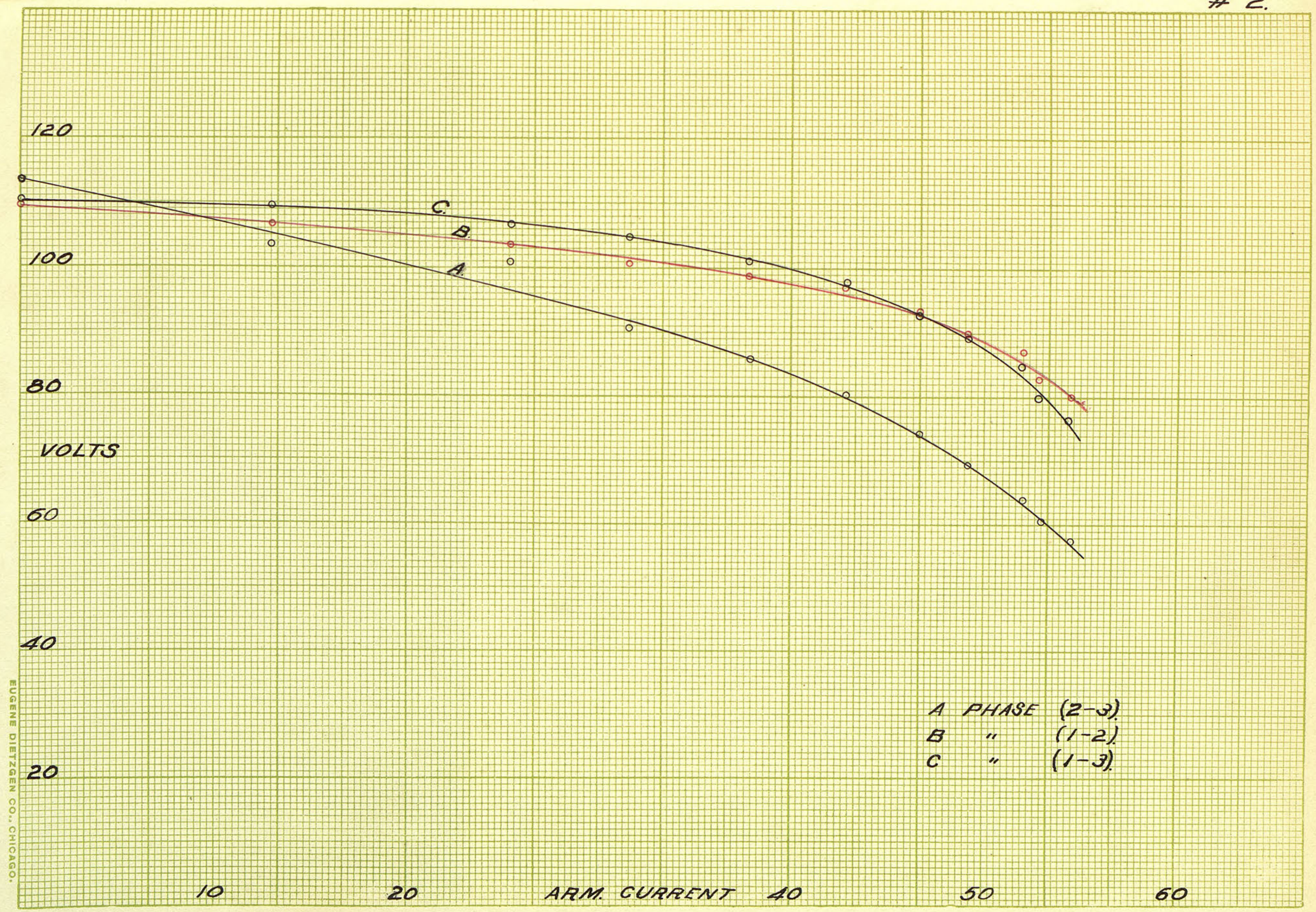
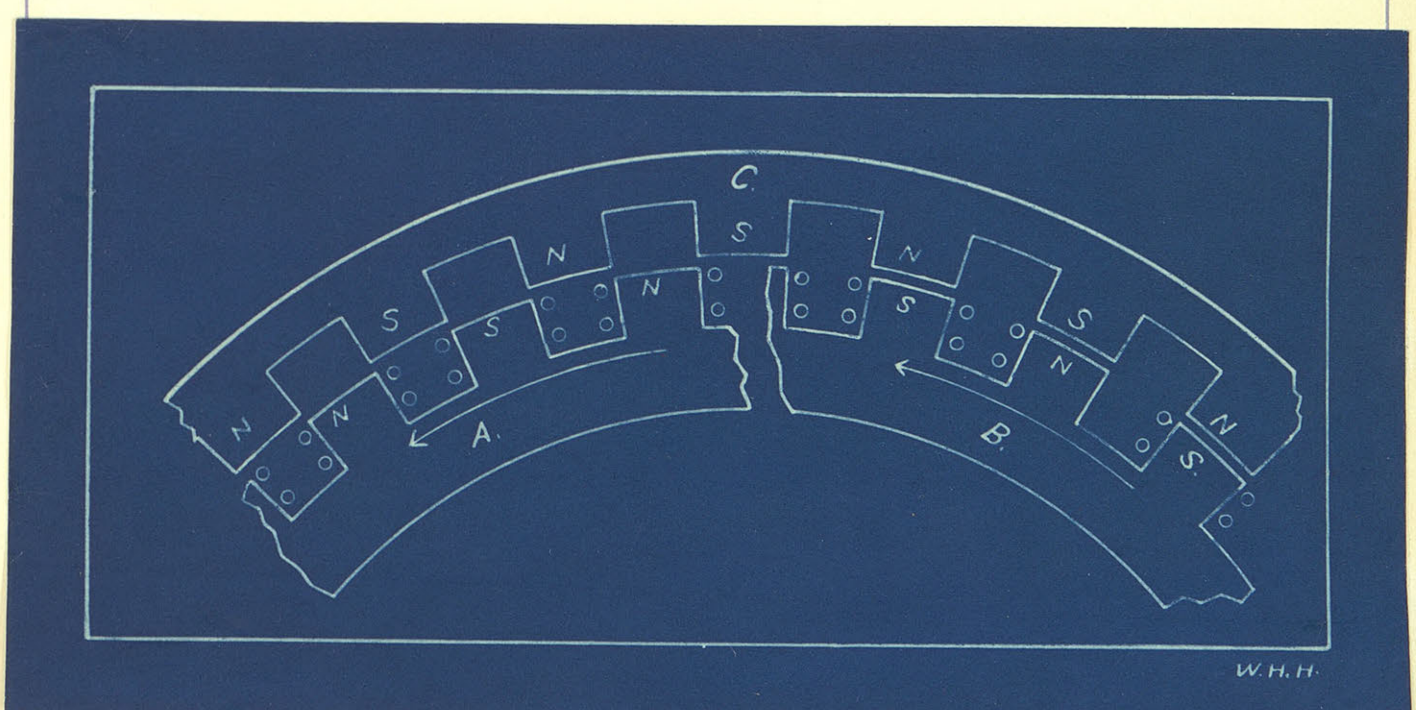


120
100
80
VOLTS
60
40
20
C.
B.
A.
A PHASE (2-3).
B " (1-2).
C " (1-3).
10
20
ARM. CURRENT
40
50
60
EUGENE DIETZGEN CO., CHICAGO.

Those causes which produce a loss of voltage have been discussed somewhat under the head of Synchronous Impedance. The two factors, armature reaction and armature inductance, are predominant in causing a loss of volts, An inspection of the characteristic curve A, Sheet # 1, shows that one or both of these factors increase at a greater rate than the load. The curve bends toward the X axis very rapidly at three fourths load. As was stated under the head of Synchronous Impedance, when the current is in phase with E.M.F. the poles which are formed on the armature ~~ampere turns~~ have maximum strength midway between two field poles, since at this point the rate of cutting magnetic flux is a maximum, and consequently the current flow is a maximum.

The poles are here of such a polarity that the approaching poles are of like polarity and those receding are of unlike polarity. The M.M.F.S set up by the armature poles begins to die away after having



reached a maximum at a point midway between two field poles as at A in above figure. When the armature poles have reached a new position as B, the M.M.F. has completely vanished and at this point reverses. The peculiar alternations of the armature poles causes the flux from the fields to tend to follow the armature poles around, a condition which increases the length of air gap and so increases the reluctance of the magnetic circuit. The magnitude of the increase of the reluctance depends upon the strength of the armature current. If the field M.M.F. remains constant when the armature current is increased, the armature flux and hence the E.M.F. must decrease.

So long as magnetic flux is proportional to M.M.F., the coefficient of self induction is constant and the loss of volts over such an impedance is proportional to the current which flows over it. In a choke coil whose flux path is not affected by an outside M.M.F., the flux is not proportional to the M.M.F. produced by the coil, but is affected by the permeability of the magnetic circuit: therefore the loss of volts over such an impedance is not proportional to the current, but is something less than a proportionality, assuming that the iron is worked at average flux densities, above 3 kilogauss.

An armature operated as in this test differs from the choke coil, in that as the armature current is increased, the flux through the armature from the fields is diminished and the permeability of the magnetic circuit is therefore increased. This raises the coefficient of self induction causing greater impedance and this causing the drop to increase more rapidly than the armature current. From this it is evident that the characteristic curve should bend toward the X axis. A stiff field would make this fault in regulation less pronounced.

Curve B, Sheet #1, is an external characteristic of the alternator run at 900 R.P.M. This curve, similar to curve A, which was taken for 1200 R.P.M., tends downward as the load is increased, but it is noticed that it does not fall toward the X axis so rapidly as does curve A, when the machine is being loaded. When a generator is run at a speed below normal; to generate normal pressure, there must be a proportional increase of field flux which requires a field current proportional to the required flux and to the reluctance. Hence, there must be a greater M.M.F. set up in the fields to generate normal pressure at 900 R.P.M. For any given load current the reaction of the armature ampere turns on the fields is the same whether the fields be strong or weak. The fields may be so weakened that the field flux is nearly neutralized by the armature ampere turns; again the fields may be so strengthened that the armature turns have very little effect on the total flux. So it is in this test run at 900 R.P.M. the reaction of the armature turns does not so affect the total flux as it does when run at 1200 R.P.M. and on a weaker field; So that, on the strengthened field the flux passing through the armature remains more nearly constant as the load comes on, and the voltage holds up much better.

Another factor which causes the characteristic curve for 900 R.P.M. to run higher than the one for 1200 R.P.M., is armature inductance. The volts lost in inductance is expressed by

$$E = I\,2\pi f L.$$

in which I is the current, f is the frequency of the current and L

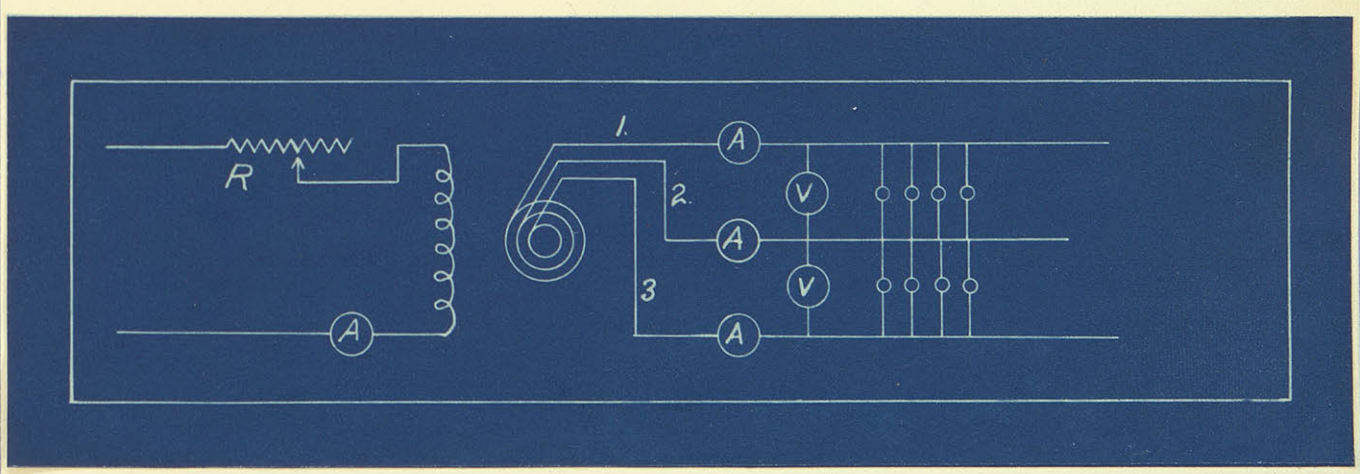
the coefficient of self induction which is expressed by

$$L = \frac{4\pi N^2}{R}$$

in which n is the number of armature turns in series, and R the reluctance of the magnetic circuit. At 900 R.P.M. f becomes $\frac{900}{1200} \times 60 = 45$ cycles per second or 75% of normal frequency and the inductive reactance of the windings is reduced by 25%. The factor R in the expressim for L is higher due to the higher armature flux density; thus the inductive reactance is further decreased.

Hence, it is seen that the loss of volts due to armature impedance, and the tendency of failure to generate volts due to armature reaction, is reduced by running at a lower speed and a stiffer field.

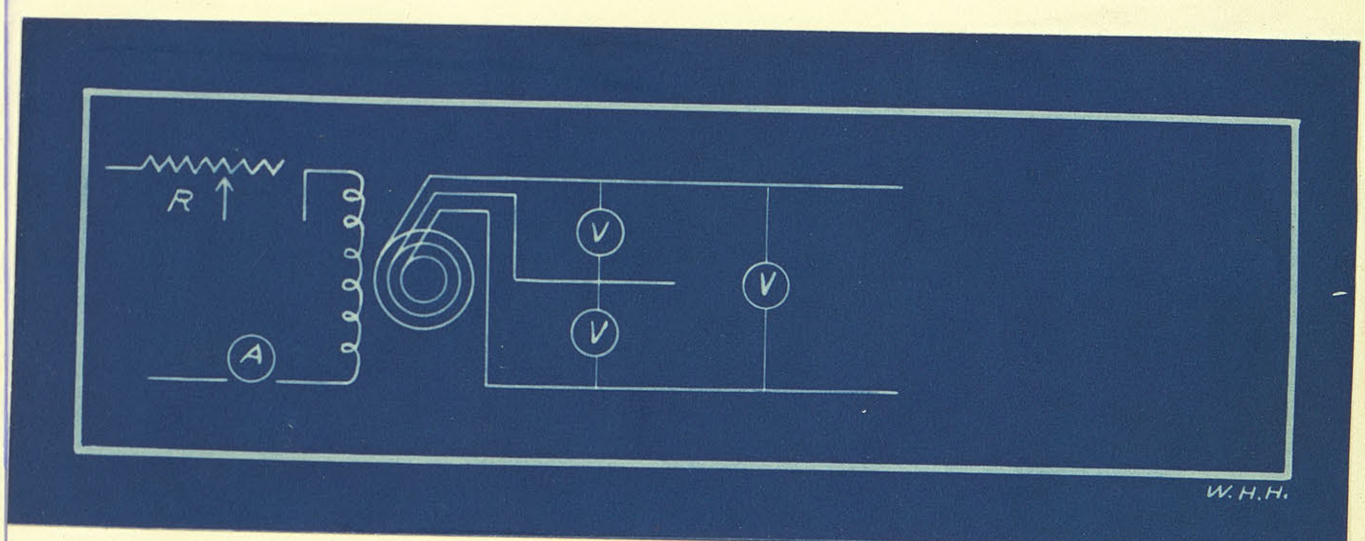
Curves A, B, and C, Sheet #2, have been plotted from data obtained in a test for external characteristic for uneven loading. Two banks of lamps were placed between two phases and the remaining phase was left unloaded.



The load was between (1-2) and (2-3). In such a test it would be expected to see the voltage between (1-2) and (2-3) to remain nearly equal to each other but decrease as the load current increases and at the same time, the voltage between (1-3) to decrease but remain above (1-2) and (2-3) throughout the test. An examination of the curves shows that this does not result. A satisfactory explanation for this has not been given.

NO LOAD SATURATION CHARACTERISTIC.

For this test the C. W. Motor drive was belted to the alternator and to the exciter. The Weston D.C.Ammeter was connected in the alternator field circuit, and the A. C. (0-130) voltmeter was connected over two of the legs of the machine. The alternator was run at constant normal speed (1200 R.P.M.), and the field circuit closed on low exciter voltage; from this point, the field current was increased step by step until the highest allowable voltage was generated, while for each change of field current, simultaneous readings of volts and field current were taken. Care being taken that in each case the field was increased to a point of reading, and in no case decreased.



The no-load saturation curve is one which represents relative values of armature fluxds generated by different values of field currents. The curve is plotted with field current, as abscissas, which current

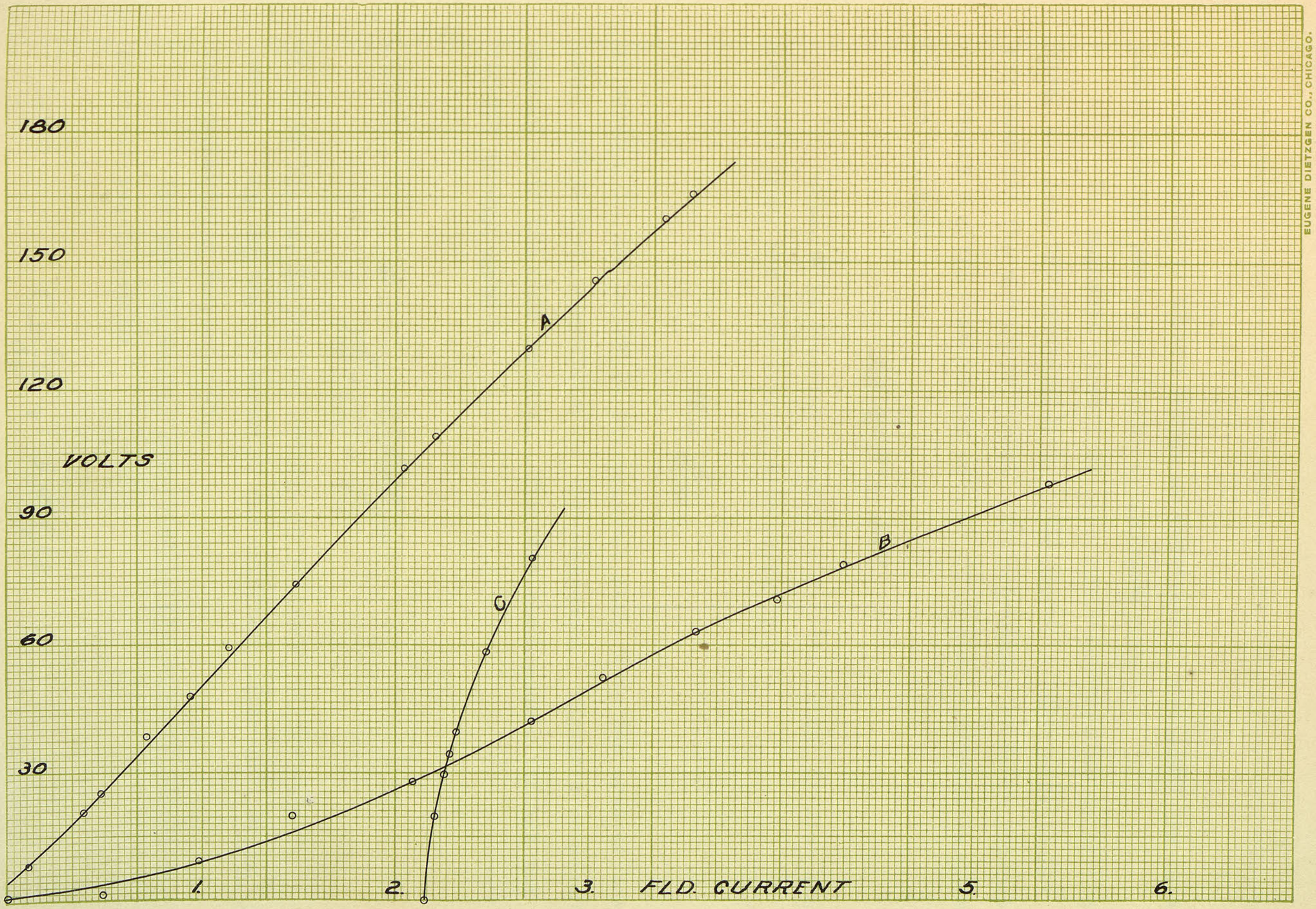
No Load Saturation Curve.

1200 R.P.M. Amp's Fld.	Volts	600 R.P.M. Amps Fld.	Volts
.10	8.3	0	1.6
.39	21.8	.5	2.0
.48	26.5	1.32	10.2
.70	39.5	1.80	20.0
.95	51.5	2.10	29.0
1.12	60.3	2.72	43.0
1.55	80.0	3.09	53.5
1.77	89.4	3.58	64.0
2.05	102.5	3.95	71.3
2.22	110.7	4.33	80.0
2.75	134.0	5.4	99.4
3.03	146.5		
3.40	160.5		
3.54	166.3		

Full Load Saturation Curve.

Amp. Fld.	Amp. Arm.	Volts.
2.22	60.	20.
2.25	"	21.
2.25	"	30.
2.26	"	32.
2.28	"	35.
2.28	"	37.
2.32	"	40.
2.37	"	46.
2.49	"	59.
2.72	"	77.
2.72	"	81.

3



180
150
120
VOLTS
90
60
30
A
B
C
1.
2.
3.
FLD. CURRENT
5.
6.
EUGENE DIETZGEN CO., CHICAGO.

is proportional to ampere turns, as ordinates of the curve are volts pressure which are proportional to armature flux.

The magnetic circuit of this alternator is made up of field core, air gaps and armature core. The magnetic reluctance is not the same for the different parts. The magnetómotive force necessary to produce a given flux in any part of the magnetic circuit is given by the equation

$$M.M.F. = \phi R$$

where ϕ is the flux density, i.e., the number of flux lines per unit area, and R is the magnetic reluctance.

$$R = \frac{l}{A\mu}$$

in which l is the length of the magnetic path, A is the area of the path, and μ the permeability of the substance. Magnetic reluctance changes with the flux changes. The flux which passes through the circuit is expressed by

$$\phi = \frac{M.M.F.}{\frac{l_1}{A_1\mu_1} + \frac{l_2}{A_2\mu_2} + \frac{l_3}{A_3\mu_3}}$$

in which l_1, l_2, l_3 are the lengths of the parts of the path in series. A_1, A_2, A_3 the areas of the different parts and μ_1, μ_2, μ_3 the permeability respectively.

The average voltage generated in the armature inductors, by the revolving fields is

$$E_{AV.} = \frac{pV}{60} \times \frac{S \phi K X 2}{10^8}$$

Where p = pairs of poles

V = revolutions per minute

S = Total number of inductors

ϕ = Flux per pole

K = Distribution constant.

The E.M.F. which causes the effective current to flow is

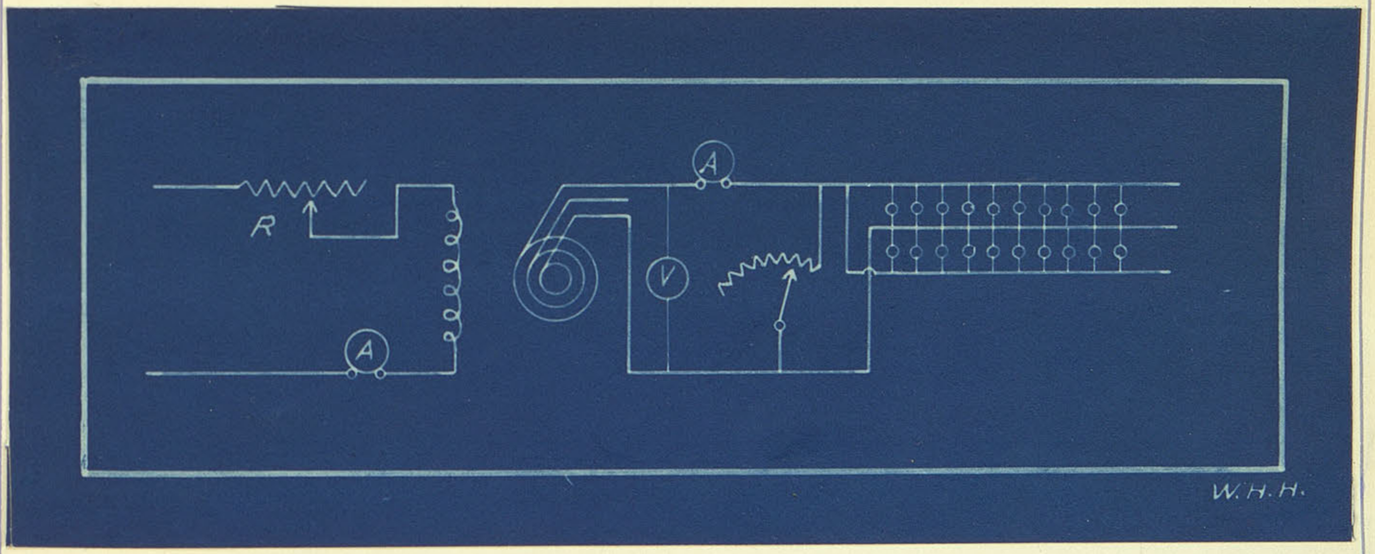
$$E_{EFF} = 2.22 \frac{pV}{60} \times S\phi K \times 10^{-8}$$

which is the voltage indicated by the voltmeter.

The saturation curve A, as obtained in the test indicates that the magnetic circuits of the machine are worked at low inductions also that the air gap is long. The air gap tends to make the curve a straight line, since μ of air is constant and equal to unity. Curve B shows a more decided variation in the value of the permeability of the different parts of the magnetic circuit. In this curve, the iron is approaching saturation as seen by the highest values of M.M.F The reluctance of the path through the armature increases very rapidly as the flux is increased, after a certain high flux density has been reached. The armature reluctance is made up of two parts; that due to the value of μ, and that due to hysteresis and eddy currents. Hysteresis varies as $B^{1.6}$ (B = induction) and eddy currents vary as B^2

FULL LOAD SATURATION CURVE.

The C.W. Motor was belted to the G. E. Alternator. The water box, in multiple with the banks of lamps, was connected between two lines of the alternator, with a Thompson A.C. (0-100) ammeter in the load circuit. The Weston voltmeter was connected over the two loaded lines and the (0-15) direct current Weston ammeter was placed in the field circuit. The machine was run at constant normal speed (1200 R.P.M.) and without excitation, was shorted through the water box. The fields were then excited until a load current of 60 amperes was indicated on the ammeter. From here the external resistance was increased step by step until maximum voltage was generated, the excitation being increased sufficiently to keep a constant load current of 60 amperes. Simultaneous readings of field current and volts were taken.



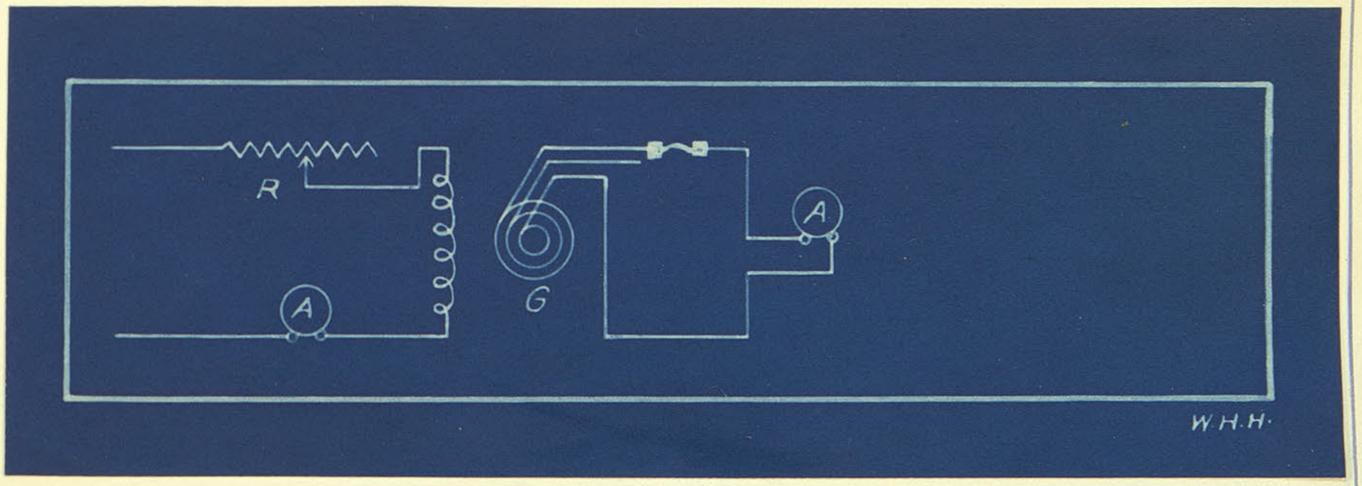
The Full Load Saturation curve has the same general tendency as the No Load Saturation curve; it bends more and more form the Y axis as the excitation is increased. The Full Load curve runs below the No Load curve: this is due to the loss of volts produced by the constant armature current, as the field current increases. It is to be observed that the difference of the ordinates of the two curves becomes less and less. An inspection of the Synchronous Impedance curve shows that as the armature current increases the impedance decreases; and so it is that the Full Load curve may approach the No Load curve. If the test could have been continued far enough, a point would have been found where the two curves would no longer approach each other, but would be parallel. This condition would in every case be beyond the working limits of the machine.

Those things which produce the difference of volts between the two curves, are discussed under External Characteristic, though in that test the conditions are somewhat different. The armature current being a constant quantity, the cross and direct armature ampere turns are constant, but the number of cross turns increases and the back turns decrease by the same amount, as the fields are strengthened by an increasing field current. Hence, in this respect the reluctance of the magnetic circuits is decreaaed, and there is a tend~~ing~~ency to decrease the loss of volts. It was seen under Synchronous Impedance, how by decreasing the permeability in the quantity $\frac{4\pi N^2 A\mu}{l}$ the impedance of the armature decreases as field flux increases. Hence, self-induction is a second factor tending to cause the two curves to approach each other.

SYNCHRONOUS IMPEDANCE.

The Crocker Wheeler Motor was belted as in previous test. A direct current (0-15) Weston ammeter was connected in the alternator field circuit, and a (0-100) A.C. Thompson ammeter was placed between two lines, making a short circuit through this instrument. The alternator was run at constant normal speed (1200 R.P.M.) throughout the test. The field circuit was closed on low exciter voltage and the field current increased step by step until the ammeter in the short circuited line read 25% overload current. Simultaneous readings of field amperes and armature circuit amperes, were taken for each value of field current.

From the No Load Saturation curve for this machine the open circuited voltage was found for each value of field current in this test. This was done because the speed raised when the load was thrown off. Synchronous impedance is expressed by, $Z = \dfrac{\text{open circuit volts}}{\text{short circuit current}}$ and from this relation the synchronous impedance for the different values of armature current, has been calculated.

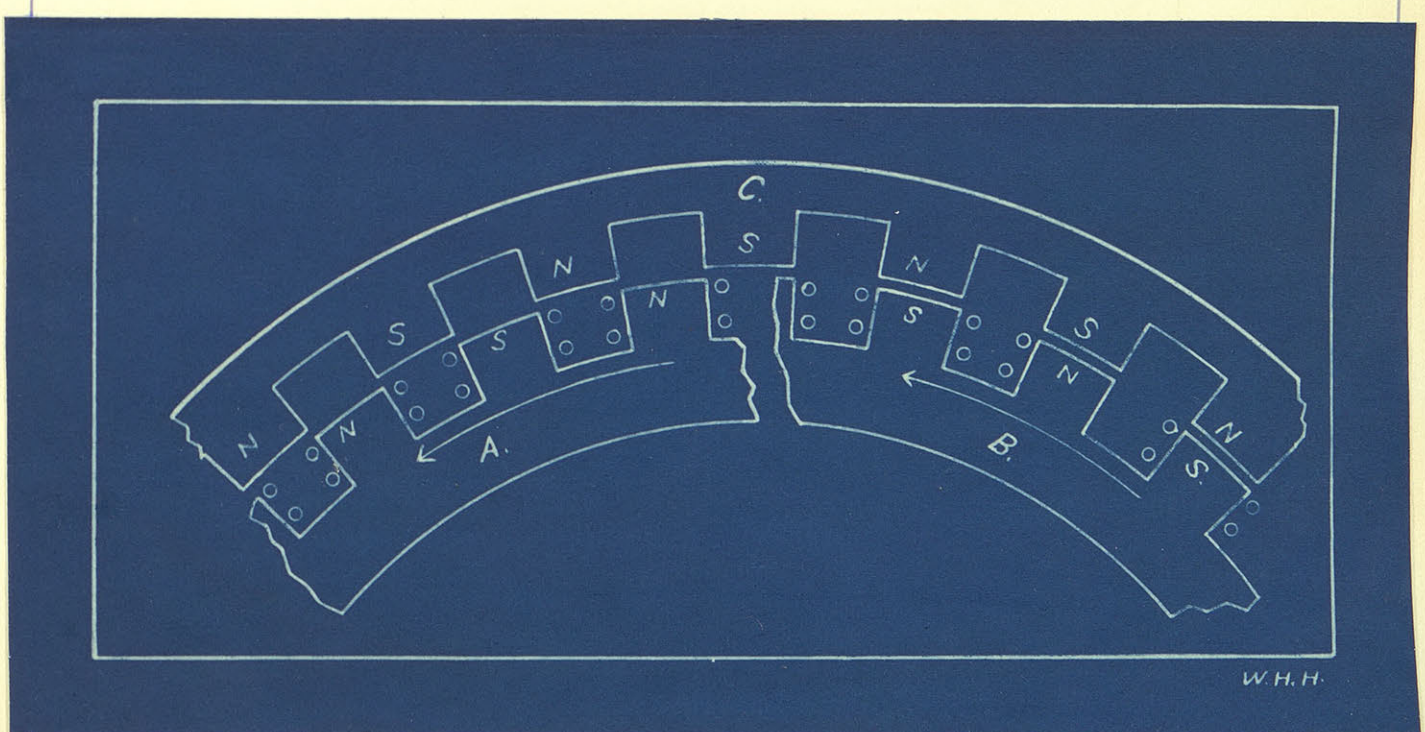


Synchronous Impedance.

Amp. Fld.	Amp. Arm.	Volts.	Syn. Imp. Ohms.
.11	4.90	8.5	1.73
.18	6.23	13.0	2.08
.29	9.15	17.0	1.86
.38	11.5	19.5	1.7
.49	14.4	26.5	1.84
.55	17.3	31.5	1.82
.86	25.6	46.5	1.82
1.22	35.5	64.0	1.80
1.6	45.5	82.0	1.80
1.95	55.0	98.0	1.78
2.22	62.5	109.3	1.75
3.2	89.	153.0	1.72

Synchronous Impedance of an alternator is that quantity which when multiplied by the current flowing through the armature windings produces the total loss of volts in the armature. Those causes which produce the synchronous impedance are, (a) resistance of armature windings,. (b) self induction in the armature windings, (c) armature reaction.

The loss of volts due to the resistance of the windings is in phase with the armature current, and the product of this quantity and the current is the watts lost in heating the windings. The loss of volts by armature self induction is not in phase with the current but 90° ahead of it. The product of this quantity and the armature current does not represent lost power, but is a wattless component and does not heat the windings. Armature reaction does not cause an internal loss of pressure generated, but prevents the generating of normal pressure, by reducing the value of the flux.



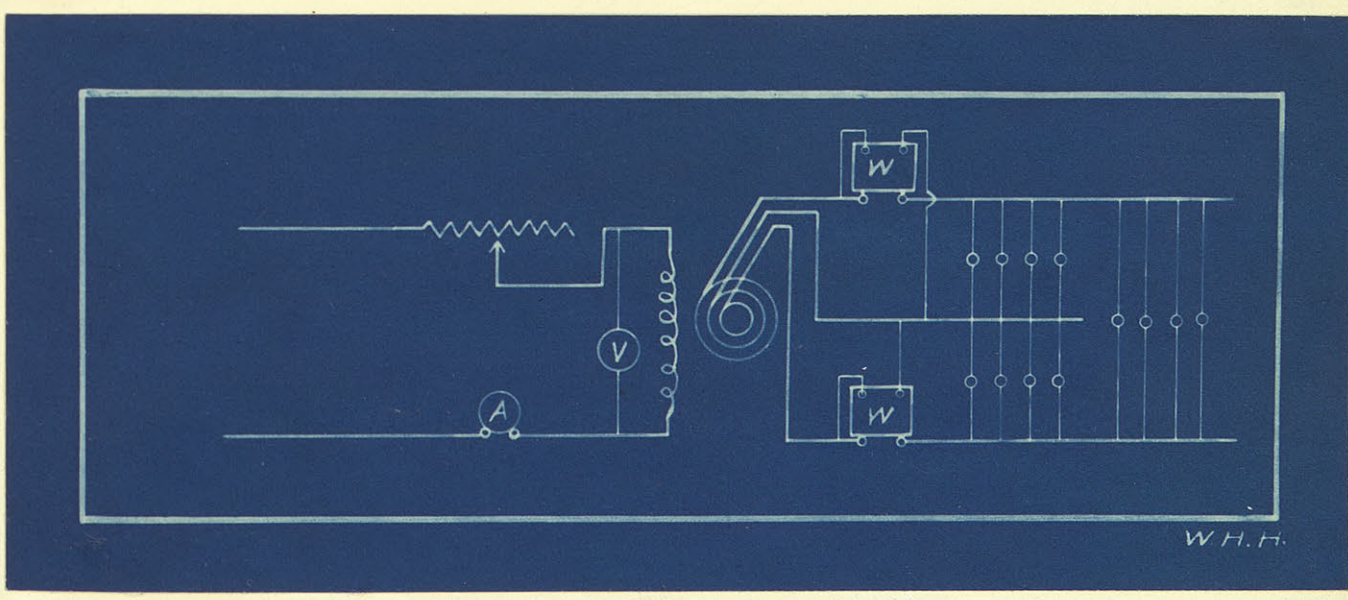
In the above figure C represents the fields and A and B the armature of an alternator. When the armature is rotating through the position shown at A, the inductors are cutting the field flux at a maximum rate, and if the current is in phase with the E.M.F., there is at this position a maximum E.M.F. generated and poles of maximum strength will be set up around the armature, which poles oppose the flux from the approaching field poles and attract it from the receding poles. This causes distortion of the field flux and consequently increases the reluctance of the magnetic circuit. This part of the synchronous impedance when load is on prevents the generation of the normal no-load voltage, hence an increased field current must be supplied. The synchronous impedance of this machine remains nearly constant throughout the working range. The decrease in its value from no-load to 25% over load is about 4%. This variation is the result of a decrease of armature inductance, due to greater saturation of the armature core at full load. Also the fields are more fully saturated, and hence less easily distorted at full load.

FIELD COMPOUNDING CURVES.

In these tests the alternator was run at constant speed and constant voltage with gradually increasing load. Simultaneous readings of the field current and generator output were taken at each variation of load, care being taken to read only ascending values of load and field current.

The regulation of the field current was performed by hand. Alternators are frequently equipped with devices to do this work automatically.

Curves were plotted from the results obtained, using the values of the field current as ordinates and the corresponding values of generators output as abscissas.



In the first test from which curve A was obtained the generator was loaded with a balanced lamp load in order to determine its

FIELD COMPOUNDING CURVE, SINGLE PHASE.

TRANSFORMER, LAMP AND MOTOR LOAD.

Volts					
1-2	1-3	2-3	Amp.	K-W	Fld. Amp.
104	119	109	15.2	1.15	2.51
"	122	109	18.5	1.40	2.59
"	129	110.	24.4	2.65	2.70
"	131	109.	28.3	3.00	2.75
"	136	111.	33.3	3.50	2.89
"	138	112.	37.5	3.85	2.98
"	142	113.	40.8	4.23	3.08
"	145	114.	43.5	4.62	3.20
"	151	117.	50.0	5.20	3.38

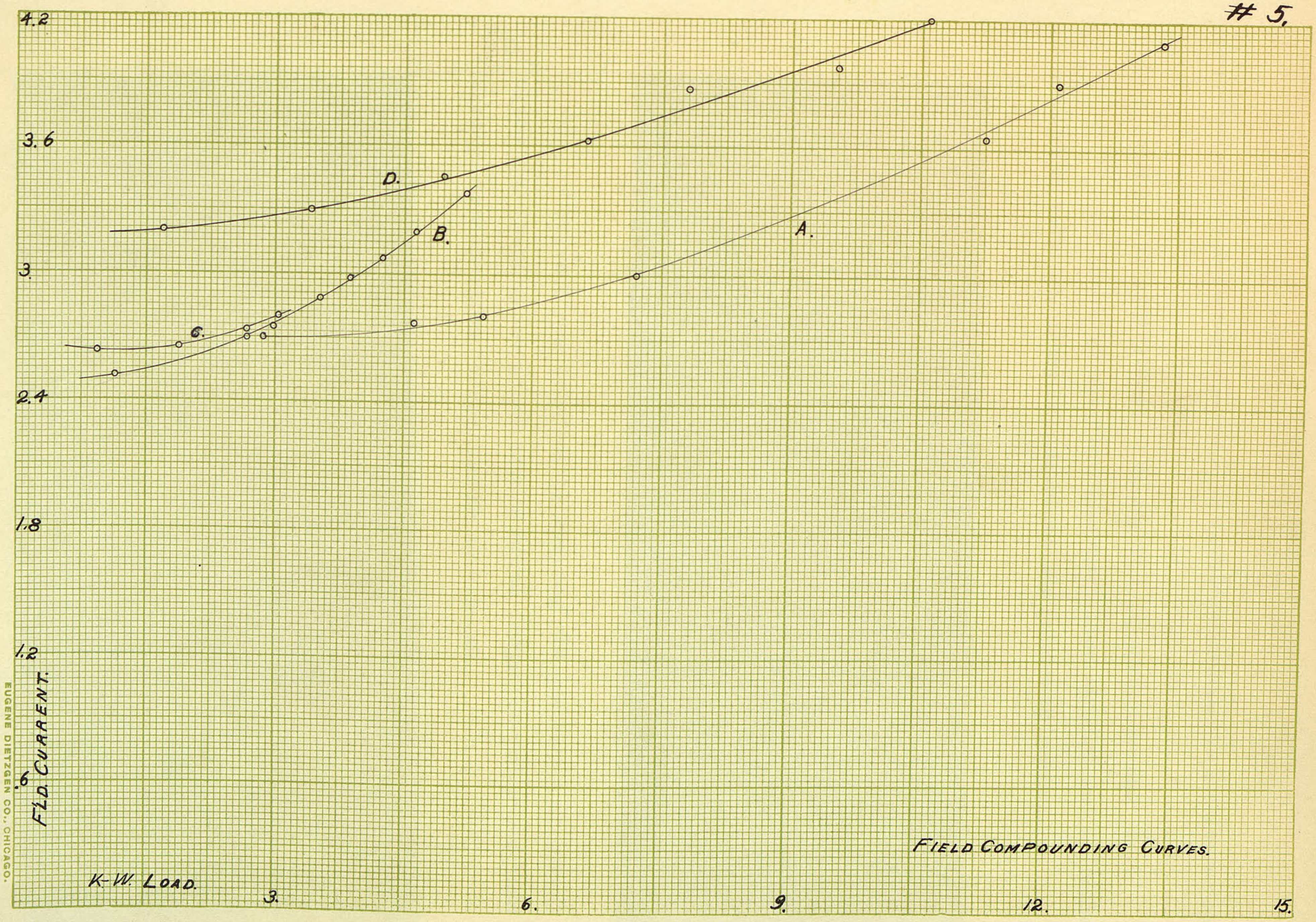
FLD. COMPOUNDING CURVE - MOTOR LOAD.

Volts		Current		K.W.		FLD.Cur.	
1-3	3-2	#1	#2	#2	#1	Total	
104	104	105	5.23	.4	.1	.5	2.65
102	103.3				.4		2.62
102	103.			.563	"	.963	"
99.3	100.5	17	8	.85	1.03	1.88	2.65
97.5	99.	21	10	1.	1.033	2.03	2.7
96	98.	24	11.1	1.1	1.55	2.65	2.73
94.5	97.3	27.5	12	1.2	1.8	2.99	2.78
98.	99.	22.3	11	1.1	1.42	2.51	2.76
98.5	99.	26.4	14.5	1.48	1.67	3.15	2.83

FLD. COMPOUNDING CURVE AT 900 R.P.M.

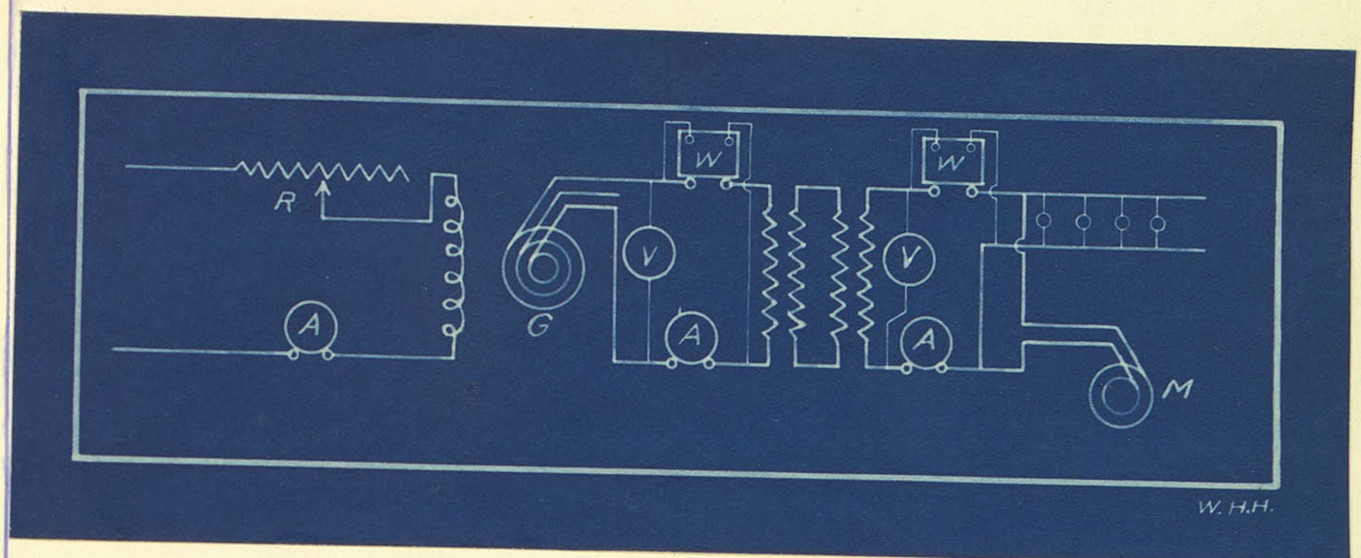
FLD. Cur.	Arm. Cur.	Out-put.
3.2	9.6	1700
3.3	18.5	3400
3.45	28.	5100
3.62	36.6	6600
3.87	42.2	7800
4.00	50.5	9500
4.22	56.2	10600
4.38	61.0	11500
4.50	68.5	12750
4.73	71.7	13650

5.

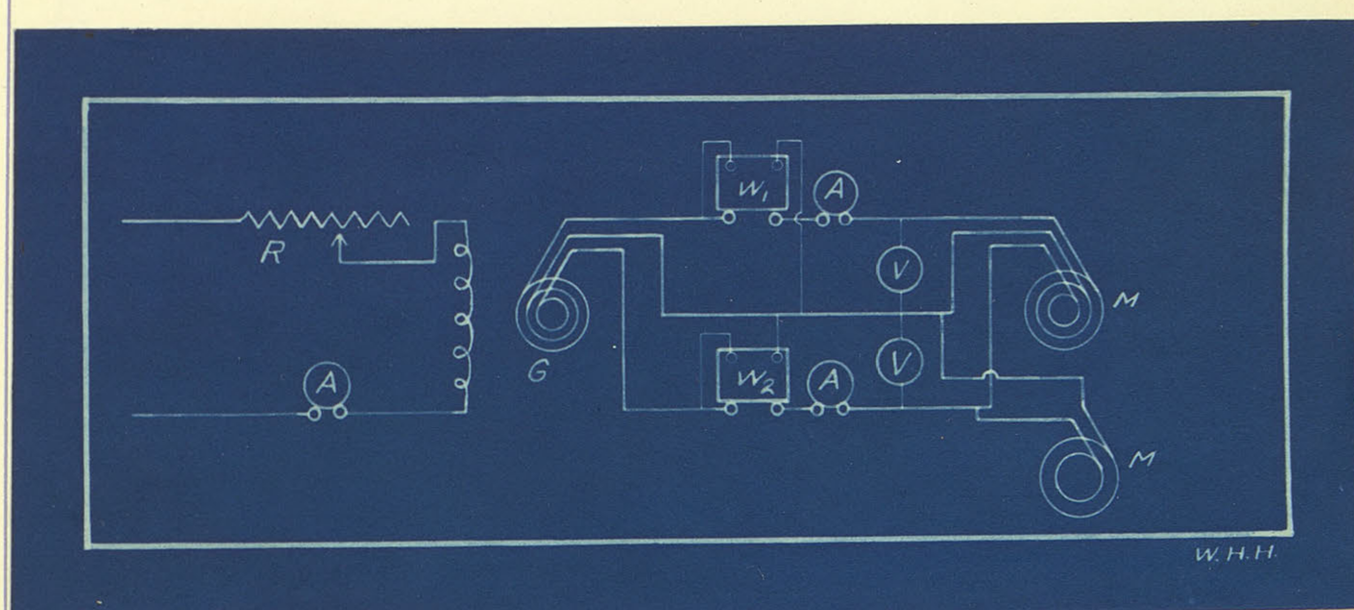

4.2
3.6
3.
2.4
1.8
1.2
.6
FLD. CURRENT.
K-W. LOAD.
3.
6.
9.
12.
15.
A.
B.
C.
D.
FIELD COMPOUNDING CURVES.
EUGENE DIETZGEN CO., CHICAGO.

commercial efficiency. It was run at normal speed.

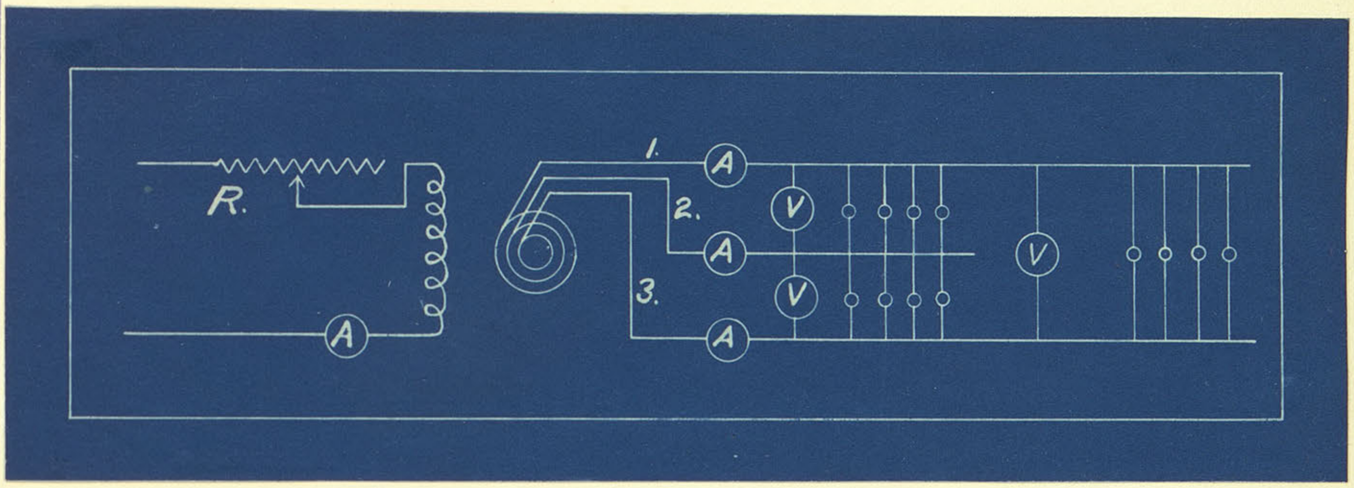
As the load was non-inductive, only ammeter and voltmeter readings were necessary to determine the generator output.



Curve B was obtained by running the generator at normal speed and loading one phase with a mixed induction motor and lamp load through transformers, using double conversion.



Curve C was obtained at normal speed with an unbalanced load consisting of one three phase and one single phase induction motor.



Curve D is the result of a test with balanced lamp load the alternator being run at seventy five per cent of normal speed. Curves A and D were taken at 110 volts; B and C at 104 volts.

The object of these tests is to determine the necessary change in field current in order to maintain constant pressure under varying conditions of load, speed, and power factor.

The external characteristic shows the extent to which the voltage is affected by changes of load when the excitation remains constant, but from it, it is not possible to determine the required variation of excitation for constant voltage.

The factors which tend to reduce the voltage with increased load have been pointed out in the discussion of synchronous impedance, as drop due to ohmic and inductive impedance of the armature, reduction of flux by distortion of field, and reduction of flux by the opposing action of a lagging current.

To overcome the effect of the first of these factors requires an actual increase of flux through the armature coils, since a higher E.M.F. must be generated in order that full pressure may be available at the machine terminals after deducting the ohmic and inductive drops. The ohmic drop remains proportional to the current, except for a slight increase of resistance with temperature, but the inductance of the armature will decrease slightly, due to the lessened permeability of the armature core, as the flux density increases.

The second and third factors do not require an increase of flux but make a larger field current necessary in order to maintain the flux at its normal value; the second because it increases the density in the path through which the greater part of the flux passes and also lengthens the path through the air gap; the third by neutralizing a part of the magneto-motive-force of the field coils.

If values of flux were plotted instead of values of field current it is probable that the resulting curve would be very nearly straight, since the slight increase in resistance would be compensated for by the decreased inductance. It is not likely that the effect of distortion increases proportionately with the current, for as the magnetic circuit becomes more highly saturated the field becomes stiffer or more difficult to skew. This is because of the decreased permeability of the highly saturated parts. The last factor, the angle of lag remaining constant, would require a field current directly proportional to the armature current since it affects the magnetic circuit in direct opposition to the field coils. It appears then that with an increasing load, of constant power factor, the upward curvature of the field compounding curve is due mainly to the form of the saturation or magnetization curve.

Since the curve A was taken with a non-inductive load it is affected by only the first three of the factors mentioned as influencing the form of these curves. Curve D is above A, because of the greater flux required at the lower speed, but rises a little less rapidly than A. The reason for its slower rise is that the iron is more fully saturated and is therefore less affected by distortion; also the inductive drop in the armature coils is reduced.

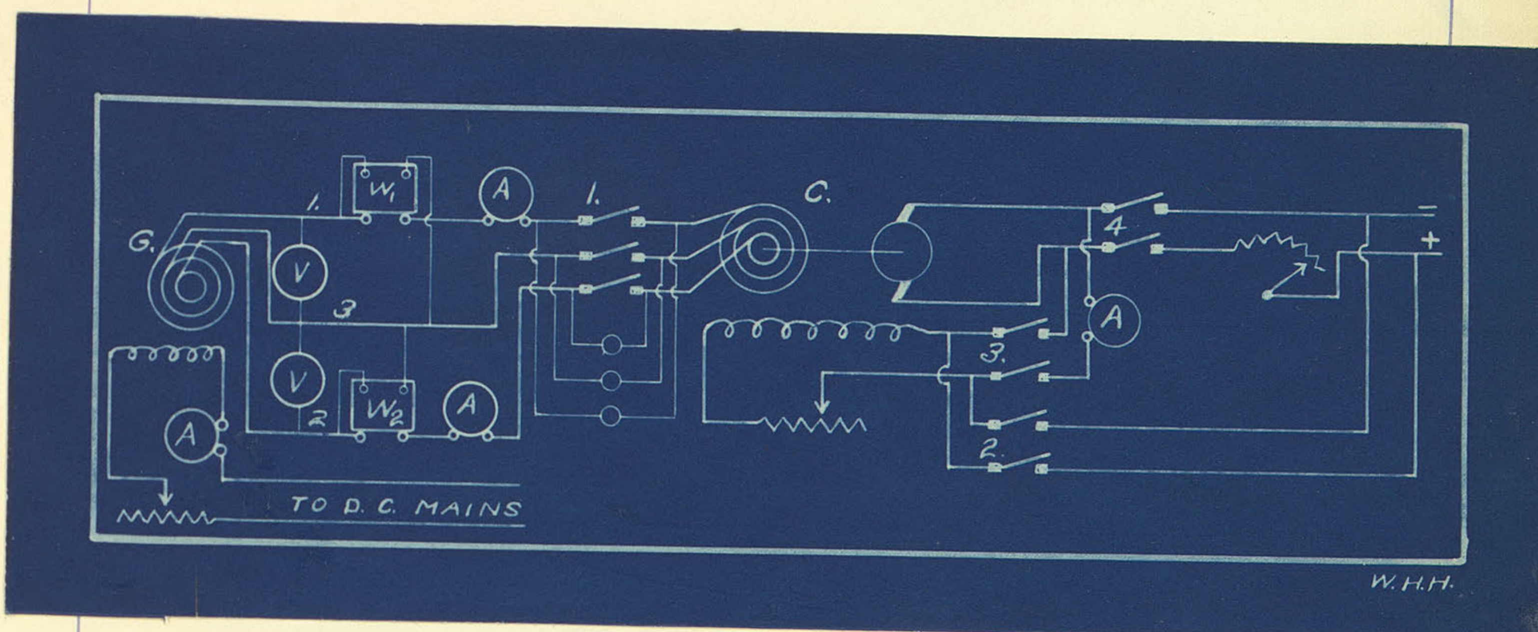
Were it not for this D would rise more rapidly that A because the iron being more fully saturated, a much greater increase of field current is necessary to compensate for the ohmic drop.

The curve B, being taken from single phase operation, cannot well be compared with the other curves. It starts lower than A because it was taken at a lower voltage. At the same voltage it would probably be above A because of a lagging current. It would rise more slowly, however, because the power factor increased with the load.

Curve C also was taken at one hundred-four volts. It starts above B, because the power factor was low while the motors were running at light load. As they were loaded up the power factor improved rapidly and a slight decrease in field current was necessary. This shows that induction motors might be run on the same circuit with lamps if run constantly and at fairly uniform loads. When they are thrown on or off the inductive effect on the generator is so great that satisfactory regulation for lamps is impossible.

These curves show rather poor design, as the no load exciting current, on a non-inductive load, is but fifty per cent of that required at full load.

REGULATION WITH SYNCHRONOUS MOTOR LOAD.



The apparatus is connected as shown in the scheme. C is the rotary converter which is run as a synchronous motor. G is the alternator. The Westinghouse generator was belted to the synchronous motor for a load.

The data taken for this experiment is shown on data sheet #6 Column #1 gives the amperes as read on line #1 of the alternator. Volts in column #3-1 were read between lines #3 and #1.

The watts in column #1 were read on line #1 etc.

The power factor as shown in the data sheet is the average power factor. The column marked G. E. F L D is the field current of the alternator and the column marked Syn. F L D is the field current

SYNCHRONOUS MOTOR TEST.

With Constant Load on Westinghouse.

#1 Amps	3-1 Volts	#1 Watts	#2 Amps	2-3 Volts	#2 Watts	Power Factor	G.E. FLD.	Syn. Fld.	West. Amps.	West. Volts.
51.	90.	562.5	48	87	3910	.437	4.	.8	13.4	109.4
42.	"	825.	40	"	3410.	.584	3.4	.9	"	"
35.	"	1450.	33	"	2900.	.723	3.	1.0	"	"
31.	"	1775.	29	"	2500.	.806	2.73	1.1	"	"
29.	94.3	2135.	27.5	"	2150.	.839	2.3	1.2	"	109
30.5	89.	2450	29.	"	1860.	.823	2.05	1.3	"	"
36.5	93.	3050	35.	"	1335.	.686	1.6	1.4	"	108.5
40.	89.	3325	39	"	1150.	.643	1.45	1.5	"	"
52.	88.7	3600								

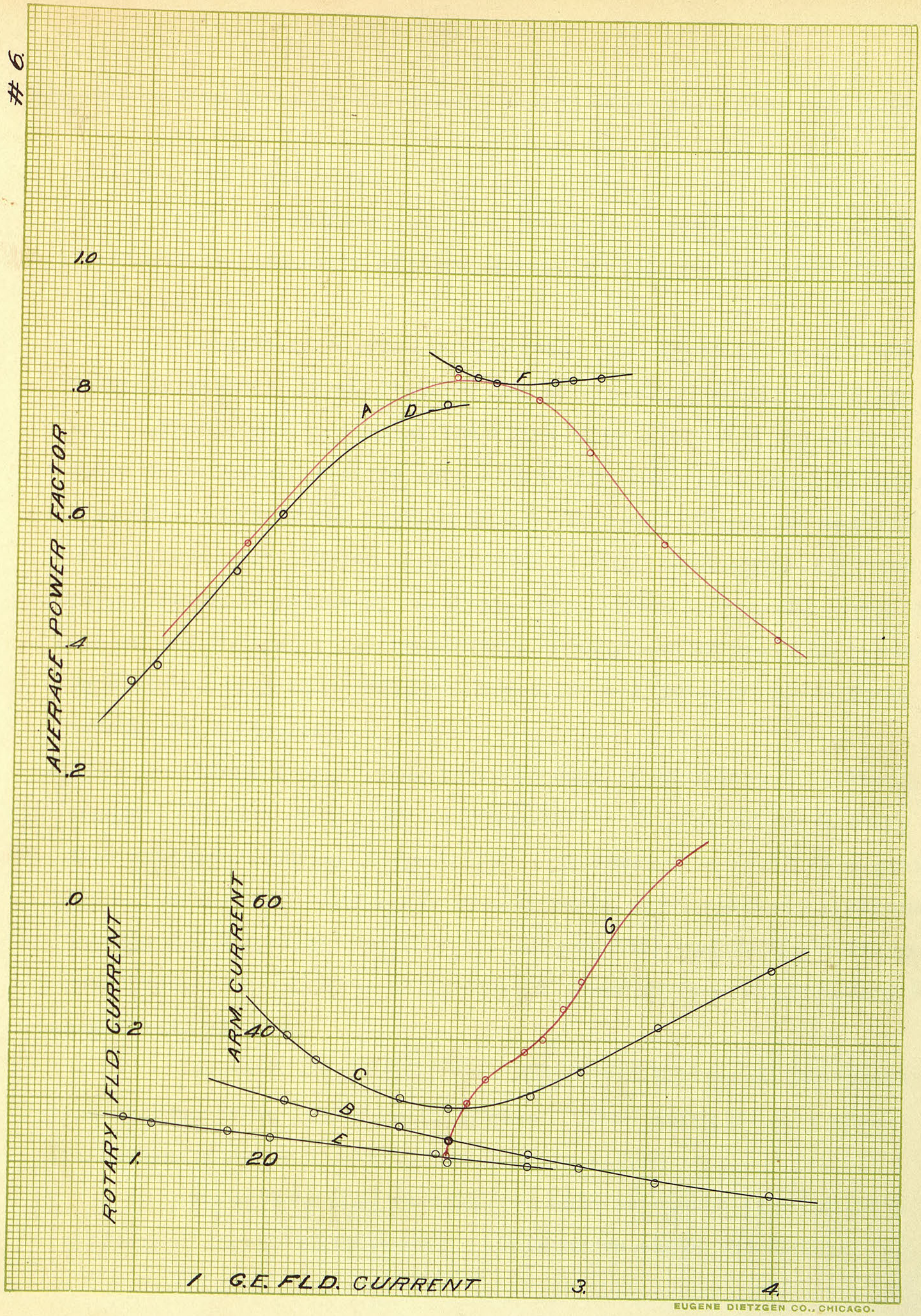
With Constant Motor Field Current.

22	89.	1425	21.	87.	1780	.849	2.3	1.2	4.2	112
27.	90.	1875.	25.	"	2000	.848	2.28	"	8.9	128
30.	89	1975 .	28.5	"	2345.	.835	2.4	"	13.3	112
34.	"	2230.	32.	"	2599	.831	2.5	"	17.7	111.5
38.	"	2450.	36.	"	2966	.91	2.7	"	22.2	111.5
40.	"	2550.	38.	"	3155.	.8325	2.81	"	26.1	108
455	"	3025.	43	"	3500.	.838	2.9	"	31.7	111.
48	"	3150.	46.	"	3800.	.84	3.05	"	34.8	109.
68	"	4525.	65.	"	4500	.7225	3.5	"	44.	110.

With Three Phase Motor in Parallel.

22.3	89	0	20.	87.5	1625.	.436	2.73	1.03	0	0
26.5	89	0	24.5	"	1900.	.423	2.3	1.03	"	"
15.	90.	775.	13.	"	1200	.796	2.25	1.2	"	"
14.	89	1200	13.	"	800	.841	1.8	1.3	"	"
19.5	"	1600	19.	"	475.	.612	1.38	1.4	"	"
24.5	"	1925	23.	"	275.	.526	1.15	1.15	"	"
35.	91.	2500	34.	"	-175.	.378	.75	1.6	"	"
40.	89.	2775.	39.	"	-325.	.352	.6	1.7	"	"

6



AVERAGE POWER FACTOR
1.0
.8
.6
.4
.2
0
A
D
F
ROTARY FLD. CURRENT
2
1.
ARM. CURRENT
60
40
20
C
B
E
G
1 G.E. FLD. CURRENT 3. 4.
EUGENE DIETZGEN CO., CHICAGO.

of the synchronous motor.

The experiment was first run with a constant load on the Westinghouse generator of 13.4 amperes at the voltage shown on the data sheet.

The field current on the motor was varied and other readings taken as shown. The voltage of the alternator between legs 2 and 3 was kept constant by varying the field current. From the readings taken as shown above three curves A, B and C on curve sheet #6 were plotted. Curve A was plotted with G. E. field current as abscissas and average power factor as ordinates. This curve shows that the power factor increases up to about .85 and then decreases. This is due to the change in the synchronous motor field as shown by curve B which is plotted with the same abscissas as A and with motor field current as ordinates.

Curve C is plotted with the same abscissas as B but with armature current on line #1 as ordinates. This curve shows that, with maximum values of power factor, the armature current is a minimum.

The test of the synchronous motor was continued by maintaining its field current constant and varying the load on the Westinghouse generator. The data is shown on data sheet #6 from which curves F and G were plotted.

Curve F was plotted with G.E. field current as abscissas and average power factor as ordinates. This curve shows a small variation of power factor as the load is varied.

Curve G is plotted with the same abscissas as F but with load current on leg #1 as ordinates. This curve shows the increase of the alternator field which is necessary to maintain constant voltage as the load is increased.

The synchronous motor was again operated with small load, the Westinghouse running light and with a three phase induction motor in parallel with the synchronous motor. The field of the Synchronous motor was varied to show the variation of the average power factor and alternator field current. Curves D and E were plotted from the data taken.

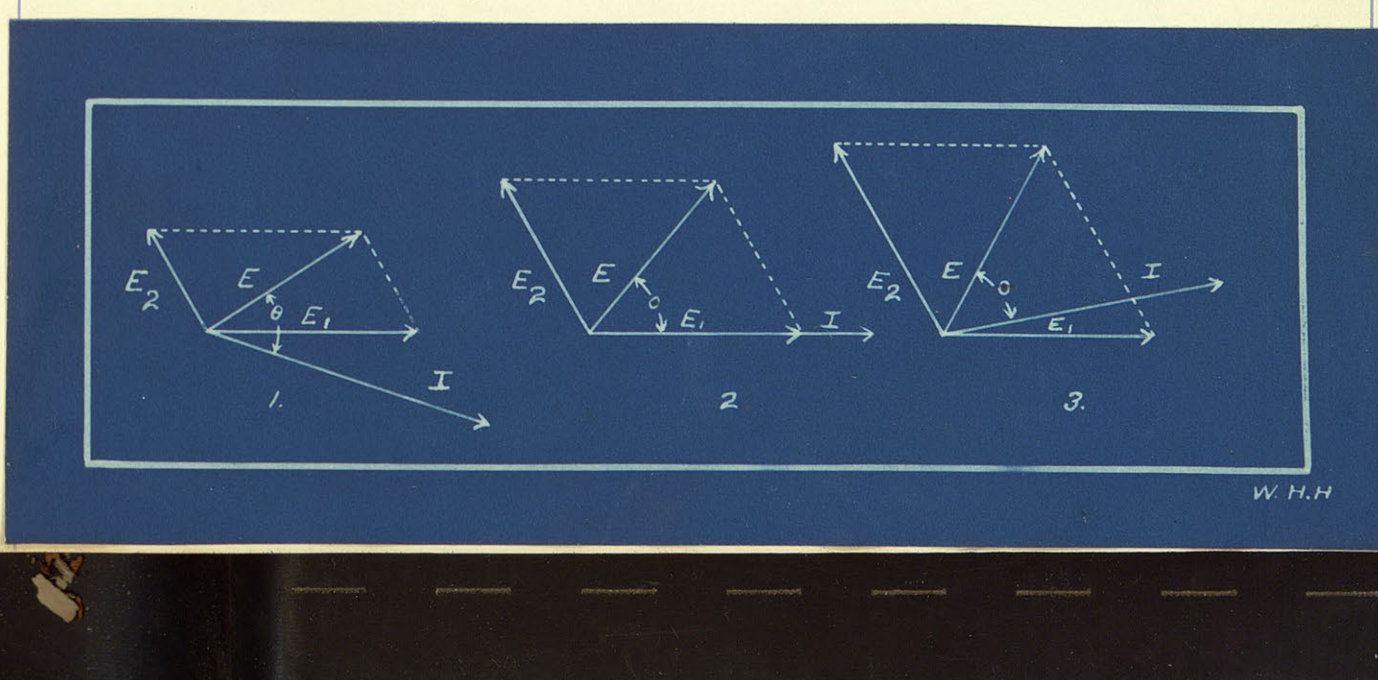
Curve D was plotted with alternator field current as abscissas and average power factor as ordinates.

This curve shows practically the same change of power factor as curve A but does not run so high because of the unbalanced load on the generator, as discussed below.

But one half of the curve was plotted on account of the uncertain data.

Curve E was plotted with the same abscissas as D but with motor field current as ordinates; this curve shows that when the motor field current is maximum the alternator field current is a minimum.

We see by the data that the power factor is varied by varying the field of the synchronous motor. The theory of this change of power factor is shown by the scheme below.

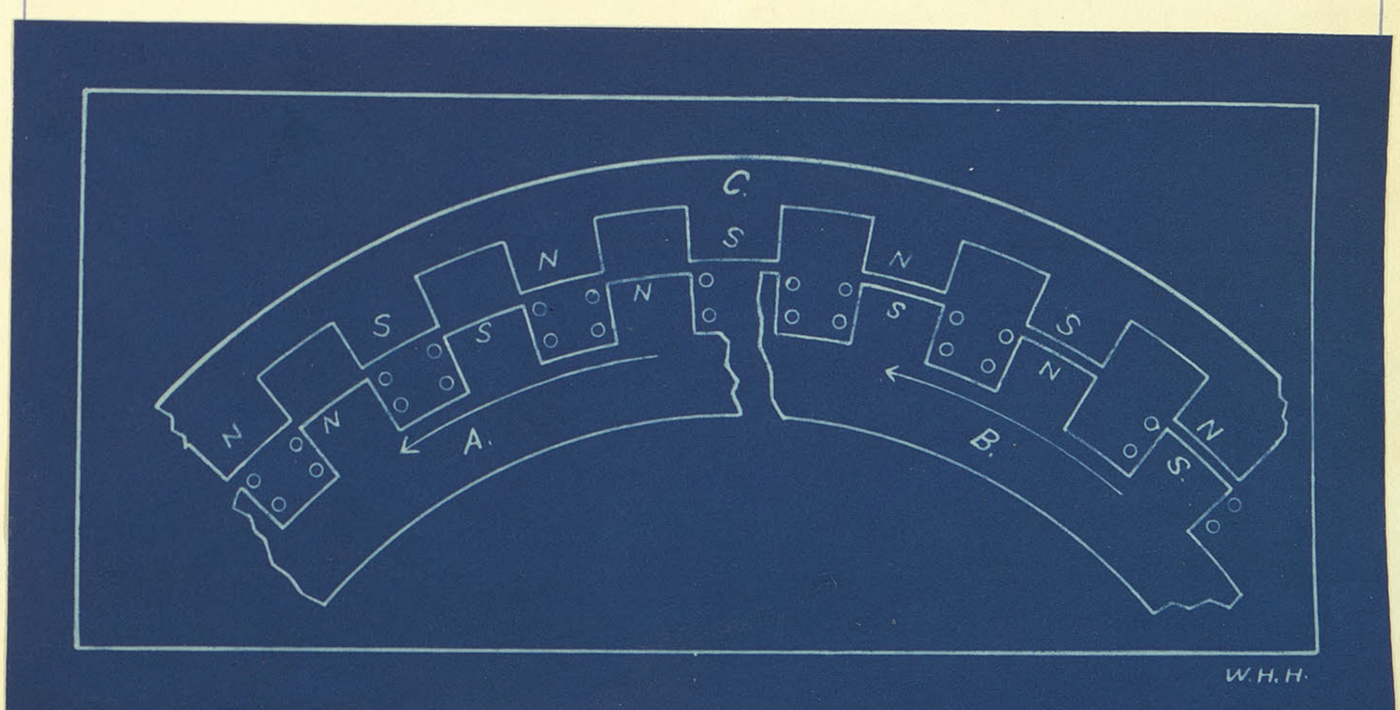


In the scheme let E_1 represent the generator voltage, E_2 the motor voltage which opposes the generator voltage and E the resultant of the two which is active in sending current through the motor. θ is the angle by which the current lags behind E.

In the scheme #1 shows the current I lagging behind E and also behind E_1. This current lags behind the resultant E be a constant angle θ. This constant angle of lag behind E is due to the constant resistance and inductance of the circuit.

If E_2 is increased, as in #2, the resultant E is increased and its direction relating to E_1 is changed, so that I is in phase with E_1. If E_2 is further increased E is again changed in direction as in #3 and the current leads E_1 by a small angle.

Thus we see that the current in the armature circuit of the alternator may be made to lag or lead. In the data on sheet #6, from which curve D was plotted, it is seen that with a strong rotary field the field current of the alternator was very small. This is the result of a leading current which magnetizes the fields.



On the above scheme C represents the fields of an alternator and A,B the armature.

At position A of the armature is shown the poles which are produced in it when the current is in phase with the E.M.F. At position B is shown the poles which are set up when the current leads the E.M.F.

It can be seen that the poles in this position magnetize the field poles, thus requiring less field current. This may be seen from the data.

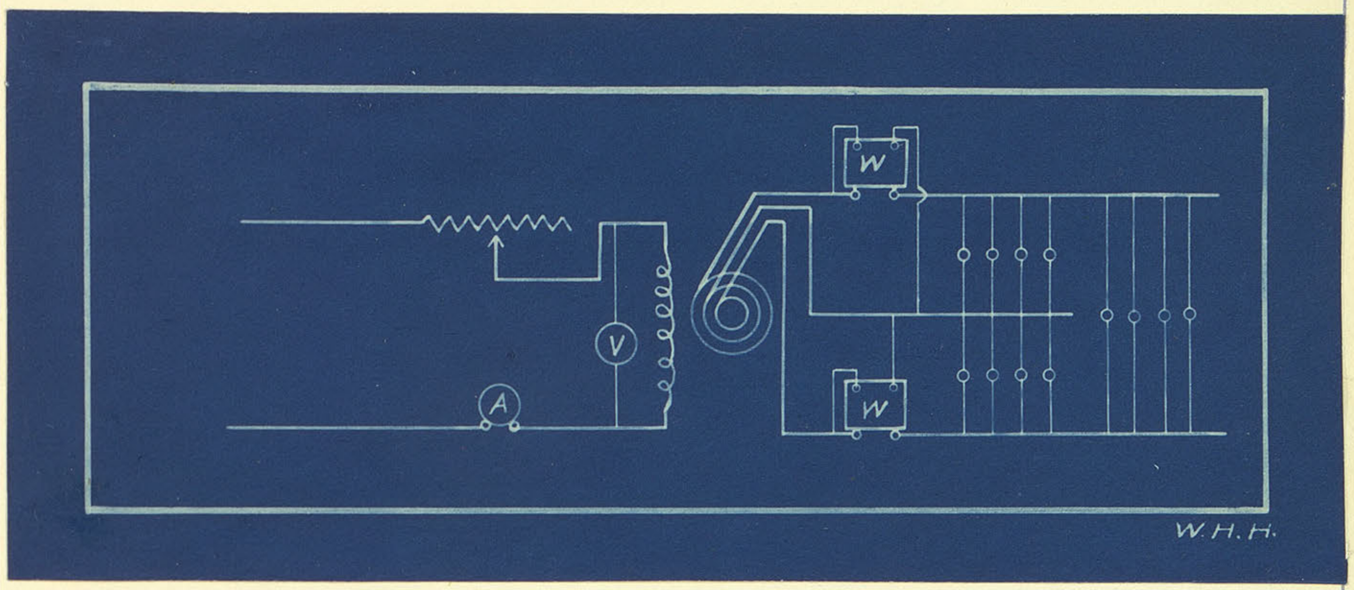
In this test we see that the average power factor does not come up to a value of unity although the power factor in the two lines does reach this value.

The average value of power factor does not come up to unity because the generator is not evenly loaded. When the field of the rotary is properly adjusted for a power factor of one on one leg it is not at the right value on the other leg for this same value of power factor.

Thus the average power factor does not come up to unity.

It is seen by these tests that a leading current produces a power factor on the machine which is as objectionable for wattless current as a lagging current. The leading current however reacts upon the fields of the generator so that much less field current is necessary and regulation is better.

COMMERCIAL EFFICIENCY TEST.



In this test the alternator was driven, at a speed slightly below the normal, by a calibrated motor, both motor and generator being belted to an intermediate shaft.

The exciter was driven by another motor, the field current and the voltage over the field being measured. The load was balanced and non-inductive, consisting of lamps. The output of the machine was measured by two indicating wattmeters. The voltage was kept constant at 110.

The shaft was first run with the alternator belt off, to find the loss in the shaft and motor belt.

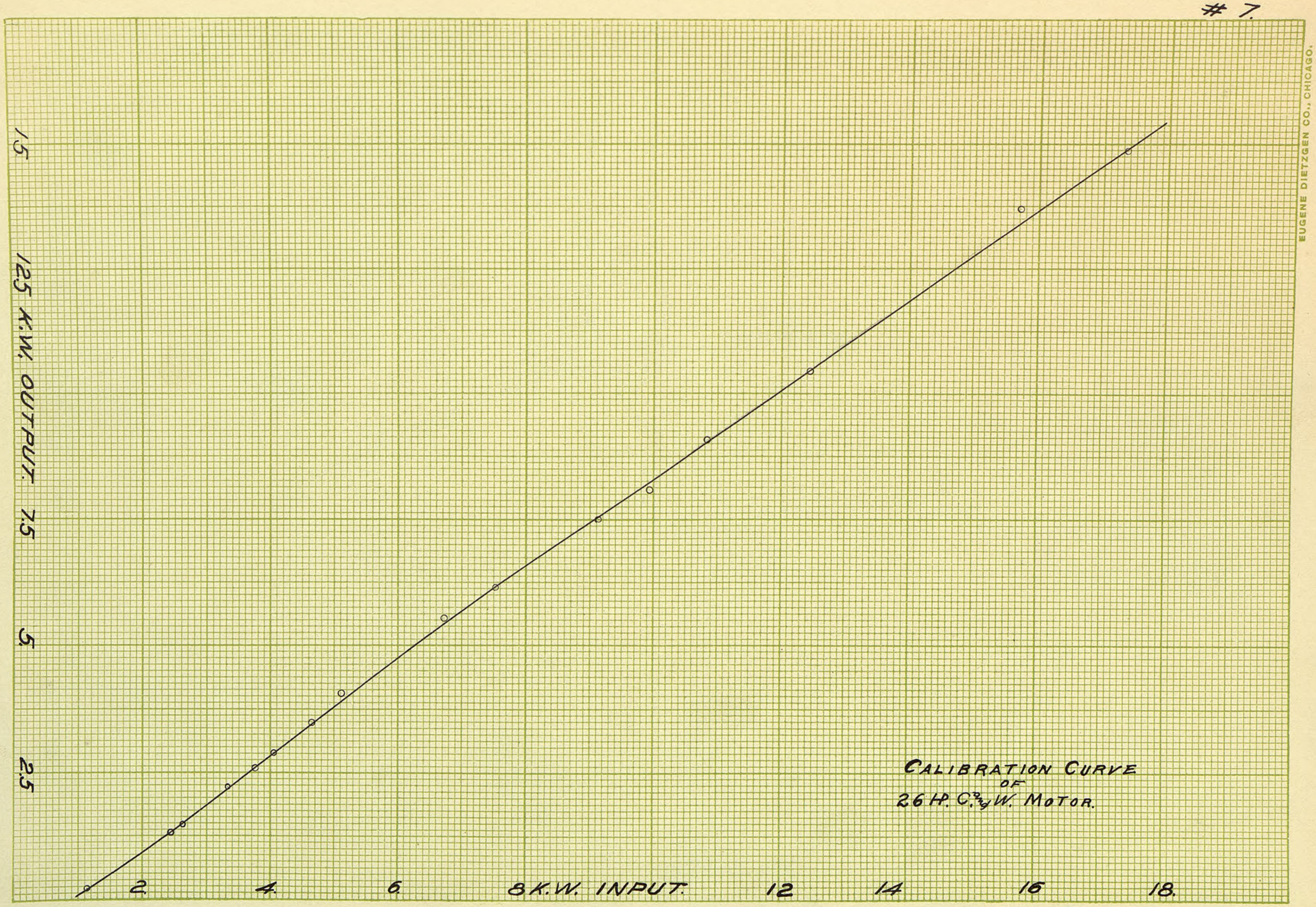
The generator belt was then put on and the machine run without excitation in order to find its friction losses. Another reading was taken with full excitation no load, to determine the magnetic and eddy current losses at no load.

Motor Input	Motor Output	Dynamo Belt	Input. Field cur.	Volts	Total	Dynamo Output Volts	Cur.	Kilowatts #1	Kilowatts #2	Total	%Eff.	Copper Loss Arm.	Fld.	Total
1670	300													
2484	1250	950			950									
2916	1690	1390	2.6	36.5	1485								94.9	94.9
4320	3150	2850	2.5	35.	2938								87.5	
5697	4475	4175	2.55	36.	4267	113		1.45	1.41	2.86	67.1		91.8	
7561	6124	5824	2.77	39.	5932	108	23.5	2.38	2.24	4.62	77.9	48.15	108.	156.2
8692	7085	6785	2.8	39.5	6896	107	30.	2.90	2.89	5.79	84.	78.4	110.5	188.9
10117	8325	8025	3.	42.	8151	112	37.5	3.8	3.4	7.2	88.3	122.5	126.	248.5
15159	12968	12668	3.65	52.	12857	111	56.5	5.65	5.58	11.23	87.4	278.	189.5	467.5
16880	14065	13765	3.9	55.	13979	109.5	63.	6.2	5.9	12.1	86.6	345.7	214.	559.7
18392	15925	15625	4.1	58.	15863.	108.	68.	6.8	6.5	13.3	83.9	403.	237.8	640.8
19897	17368	17068	4.3	62.5	17336	"	77.5	7.48	7.1	14.6	84.	522.	268.5	790.5

R.P.M. = 1150

COMMERCIAL EFFICIENCY.

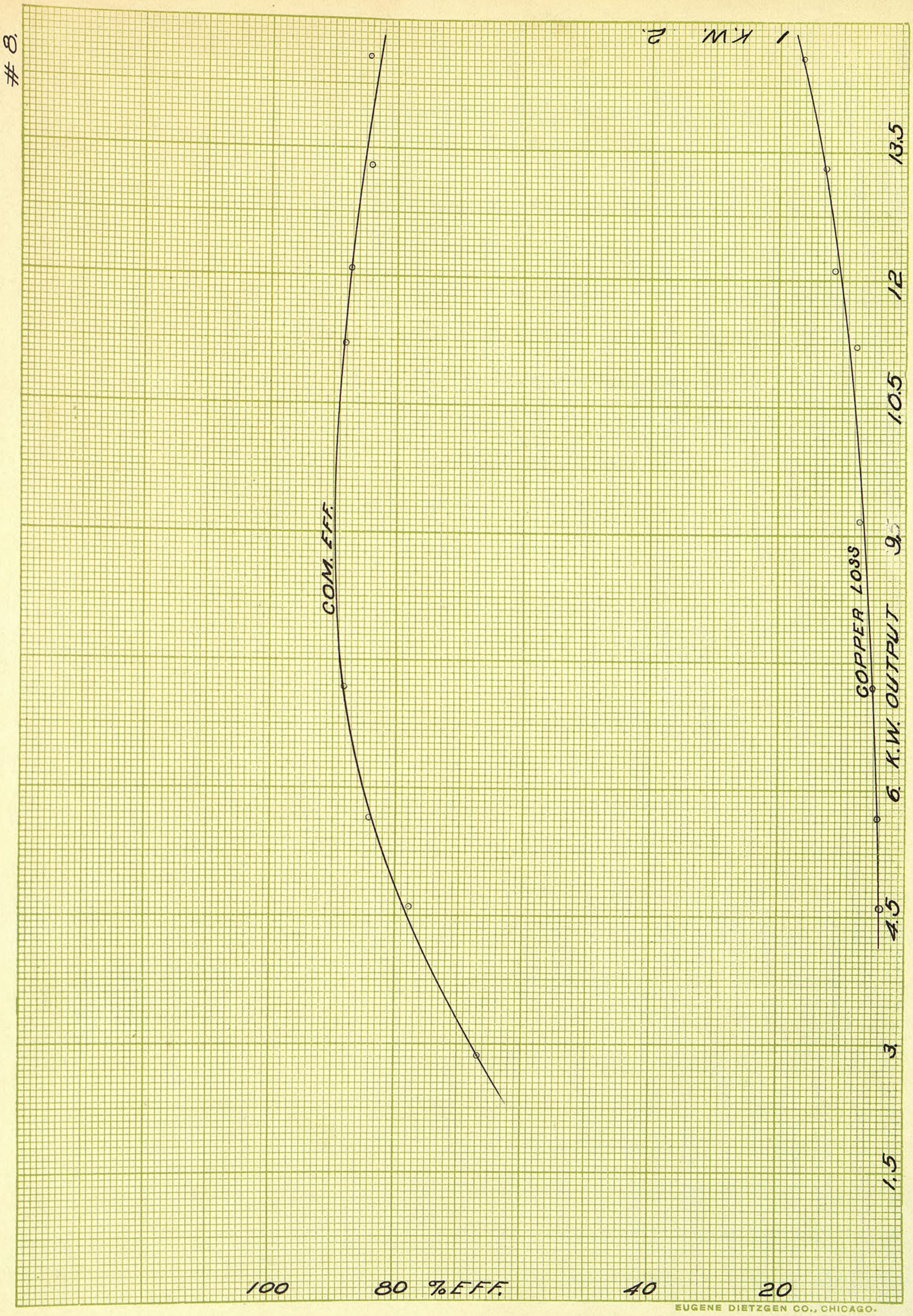
7.



EUGENE DIETZGEN CO., CHICAGO.

301

#8


COM. EFF.
COPPER LOSS
1 K.W. 2.
6 K.W. OUTPUT
1.5
3
4.5
9
10.5
12
13.5
100
80 %EFF.
40
20

The load was then gradually turned on until full load was reached. Simultaneous readings of the motor input, the alternator field input, and the alternator output being taken at each variation. In calculating the commercial efficiency it was assumed that the motor belt and the shaft friction losses remained constant. This constant was subtracted from the output of the motor at each load, as shown by the motor calibration curve, curve sheet #7. The alternator was charged with the loss due to its driving belt.

The equation used was

$$\text{eff} = \frac{\text{generator output}}{I^2R \text{ of fields} + \text{motor output} - \text{shaft loss}}$$

The efficiency curve was plotted, using values of the efficiency in per cent as ordinates and output as abscissas. The losses which cause the efficiency of the generator to be less than unity are friction and windage, copper losses, eddy current losses, and hysteresis loss. The friction and windage are usually assumed to be constant for a given speed but in this test the friction loss decreased up to about fifty per cent of full load. This was probably caused by the chasing of the generator belt while the load was light. After 50 per cent of full load was reached it was necessary to tighten the belt, which caused the friction loss to increase slightly.

The armature copper loss varies with the square of the armature current, and the field loss as the square of the field current. The field compounding curves show that the field current must be increased more rapidly as the load increases. It is evident that the

the total copper loss varies with a power slightly greater than the square of the load.

The iron losses are usually found in the factory by testing small rings built up of laminations of the iron used, the thickness of the sheets and the insulation between them being the same as those used in the machine. In the completed machine the combined hysteresis and eddy current losses may be determined by deducting from the total loss at any load the friction loss and the calculated copper loss. In order to obtain correct results by this method it is necessary to know that the friction loss does not vary with change of load. The armature core and field spider are built up of laminated iron, in order to reduce the loss by eddy currents in the iron.

A machine with a high efficiency must have a large amount of copper in the armature and field conductors. The inductance of the armature lowers the efficiency by causing the current to lag slightly, thus making a larger field current necessary, and also requiring a larger current for the same output of power.

The machine under test has a rather high inductance, which is somewhat reduced, however, by the distribution of the armature coils.

In connection with the efficiency test the resistance of the field coils and the armature were measured by the fall of potential method. In order to determine the inductance of the armature, alternating current of known frequency was passed through it, and the fall of potential, and value of the current noted. The impedance was then calculated by means of the formula

Impedance = $\frac{E}{I}$; when E = the fall of potential and I = the current.

The inductance was then calculated from the formula

$$IMP. = \sqrt{R^2 + \overline{2\pi f L}^2}$$

where R = the ohmic resistance, L = the inductance in henrys, and f = the frequency.

The resistance used in calculating the copper loss in the armature was the sum of the resistance of all the coils, and was obtained by taking one half the sum of the resistances of the three circuits.