Tests and Efficiency of A.T.B.G.E.Alternator

by

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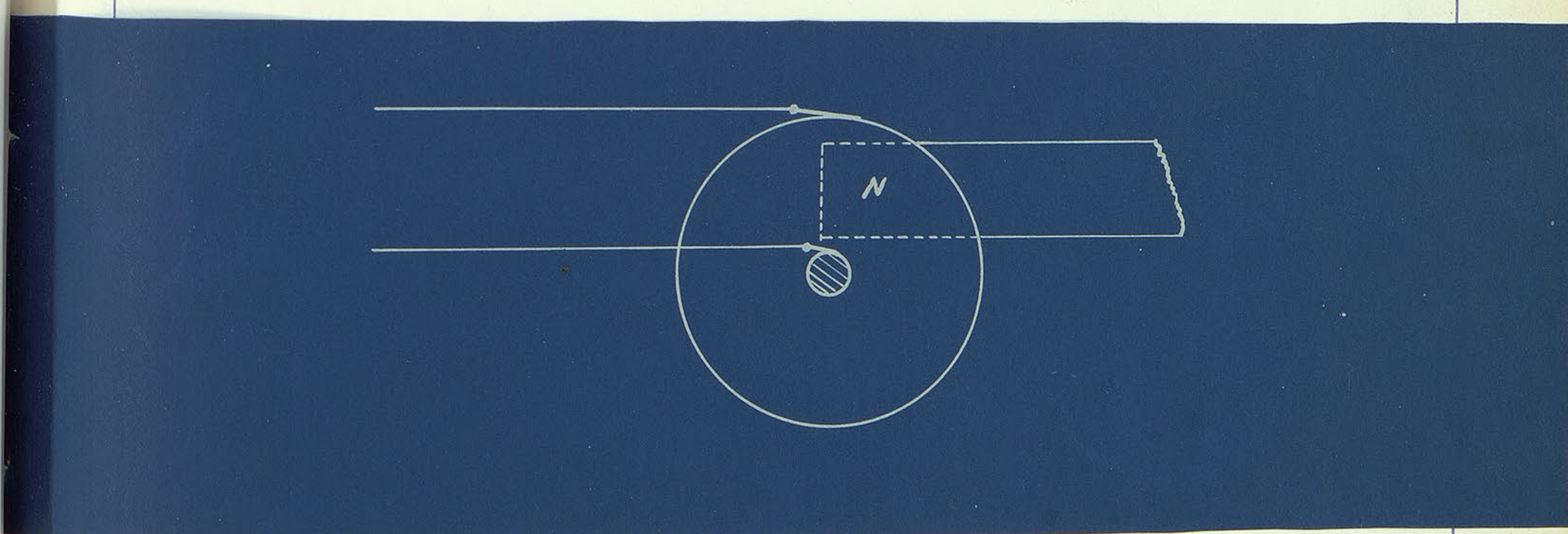
Tests and Efficiency of A.T.B.G.E.Alternator.

In the fall of 1831,Michael Faraday discovered the "electro-magnetic induction of currents." His discovery was communicated to the Royal Society November 24th of the same year. A discussion of these experiments appears in the first volume of Faraday's Experimental Researches in Electricity.

He first induced currents in a coil,by starting and stopping a current in a near by coil,next he induced a current in a coil,by moving it rapidly past the ends of a powerful horse-shoe magnet,the direction of flow of the current depending on the direction of motion and finally he constructed the first known dynamo.

The following figure illustrates his electrical machine.

Fig. I.



This machine was made by mounting a copper disc twelve inches in diameter and one fifth of an inch thick,on a brass axle. The disc was placed so as to be revolved between the poles of a horse-shoe magnet. The current was commutated by means of two brushes, one on the axle and the other on the circumference of the disc. The circuit being completed through a galvanometer. When the disc was rotated deflections were obtained, the direction of deflections, depending on the direction of rotation.

Consider a closed coil of wire placed between the two poles of a magnet so that its plane is perpendicular to the direction of the flux. Remembering that the E.M.F. generated depends on the time rate of cutting of flux, then when the coil is in this position, the greatest flux threads thru the coil but no E.M.F. is generated. If the coil be revolved right-handedly it will begin to cut flux. The greatest rate of cutting will occur when the coil is moving perpendicularly to a line connecting the centers of the two poles, or when it has revolved 90° from its initial position. This will be the point of maximum E.M.F. While the coil is revolving through the next quadrant the E.M.F. decreases, and becomes zero when the coil has made one half of a revolution. During the next quarter the E.M.F. will become maximum but the direction of flow of current will be reversed, or opposite from that during the first half revolution. It will then decrease and become zero, when the coil has made one complete revolution. Here then we have the principle upon which alternating currents are produced. By definition, an alternating current of electricity is a current that changes its direction of flow at regularly recurring intervals.

If in the last instance we should use an open coil and a two part commutator and measure the E.M.F. or current for different positions of the coil, by means of a galvanometer, and plot these results with deflections as ordinates and angular rotation as abscissae, considering the deflection in one direction as positive and the opposite as negative, we would get a curve approximating the sine curve. In general,the form of the E.M.F.and current waves are considered as sine curves.

If the single coil with its two poles be developed into many coils with a pair of poles for each coil,and the ends of each coil be properly connected to one of the two slip rings,we have a single phase alternating current dynamo.

When a coil is placed in a single slot of the armature,it is said to be of the concentrated wihding type. If the different turns of a coil should be placed in closely adjacent slots,it is said to be a distributed winding. The effect of a concentrated wihding is to have the induced E.M.F. of each separate turn of the coil to be of the same value. In a distributed winding the position of the differebt turns of the coil are not the same relative to the strongest or weakest part of the field,therefore the induced E.M.F. is not the same in each turn. If the E.M.F.of a dynamo with concentrated windings is 100,then for the same dynamo distributively wound,the E.M.F.would be between 90 and 100,the real value depending on the number of slots per coil.

The early types of alternators were built similar to the early D.C.Machines,that is,with stationary fields and revolving armatures. With the introduction of high potential machines we find a reversal of the old custom,and have a stationary armature and revolving field. It was found more practical to feed the exciting current into a revolving field through slip rings than to take off current at high potential from the slip rings. Also in the stationary armature there is no chafing of conductors,better insulat-tion is possible,more air space and consequently a larger current is permissible,and repairs,when necessary,are more easily made.

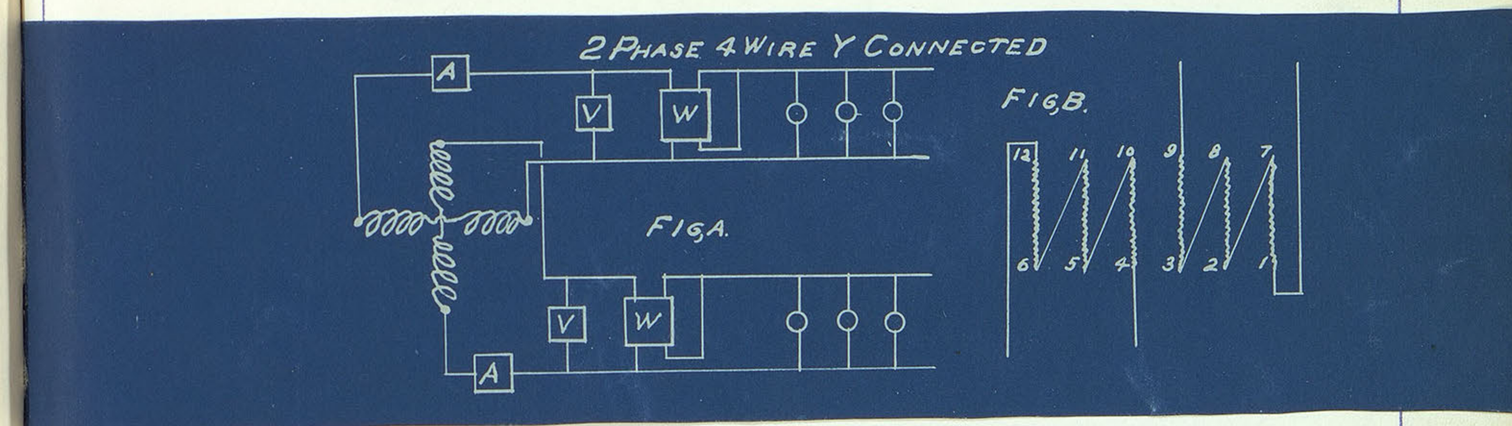
The Alternator tested is a 15 K.W.125 volt,60 cycles. It is of

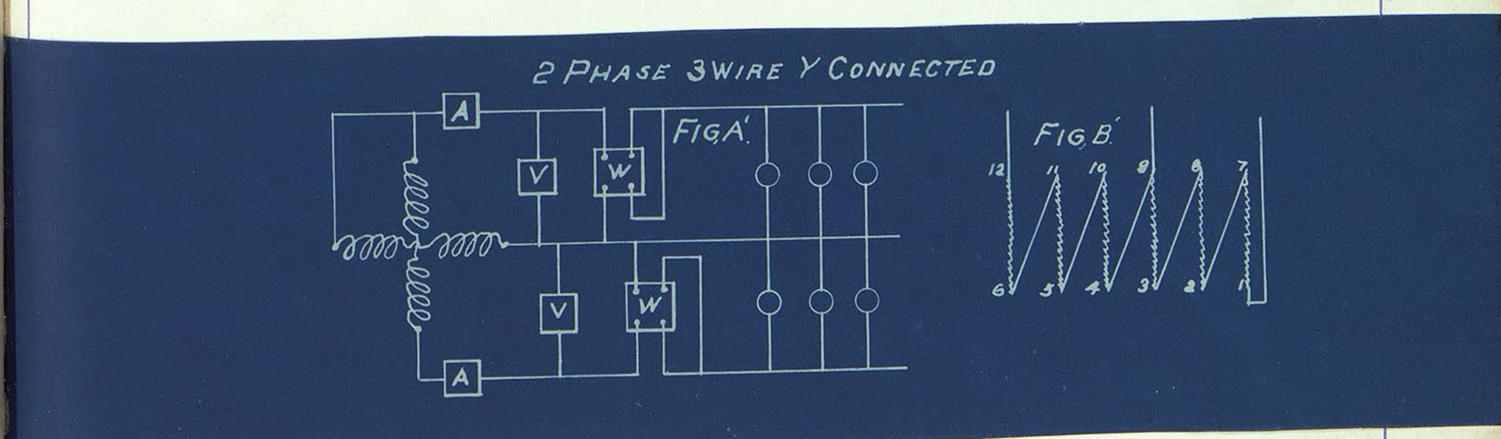
CONVENTIAL REPRESETATION OF THE ARMATURE WINDINGS.

the revolving field type and has six spools. The armature has six coils distributed over the entire surface. Each end of all the different coils is brought out to a terminal block on top of the frame.

Six independent single phase circuits may be obtained by connecting one circuit to each of the coils. Two and three phase circuits may be obtained by properly connecting different coils. The following diagrams show the method of connecting for a 2 phase 4 wire and a two phase 3 wire system. also method of connecting instruments in circuit for measuring the power.

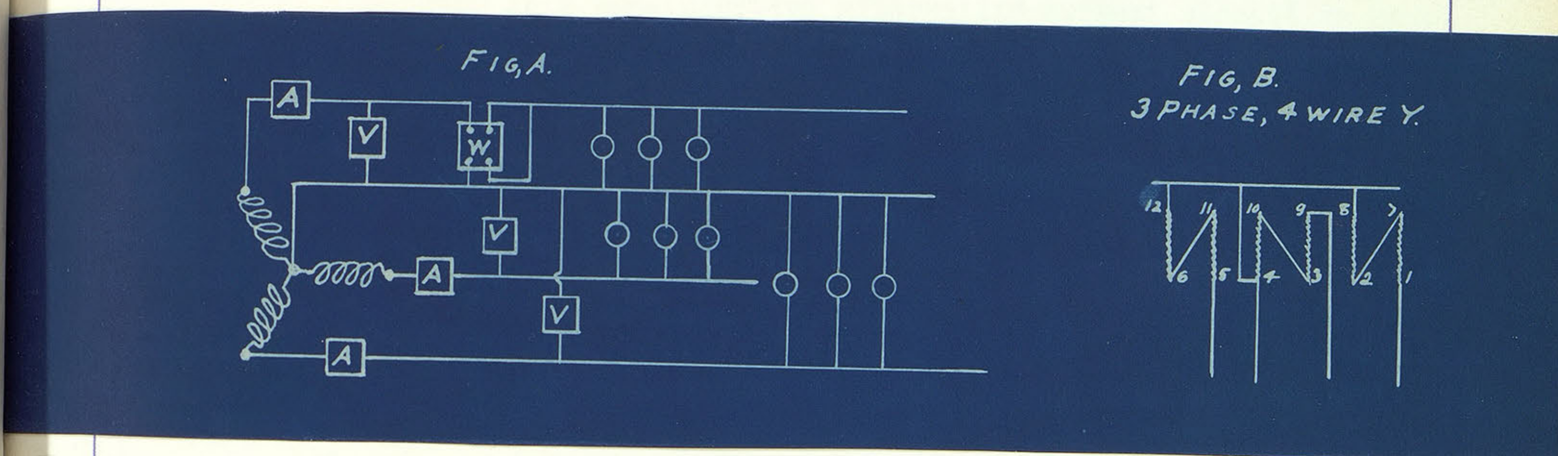
Fig.2.

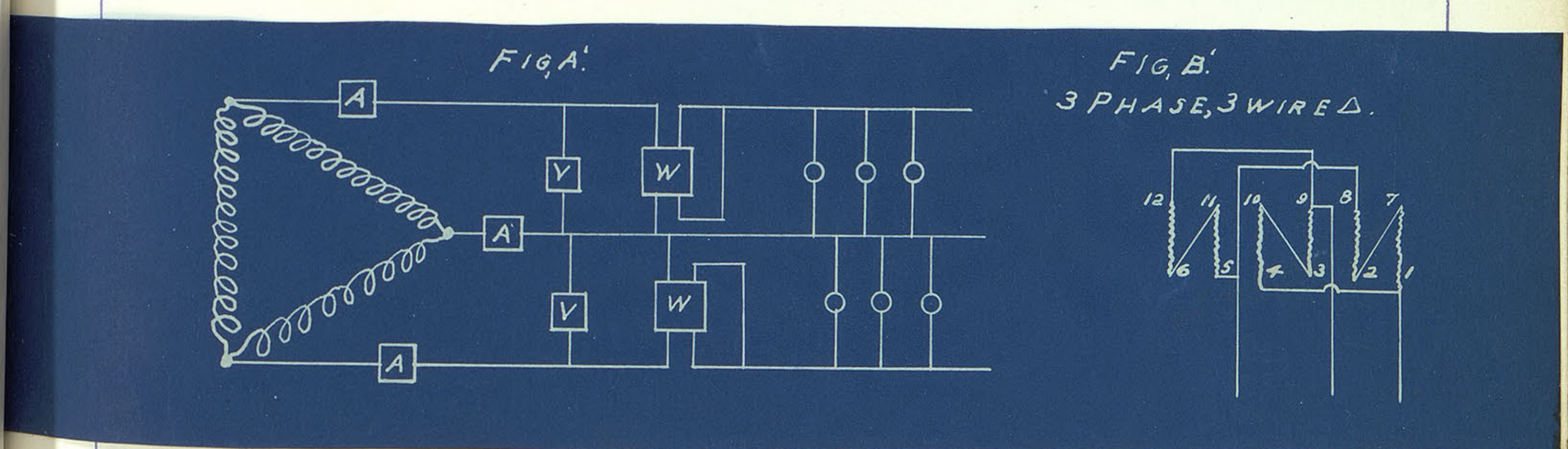




The following figures illustrate the methods of connecting for a 3 phase 4 wire Y and for a 3 phase 3 wire delta with the instruments properly placed for determining the out-put of the machine. In the 3 phase 4 wire Y the load is balanced and the power is obtained by multiplying the wattmeter reading by 3.

Fig.3.





In the star or Y connection one end of each coil is fastened to a common point. In the delta system, the current generated in one coil, after making the complete circuit, must pass back through one of the other coils before reaching the starting point.

The above diagrams show the conventional method of representing the delta and Y connections. The potential between any two wires,Y connected, is the vector sum of the two coils. If the E.M.F. of one coil be E.,that across the two would be 1.73E. The current in any line is the same as in any coil. In the delta or mesh connection,the potential between any two lines is the same as that of any coil. The current in the line is 1.73 times that of any coil.

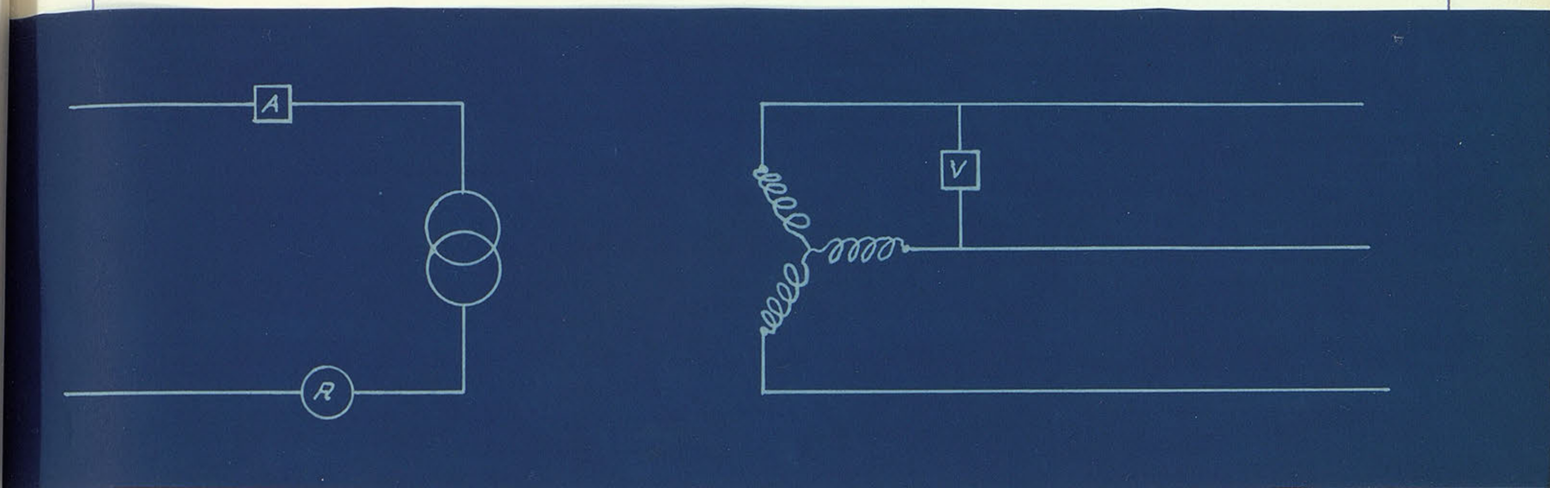
The power in a non-inductive alternating current circuit is equal to the product of the volts times the amperes. When there is inductance or capacity in circuit,the current lags behind or leads the impressed E.M.F. In this case the maximum of the E.M.F.and current curves do not occur at the same time. Alternating current instruments are made to read effective values,hence the product of the two would not be the true power,but would be greater by an amount depending upon the phase angle.

The true power of any circuit may be obtained by a non-inductive watt meter. The watt meter reading divided by the volt-ammeter readings gives the cosine of the angle of lag or lead. This is also the power factor.

Tests of A.T.B.Generator.

Magnetization Curve.

Fig.4.



The connectiomns were made as represented above. The speed of the Alternator was kept constant at 1200 R.P.M. Exciting current was obtained from the Crocker-Wheeler D.C.dynamo. This current was varied from .3 amperes to 2.9 amperes. At each variation volts and field current were read simultaneously.

Data:

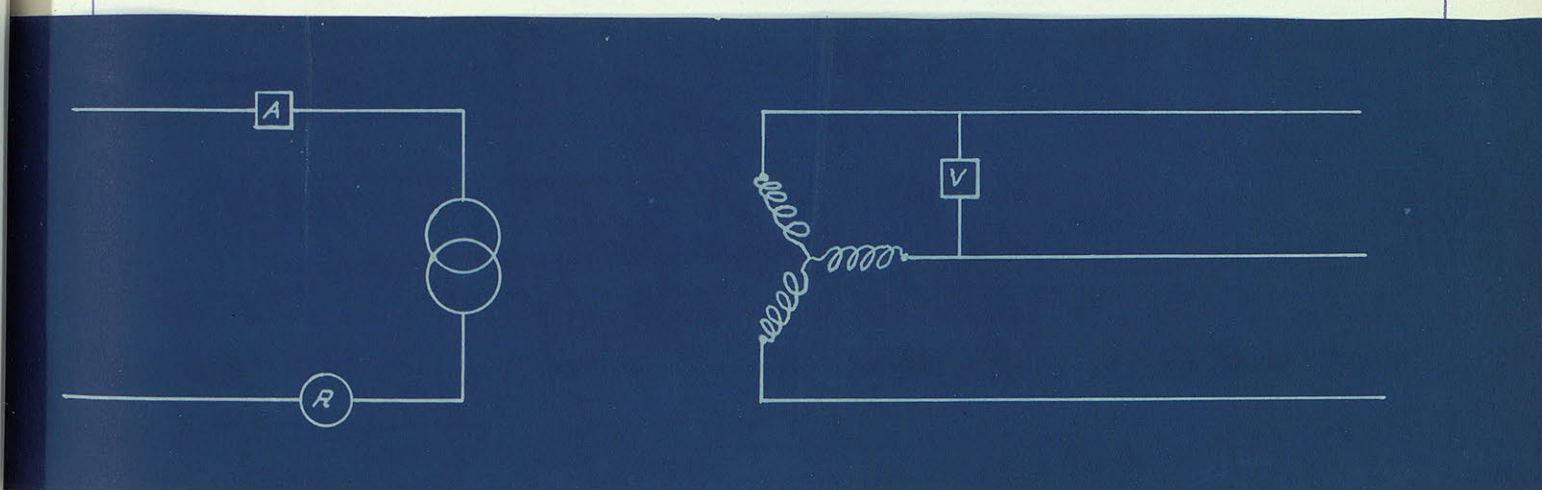
Speed	Fld.Cur.	Volts.	Fld cur.	Volts.
1200	.3	33.5	1.7	95.8
Constant.	.4	37	1.8	101.
	.5	41.5	1.9	106.7
	.6	45.	2.02	110.8
	.7	50.	2.25	120.5
	.8	54.5	2.45	129.5

Fld.Cur.	Volts.	Fld.Cur.	Volts.
.95	61.8	2.7	141.
1.3	79.	2.9	148.5
1.6	91.		

The magnetization curve obtained was a straight line. This shows that the saturation point was not reached. The curve shows that between 33 and 148 volts, that there is a direct and constant ratio between the exciting current and E.M.F. generated by the machine.

Speed ~~Special~~ Characteristics.

Fig.5.



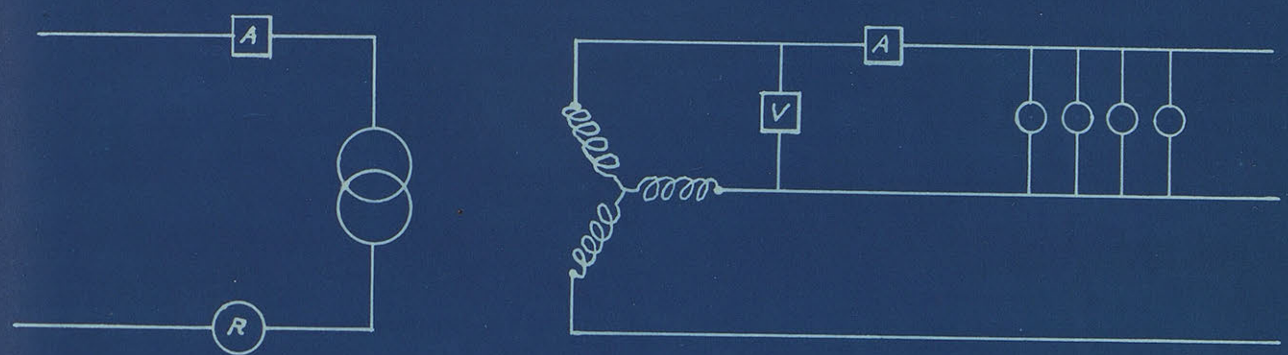
The exciting current was kept constant at 2.36 amperes. The speed was varied from 698 to 1193 R.P.M.

Data.	R.P.M.	Volts.	R.P.M.	Volts.
	698.	68.5	1048	102.3
	737	70	1086	107.
	815	79.	1125	110.5

R.P.M.	Volts	R.P.M.	Volts.
892	86.5	1164	114.5
970	94.3	1193	119.5
1009	99.		

Field Compounding Curve.

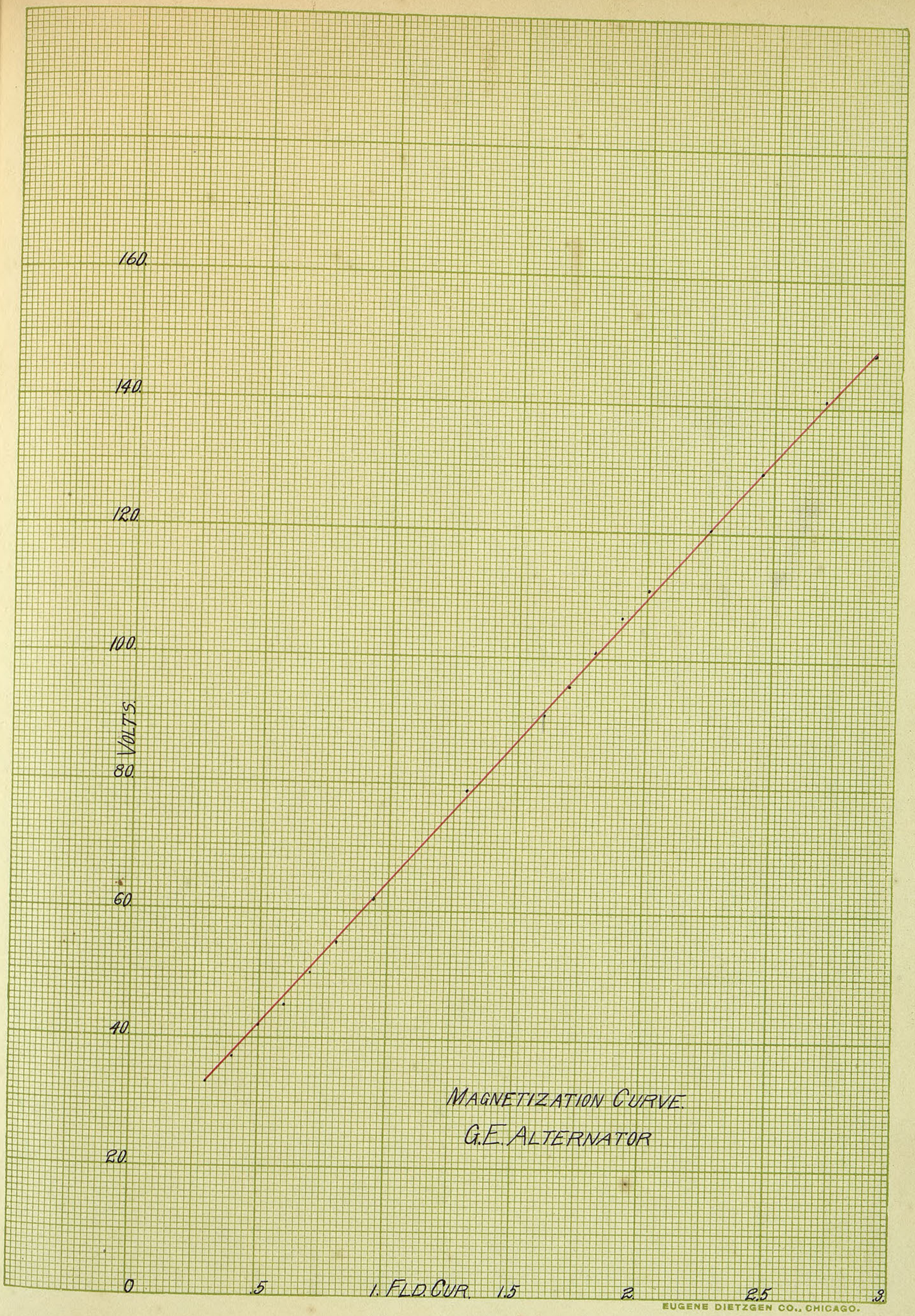
Fig.6.

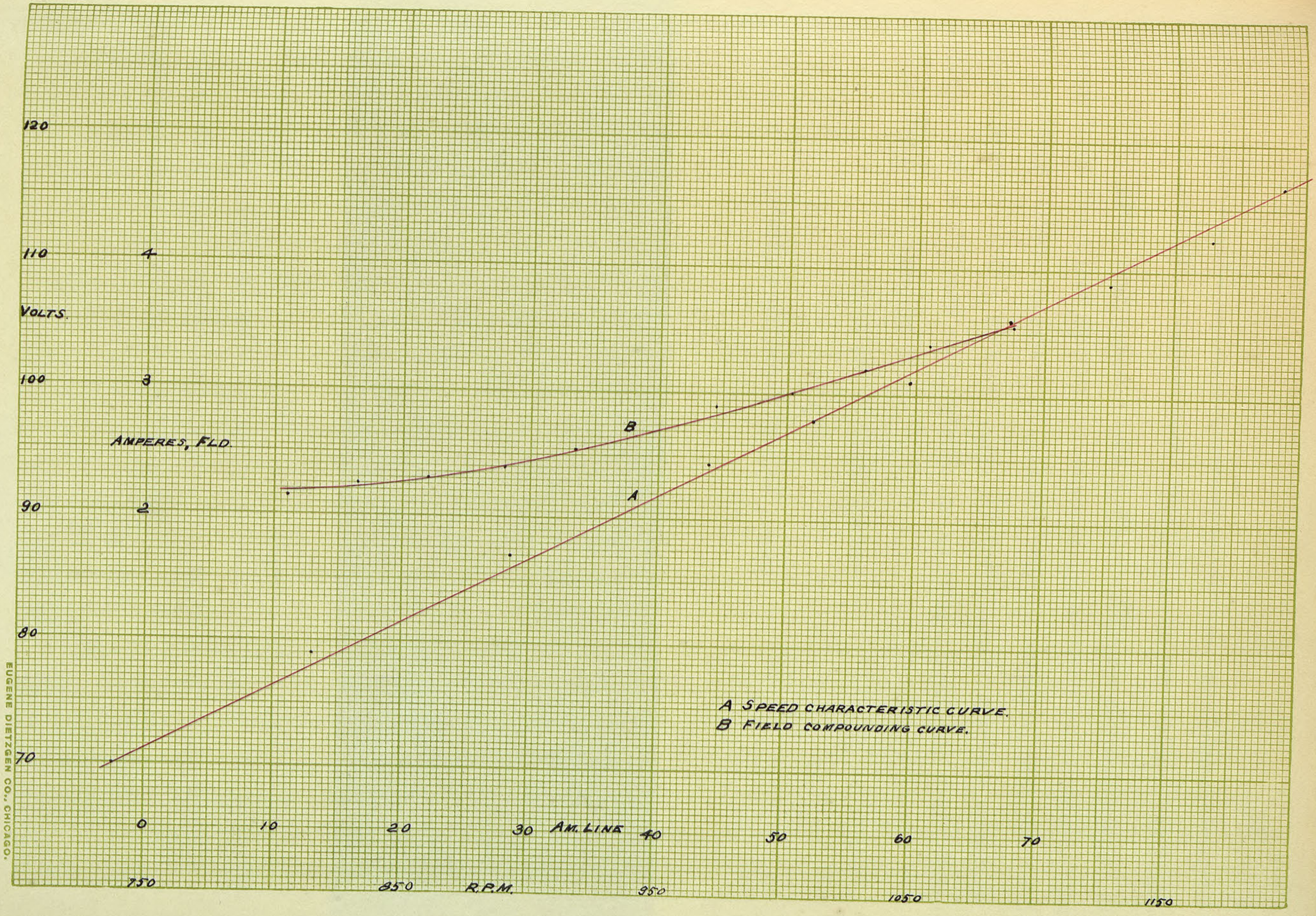


Data;	Volts.	Fld.Cur.	Load	Fld.Cur.	Load	R.P.M.
	110	2.15	11	2.9	44.5	1200
	Constant	2.25	16.5	3.	50.2	Constant.
	"	2.3	22.2	3.2	56	"
	"	2.4	28.	3.4	61.	"
	"	2.54	33.5	3.55	67.5	"

The speed characteristic obtained was a straight line. It shows that the E.M.F.generated is directly proportional to the flux cut or to the speed.

The field compounding curve shows the necessary increase of field current to keep constant potential with increasing load. It also shows that as the load is increased,from the initial load,by equal steps,that the corresponding field current does not have to be increased as rapidly in propor-


160.
140.
120.
100.
VOLTS.
80.
60.
40.
20.
0
.5
1. FLD. CUR.
1.5
2.
2.5
3.
MAGNETIZATION CURVE.
G.E. ALTERNATOR



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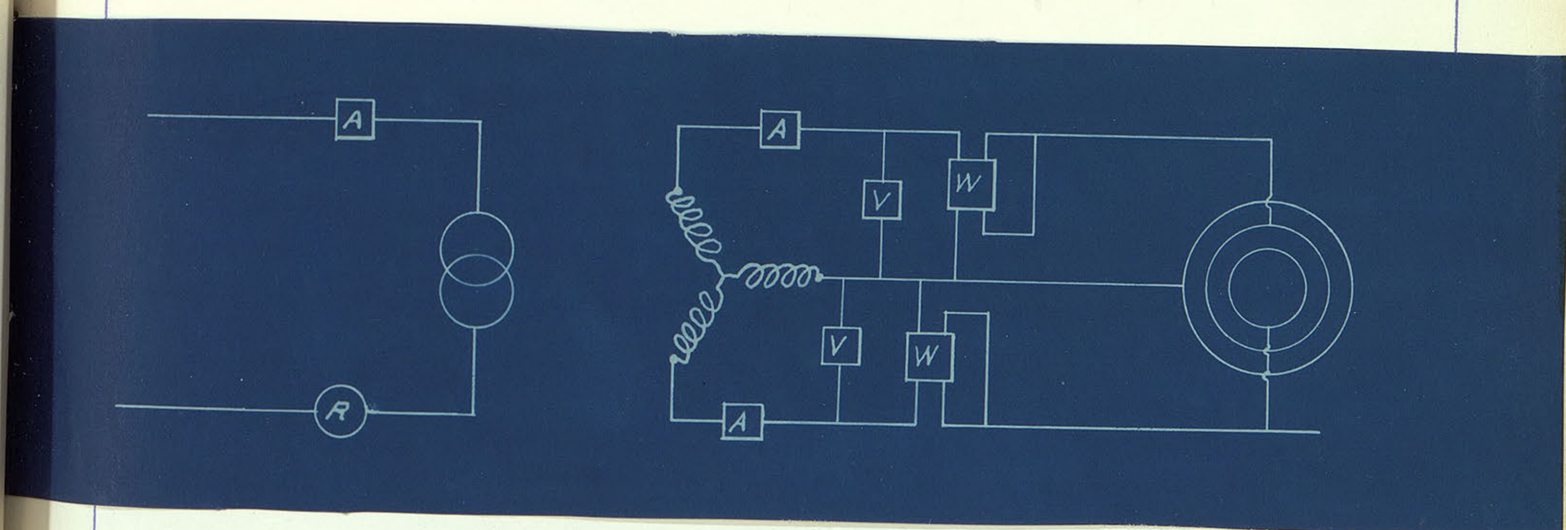
tion as it does with a larger load. This is due to the residual magnetism, which with a small load, causes a marked effect on the nature of the curve, but with large loads the effect of residual magnetism, is so small in comparison with the exciting current necessary to maintain constant potential that the curve becomes approximately a straight line. If there were no residual magnetism there would be a direct ratio between the exciting current and load, and the curve would be a straight line.

Variation of Field Current

with

Inductive and non-Inductive Loads.

Fig.7.

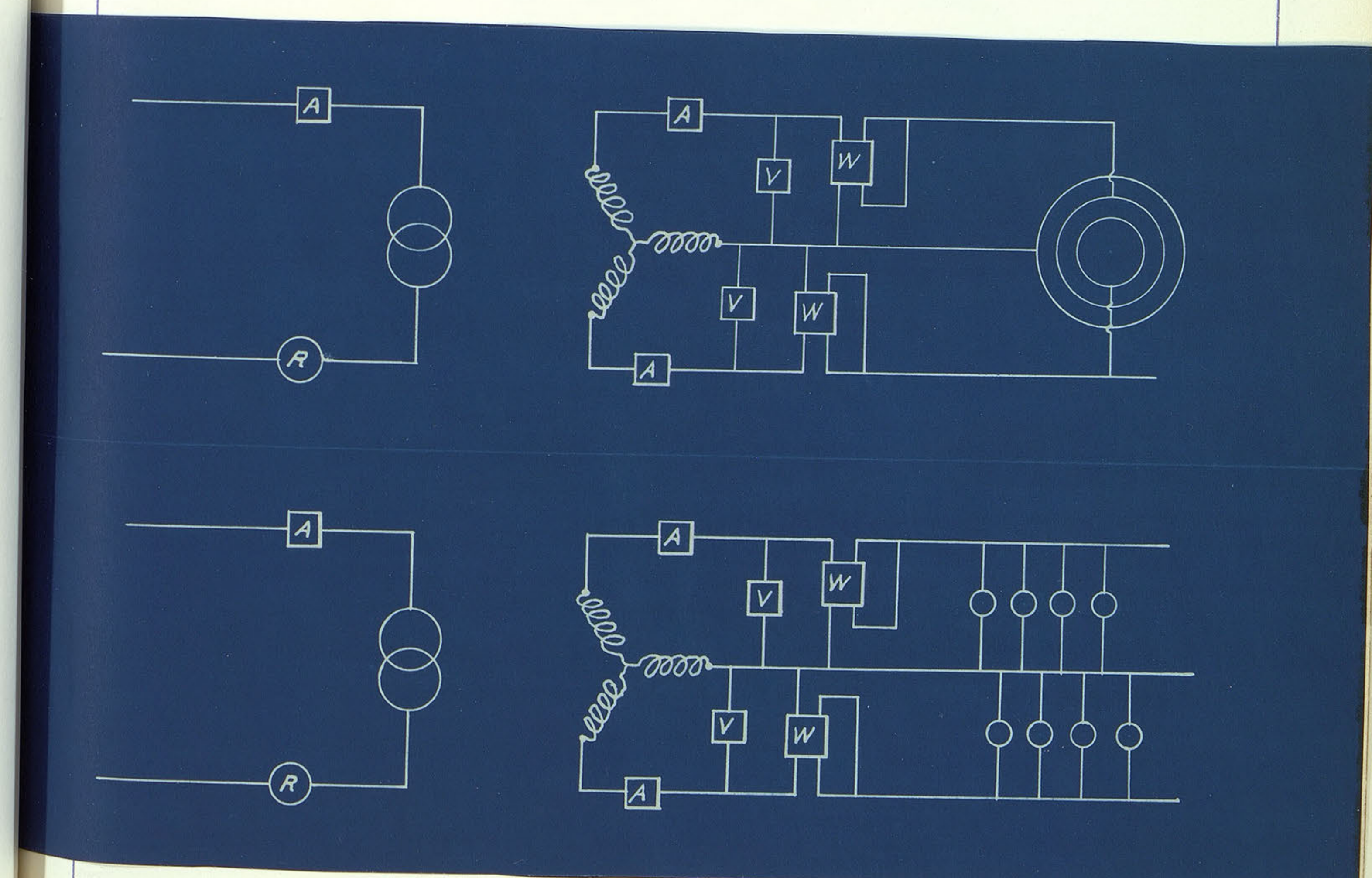


The above diagram represents the connections for an inductive load. The instruments were connected as shown. The inductive load consisted of the rotary converter operating a load of lamps.

Data: Ind. Load.

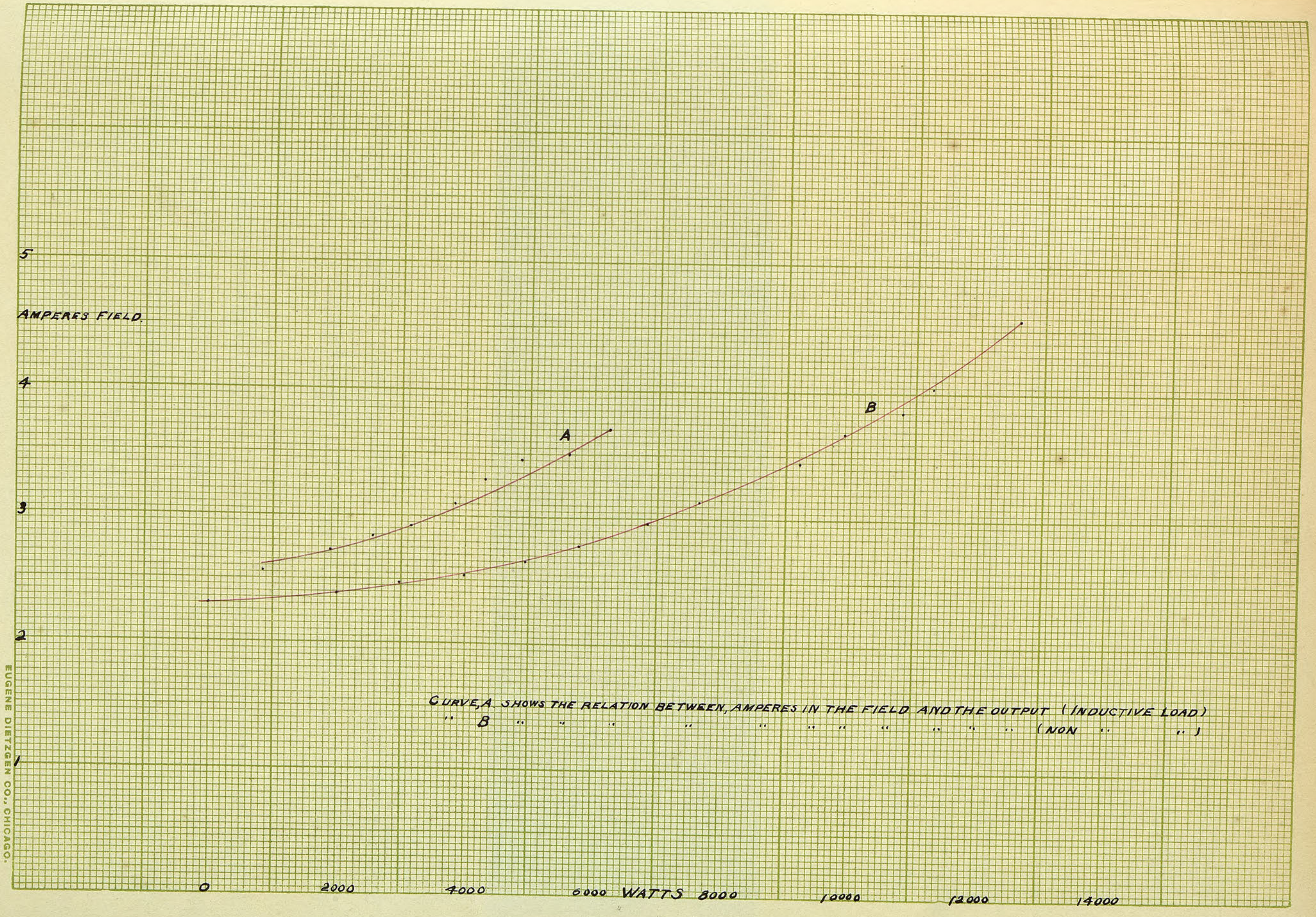
Am. Field.	Volts.	Amperes.	Watts.	Volts.	Amperes	Watts	Cos. ϕ	RPM.
2.58	71	12	500	71	11	800	.83	1200
2.73	71.4	15.5	750	71.5	16	1240	.83	constant.
2.84	71.7	20.5	1100	72	20.75	1450	.86	
2.92	72.	25.	1400	72	25	1740	.87	
3.1	72.5	30	1800	73	30	2140	.81	
3.3	74.3	34.3	2000	75.5	34.5	2300	.84	
3.45	75.	39.	2200	75.5	39.5	2690	.85	
3.5	75.25	44.	2700	77.	44.	2900	.83	
3.7	75.5	48.5	3000	77.	49.	3230	.84	

Fig.8.



Data. Non-Inductive.

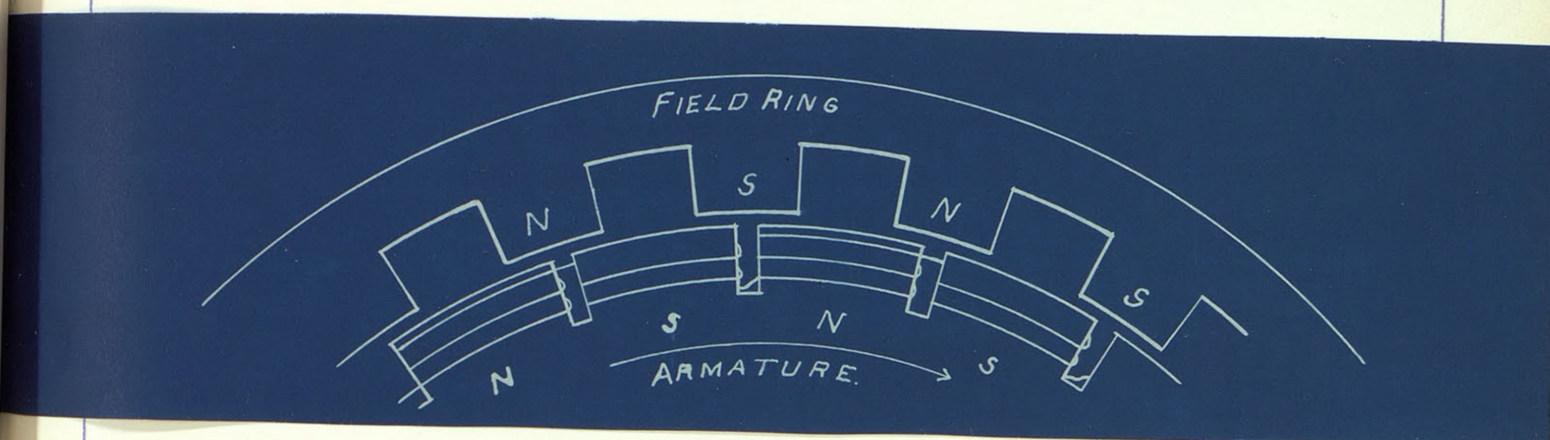
Ex.Cur.	Volts.	Amp.	Watts	Volts.	Amp.	Watts.
2.3	110	0	0	109	0	0
2.39	constant	5	490	104.5	5	500
2.39	"	10	1000	97.9	10	1000
2.48	"	16	1600	96.	14	1380.
2.54	"	22	2250	93.5	18.5	1740.
2.64	"	27	2900	90.2	22.5	2040.
2.78	"	33	3490	87.5	26.4	2300.
2.96	"	37.5	4100	83.	33.	2750.
3.14	"	43.	4650	81.5	36.8	2990.
3.44	"	53.5	5800	78.5	43.4	3400.
3.67	"	59.	6350	77.	46.5	3550.
3.85	"	64.	7000	75.8	50.5	3800.
4.04	"	78	7330	74.5	53.4	3900.
4.58	"	84.	9000	73.	61.4	4450.
4.7	"	85.	9100	68.5	68.	4600.


AMPERES FIELD.
5
4
3
2
1
A
B
0
2000
4000
6000
WATTS
8000
10000
12000
14000
CURVE, A. SHOWS THE RELATION BETWEEN, AMPERES IN THE FIELD AND THE OUTPUT (INDUCTIVE LOAD)
" B " " " " " " " " " " (NON " ")

On a non-induction circuit, the current is in phase with the E.M.F. and the product of the two, volts times amperes gives the power consumed in the circuit. All alternators have some inductance hence there will be a lag of current on any non-inductive load.

In the case of a non-induction load, the current and E.M.F. are very nearly in phase and there is little demagnetization of field due to armature reaction. If there is a lag of current the reaction will be greater. The following figure shows this.

Fig. 9.



When the armature has the position shown relative to the field and the load is non-inductive, the lines from the N poles will pass in the shortest paths to the S poles.

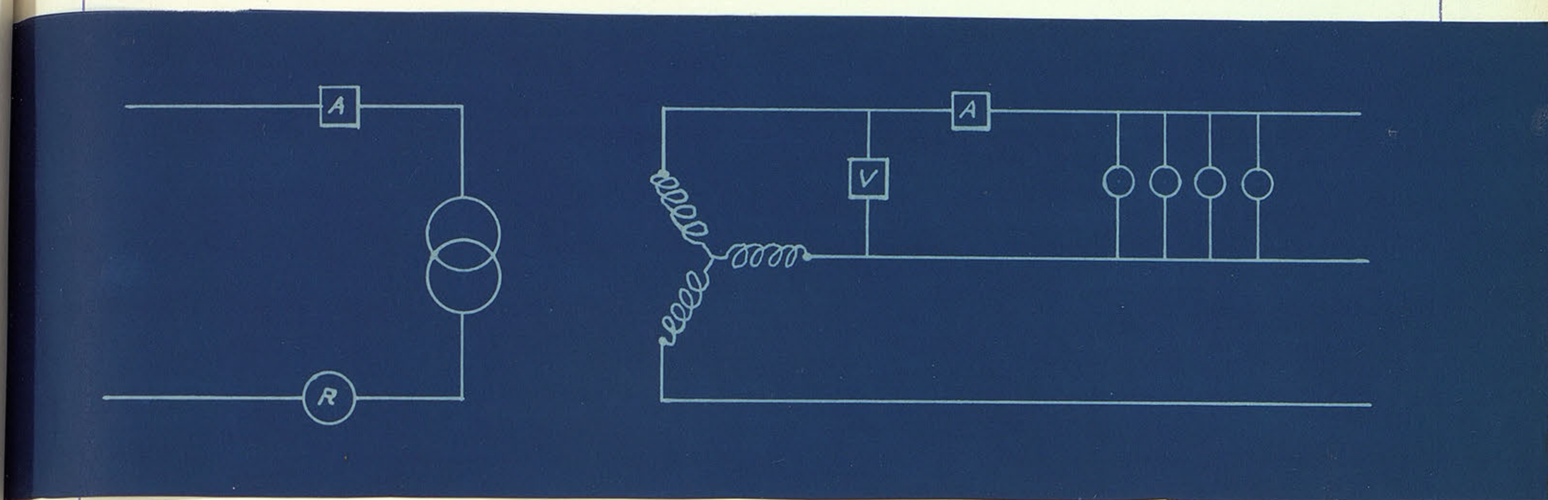
On an inductive load the armature would be more advanced, when the current was a maximum, and a S pole more nearly under a S pole, and the N pole the same relative to each other. As a result a greater demagnetization takes place. There must be an increase of field current to compensate for this loss. The more the current lags in the armature, the greater must be the field current to compensate for the losses. Therefore the field current for an inductive is greater than the field current for the same load non-inductive, and the excitation must be increased much more rapidly for the former, than for the latter.

This curve differs from the magnetization curve, in that the poles were more nearly saturated in this experiment.

For the non-inductive load, the curve is more nearly straight for small loads, and then as the load increased the proportionality was broken and the field current was increased rapidly. The same is true of the curve for the inductive load except that the field current was larger at the start and increased rapidly as the load came on.

External Characteristics.

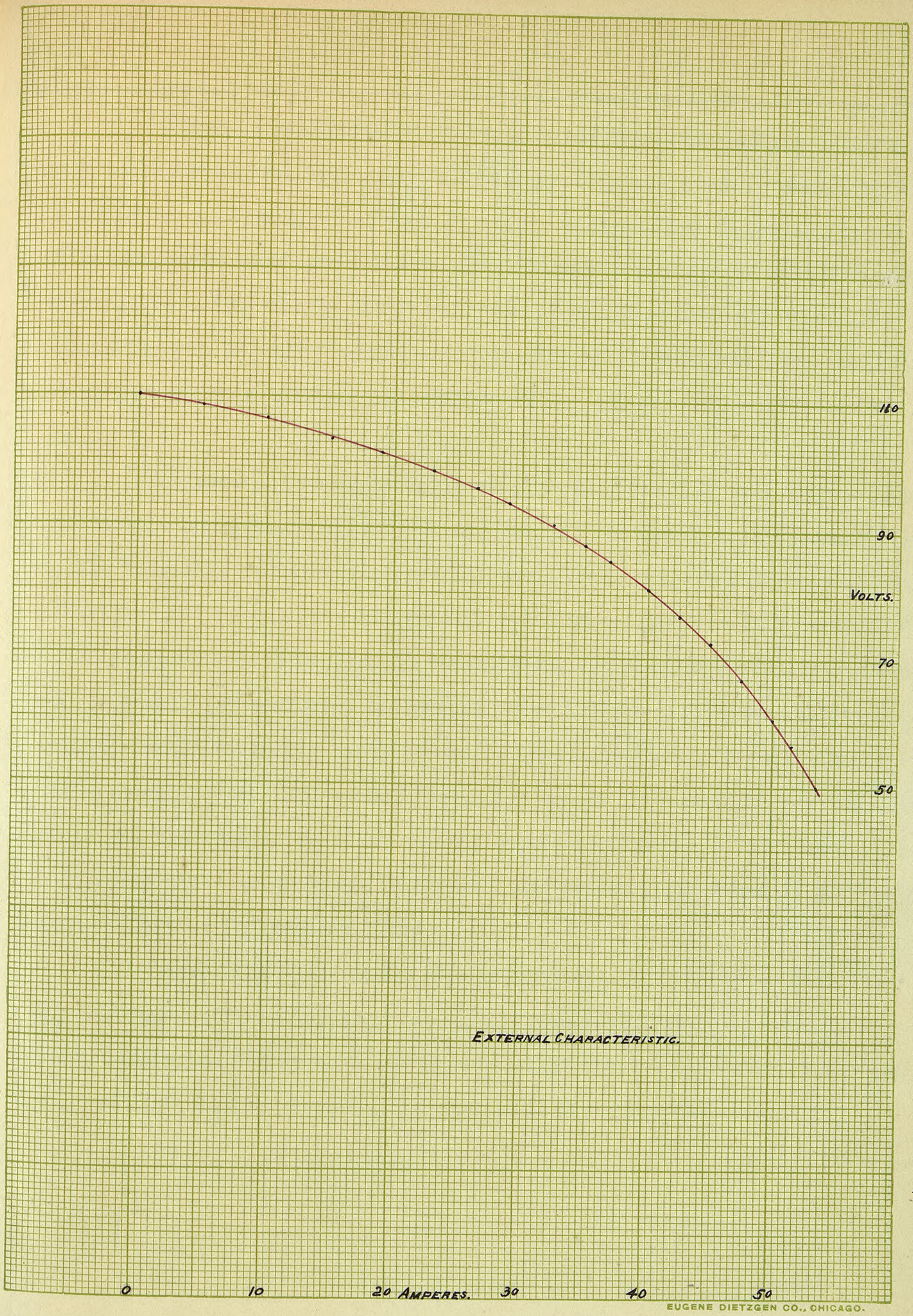
Figure 11.



The instruments were connected as in the above figure. The alternator was run at normal speed and field excitation, both being kept constant through out the experiment. A non inductive load of lamps was used, and the load varied by steps from no load to a load of 53.5 amperes. At each step simultaneous readings were taken on the voltmeter and ammeter.

Data (External Characteristics)

R.P.M.	Exciting current	Volts	Amperes.
1200	2.3	110	0
Constant	Constant	108.5	5.
		106.6	10.
		103.5	15.
		101.6	19.
		98.8	23.
		96.1	26.5
		94.0	29.
		90.6	32.5
		87.7	35.
		85.2	37.
		81.0	40.
		76.8	42.5
		72.4	45.
		66.9	47.5
		60.5	50.
		56.5	51.5
		50.	53.5



110
90
Volts.
70
50
External Characteristic.
0
10
20 Amperes.
30
40
50

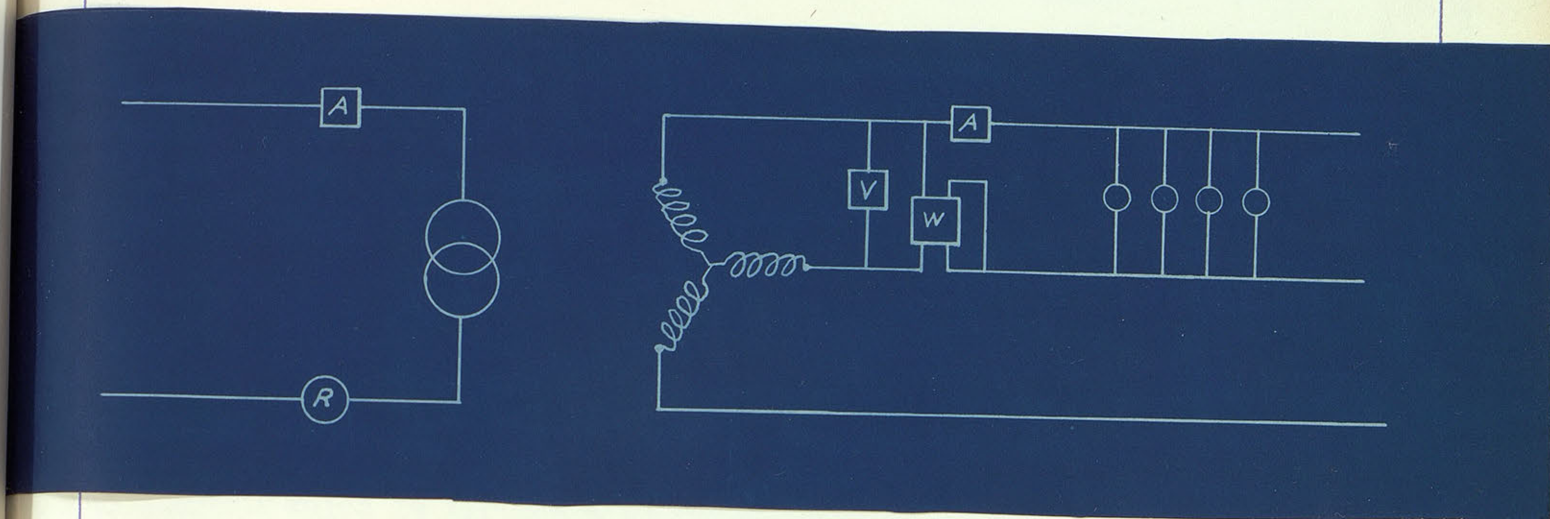
The external characteristics of a new type of a machine is always taken by all reputable builders. This is necessary in order to determine the relation of the pressure and current, and, to discover any irregularities at different loads which could not be readily remedied, except by reconstructing the machine. The external characteristic of types of machines other than separately excited are of great value, as one can readily determine the amount of line drop the alternator is compensated for, and make allowances accordingly.

The external characteristic as plotted shows, that even with a very small load a decrease of voltage is the result. As the load is increased the voltage decreases somewhat slowly, until the load becomes 30 amperes, then with a further increase of load, the voltage falls very rapidly. This curve somewhat resembles the upper limb of the external characteristic of a shunt wound D.C. machine. The principal difference being that, in the latter machine, the voltage decreases nearly directly as the load increases, to a point termed the critical point. At the critical point as the load is increased the voltage drops, and the turning on of more lamps causes the current to decrease. Theoretically with enough lamps in parallel the pressure and current would both become 0 except for residual mag.

However the alternator field is constant, so that the current does not decrease with an increase of load, all though theoretically with enough lamps in parallel there would be so many paths for the current, that the machine would practically be short circuited, and the pressure would become 0.

Relation Between Frequency and Field Cur.

Fig.12.



When a current passes from zero to mazimum in one direction, to zero, & maximum in the other direction, and then to zero again, it is said to have completed one cycle. It takes two alternations to make one cycle. The frequency of a machine is the number of cycles completed in unit time, usually one second. The frequency of a machine is equal to the product of the revolutions per minute and the number of pairs of poles divided by sixty.

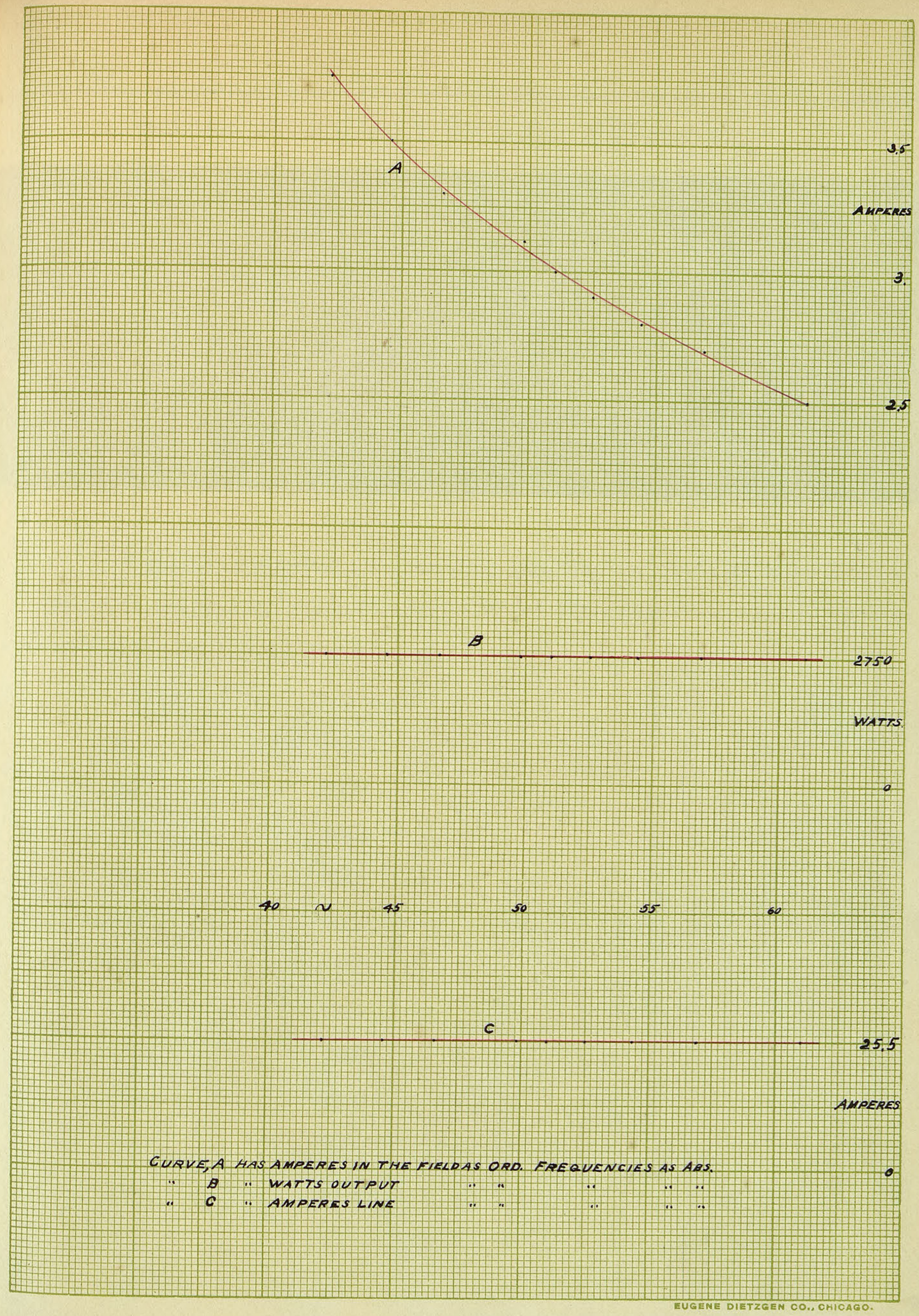
In this experiment the pressure and current were kept constant and the speed varied. In the following data the frequency has been calculated for each speed. The data also shows that the power factor is constant at .98 for all frequencies.

Data.	Ex.Cur.	Volts.	Amp.	Watts	R.P.M.	Freq. ~~Ems~~.	Cos ϕ
	2.5	110	25.5	27.50	1220	61	.98
	2.7	Const	Const	Const	1135	56.8	Const.
	2.8	"	"	"	1086	54.3	"
	2.9	"	"	"	1062	52.5	"
	3.0				1022	51.	
	3.12				970	49.8	
	3.3				931	46.6	
	3.5				892	44.6	
	3.75				844	42.2	

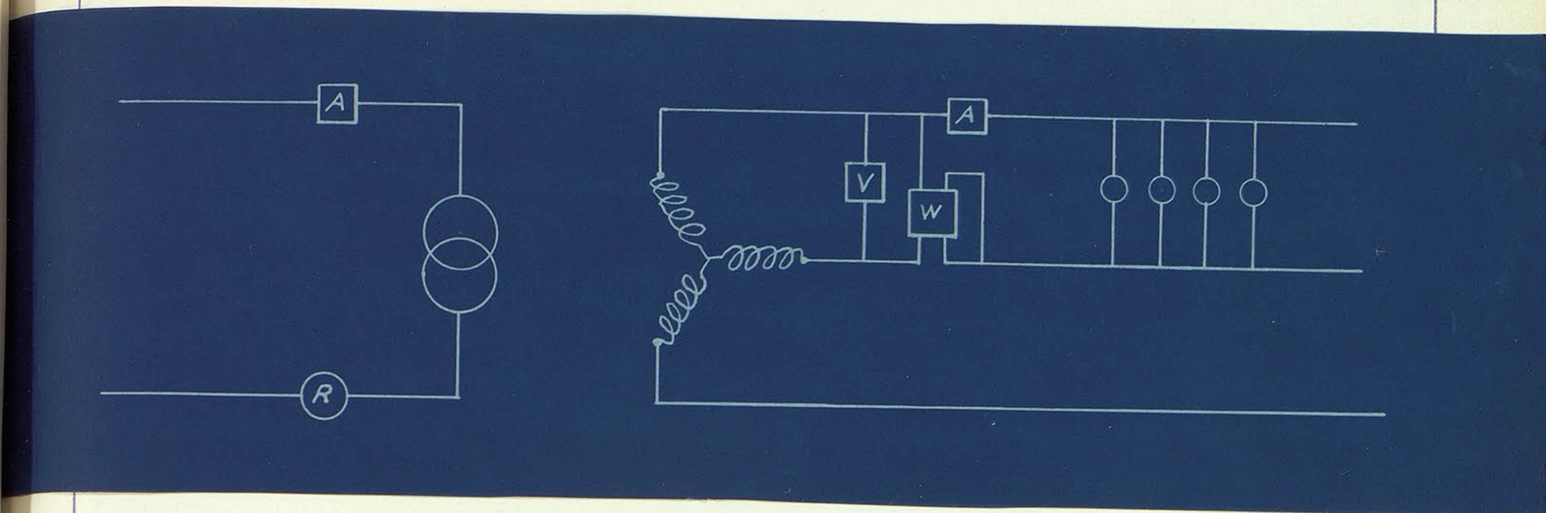
Curve A which is plotted with frequencies as abscissas and field current as ordinates, shows that when the frequency is reduced from 60 to 55 an increase of .18 amperes in field current is required. A change of frequency from 47.5 to 42.5 requires an increase of .32 amperes exciting current.

This shows that there is an inverse ratio between frequency and field current and that as the former is decreased, the latter must be rapidly increased in order to keep constant potential.

Curves B and C show that the current and watts are constant at all frequencies, the load and potential being kept the same.

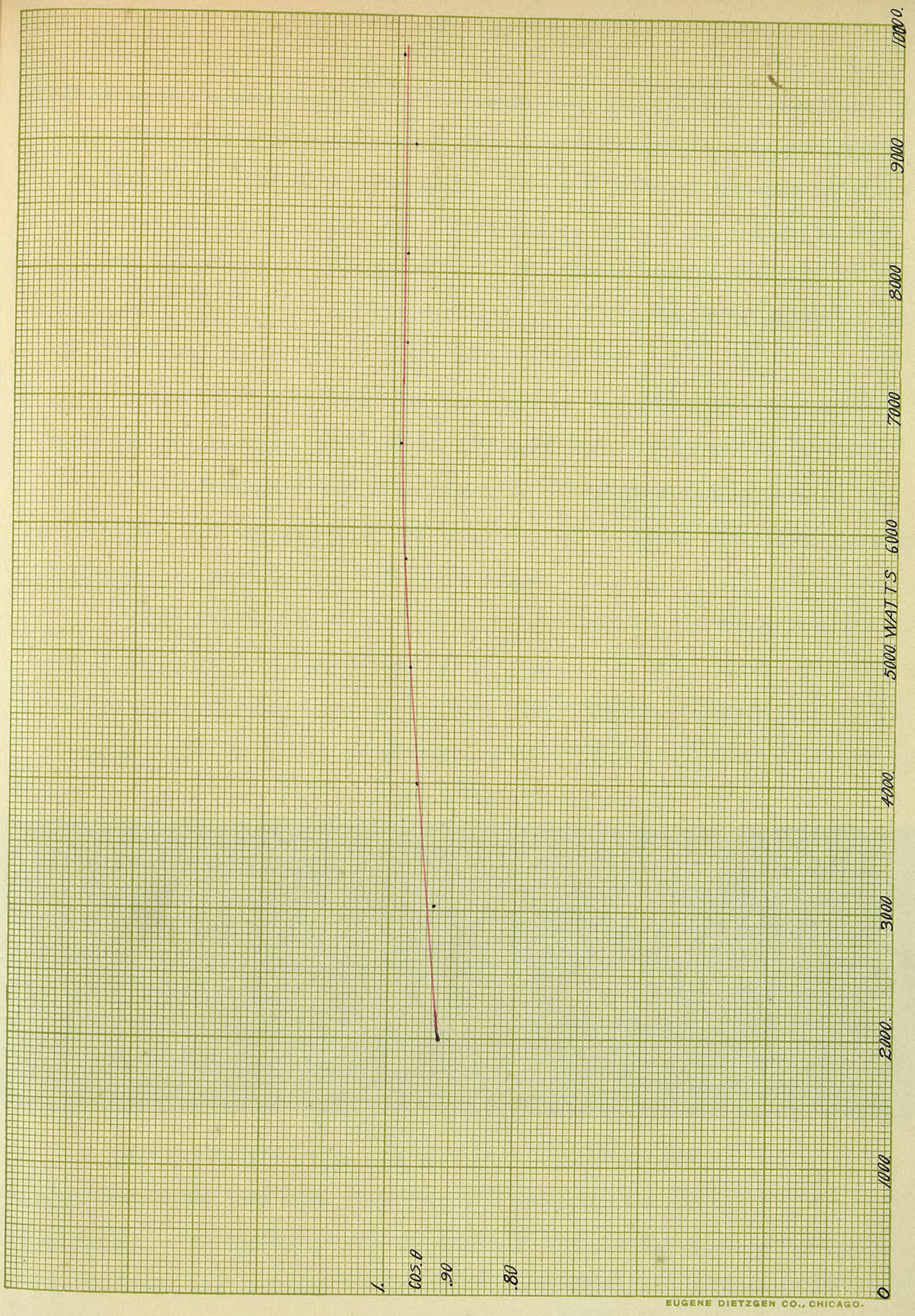

A
3.5
AMPERES
3.
2.5
B
2750
WATTS
0
40
~
45
50
55
60
C
25.5
AMPERES
0
CURVE, A HAS AMPERES IN THE FIELD AS ORD. FREQUENCIES AS ABS.
" B " WATTS OUTPUT " " " "
" C " AMPERES LINE " " " "

Variation of Power Factor With a Non-inductive Load.



The alternator was loaded with incandescent lamps as shown above. The following curve shows the variation of the power factor as the machine was loaded from 0 to 10,000 watts.

Data	Loads.
Cos. ϕ	Load.
.92	2000.
.93	3030.
.96	3995.
.97	4900.
.98	5750.
.99	6660
.98	7450.
.98	8150.
.97	9000.
.99	9705.



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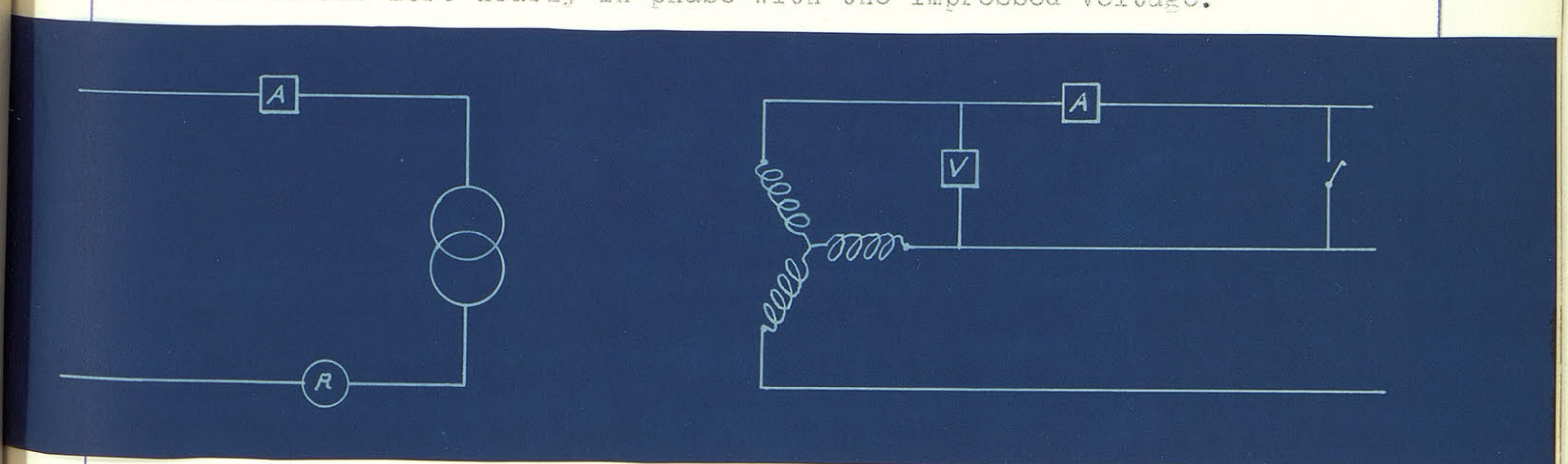
There is always some inductance in an alternating current circuit even though the load be non-inductive. Every alternator has some inductance, the amount depending on the type and windings. With a non-inductive load, only the inductance of the machine acts to cause a lagging current. With a lamp load of 2000 watts the angle of lag was 23°4'. With 5750 watts the angle was 11°28' and for a load of 9705 watts it was 8°6'.

From this it is seen that the angle of lag decreases and that the power factor increases with increase of load on a non-inductive circuit.

An alternator loaded with lamps has its current lagging behind the impressed E.M.F. the amount of lag depending on the load. For small loads the inductance is greater than for large loads.

The inductance of the machine causes quite a lag of current for small loads. As the load increases the flux set up by it in the armature is acted on by the flux of the field. This almost entirely neutralizes the armature flux and results in decreasing the back pressure. This allows the current to become more nearly in phase with the impressed voltage.

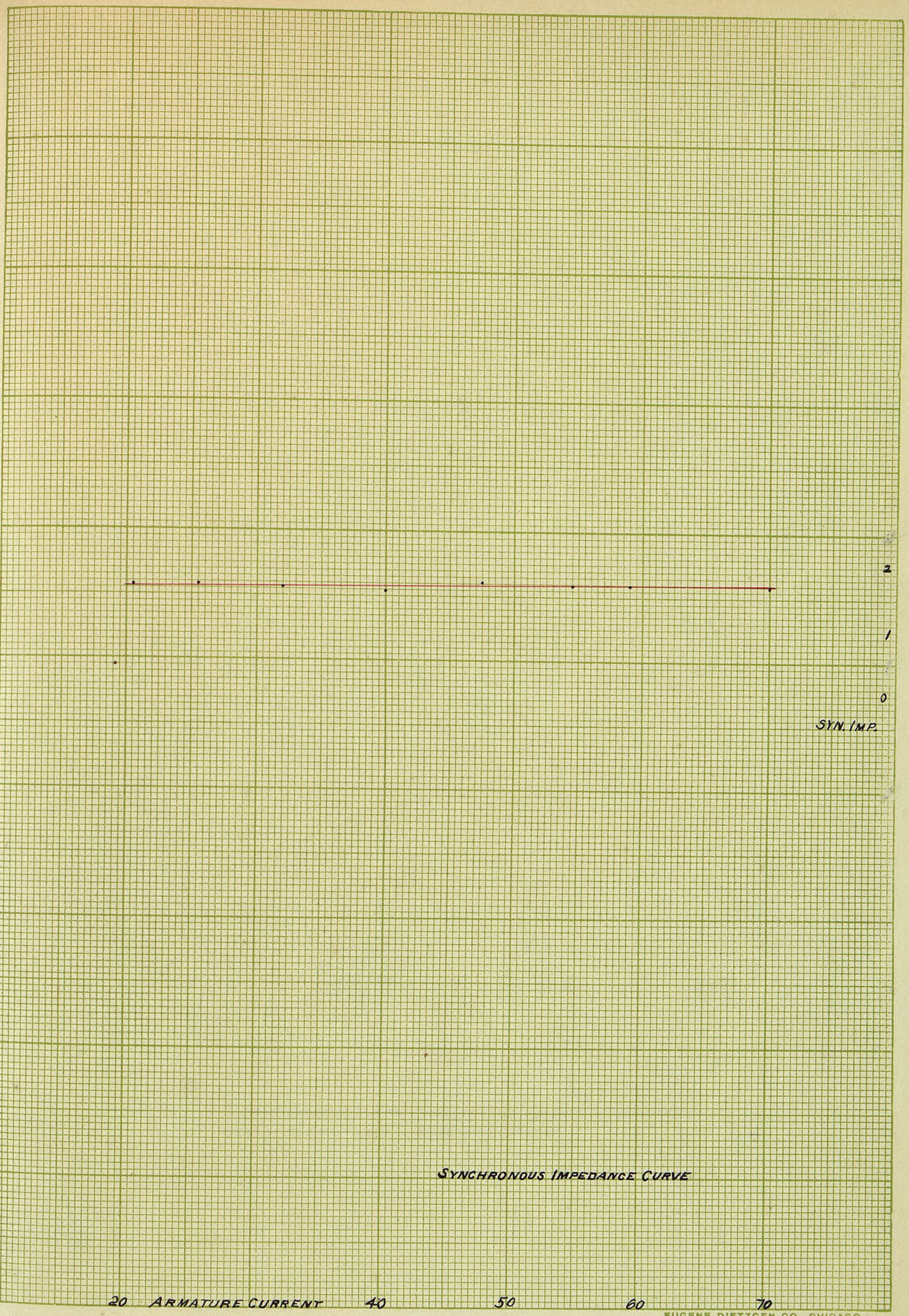


Synchronous Impedance.

The instruments were connected as shown in the above figure. The speed was normal and kept constant. The armature was short circuited through an ammeter. The field current was varied by steps from .7 to 2.53 amperes and readings were taken of the armature current at each corresponding change of field current. The switch was then opened and with the same value of field current as before, the open circuit voltage was noted.

Data (Synchronous Impedance)

Volts.	Amperes	Exciting Currents	Syn. Imped.	RPM
34.	20.5	.70	1.65	1200.
43	25.5	.90	1.68	Constant.
52.	32.	1.20	1.62	
63.5	40.	1.45	1.58	
81.5	47.5	1.75	1.71	
91.75	54.5	2.00	1.68	
99.5	59.	2.15	1.68	
117.	70	2.53	1.67.	



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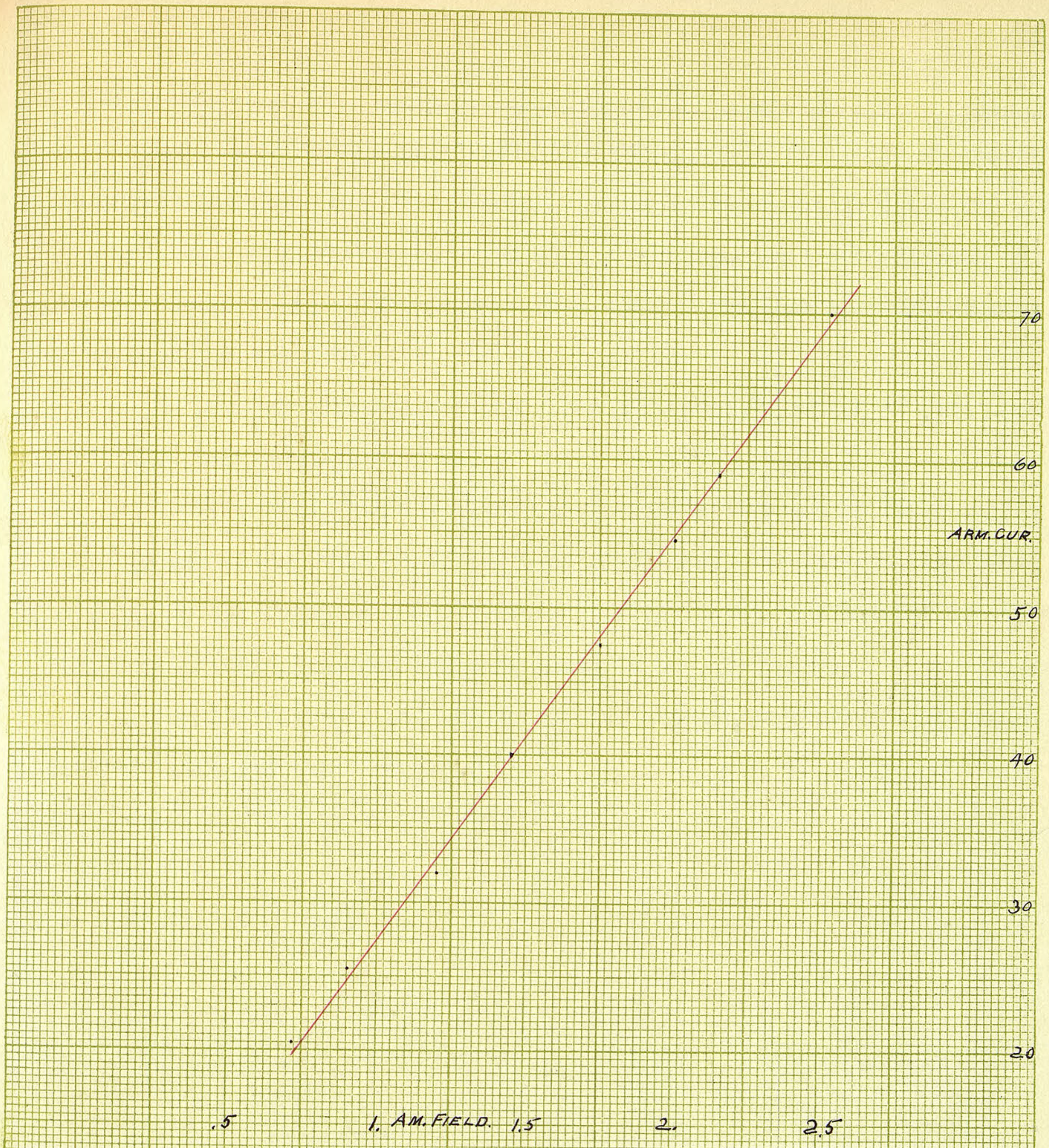


CURVE SHOWING THE RELATION BETWEEN THE FIELD CURRENT AND THE SHORT CIRCUIT ARMATURE CURRENT.

The synchronous impedance is equal to the open circuit voltage divided by the short circuit amperes. The impedance was calculated for each step and the curve was plotted with synchronous impedance as ordinates and the armature current as abscissas. This curve shows that the impedance increases directly as the load.

The synchronous impedance has 2 components acting at right angles, resistance and inductance.

$(\text{Syn.Imp.})^2=(R)^2+(2\pi f l)$. The hot resistance of the armature coils connected as shown in Figure 6 is .0197 ohms. The maximum impedance as shown by the curve is 1.7. By substituting in the formulae for impedance and solving for L, the inductance is found to be .0045 Henry.

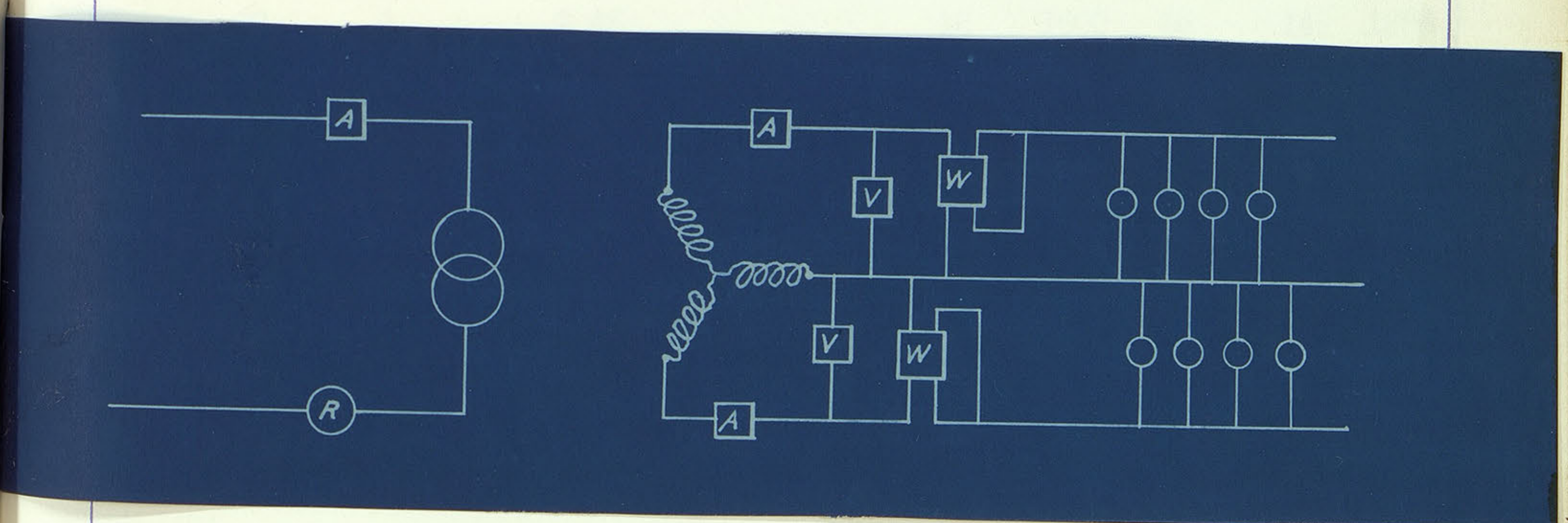
The curve on page 31 shows that the armature current increases directly with the field current.

Alternator Efficiency.

To determine the efficiency of the alternator a rated motor was used. An Am-meter was placed in the line and a volt-meter across the brushes. The product of the two gave the total input into the motor. This multiplied by the efficiency for that load gave the out put of the motor. This input into the motor, plus the I R loss of the exciting current, minus the power required to run the shafting gives the total input into the alternator. The instruments and load for this test were connected as in the following scheme.

The out put of the alternator is the sum of the two wattmeter readings. The efficiency is equal to the out put divided by the input times 100.

Fig.14.



Data;

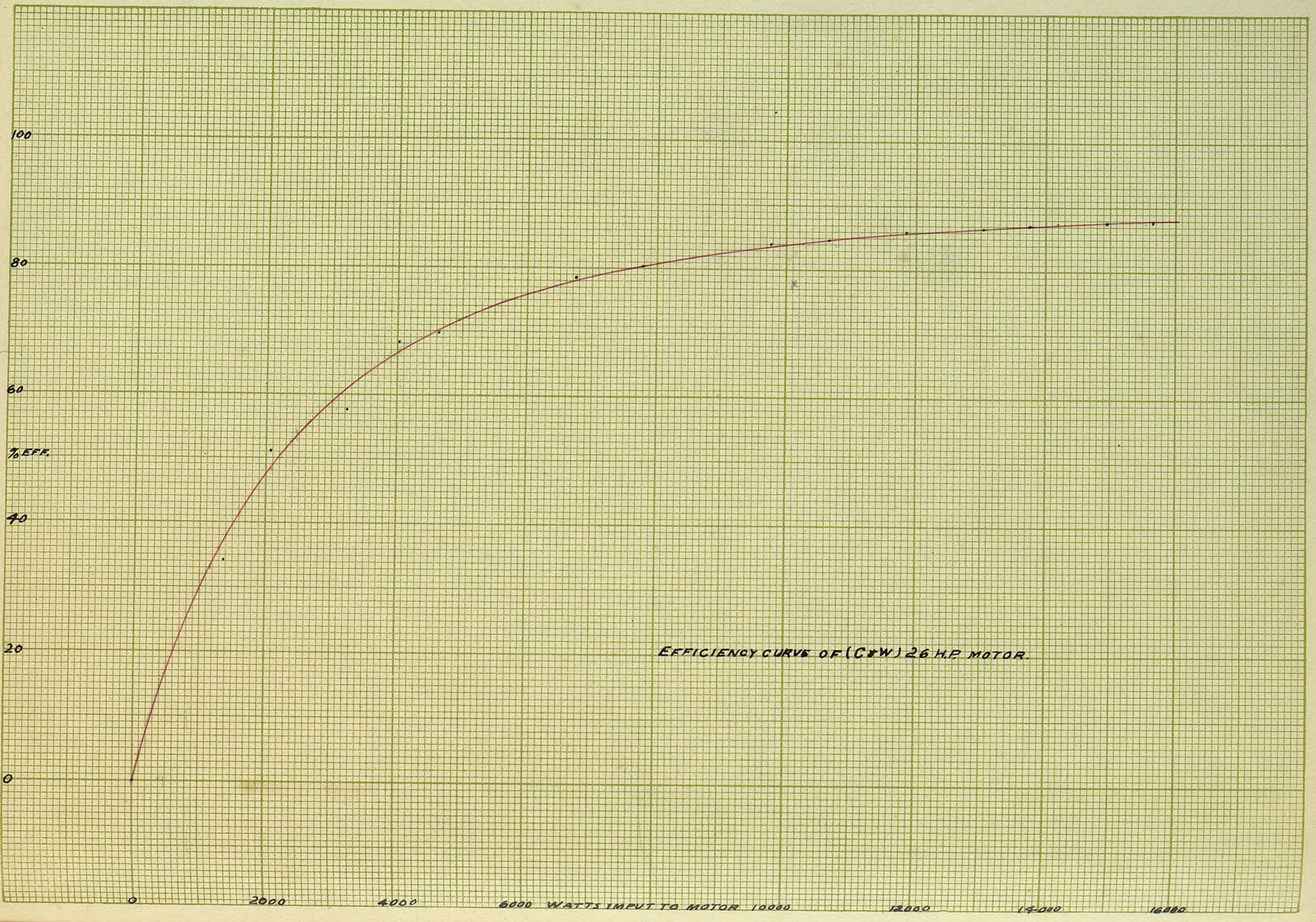
Input				Output.					
Volts	Amp.	Amp Fld	Ex.Cur.	Volts	Amp.	Watt	Volts	Amp.	Watts
(C+W)	Motor running light.								
210	6.5	.9							
	Motor and shaft.								
2.09.	10.	.9 motor.							
Motor, Shaft and Alter.									
213.3	12.6	.9							
Alternator fld.exc.									
216.	13.8	1	2.3	110	0	0	109	0	0
217	20.5	1	2.39	Const	5	490	104.5	5	500
217	25.5	1.05	2.39		10	1000	97.9	10	1000
209	31.	1	2.48		16	1600	96	14	1380
205.5	37	.95	2.54		22	2250	93.5	18.5	1740.
205	42	.92	2.65		27	2900	90.2	22.5	2040
204.	47	.9	2.78		33	3490	87.5	26.4	2300
204.5	53	.9	2.96		37.5	4100	83	33	2750
203.5	58	.9	3.14		43.	4650	81.5	36.8	2990
202	67	.92	3.44		53.5	5800	78.5	43.4	3400
202	72	.9	3.67		59.	6350	77	46.5	3550
214	72	1.	3.85		64	7000	75.8	50.5	3800
213	75	1	4.04		78	7330	74.5	53.4	3900
206	92.5	1	4.58		84	9000	73	61.4	4450
206	93.	1	4.7		85	9100	68.5	68	4600

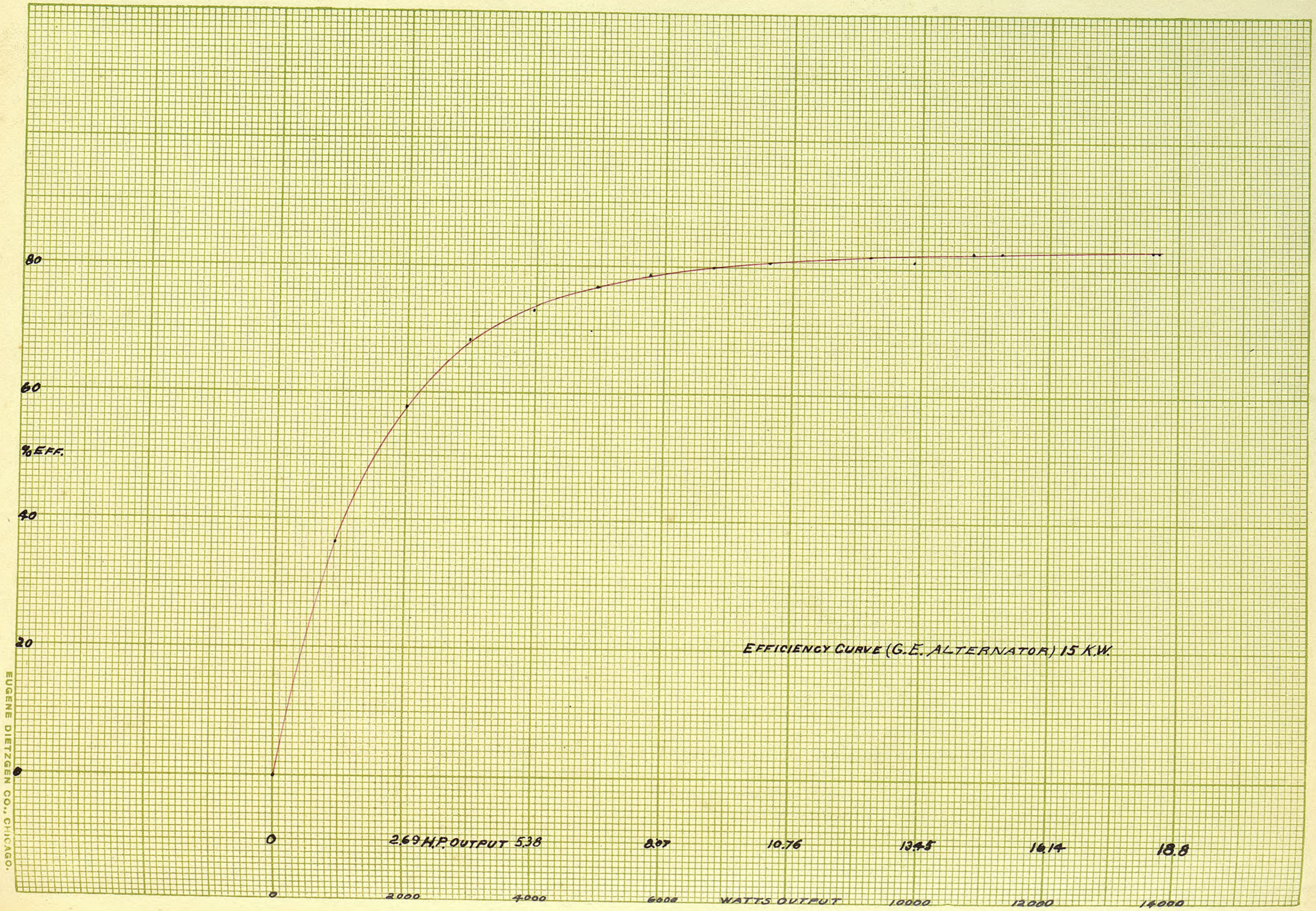
The speed was constant at 1200 RPM

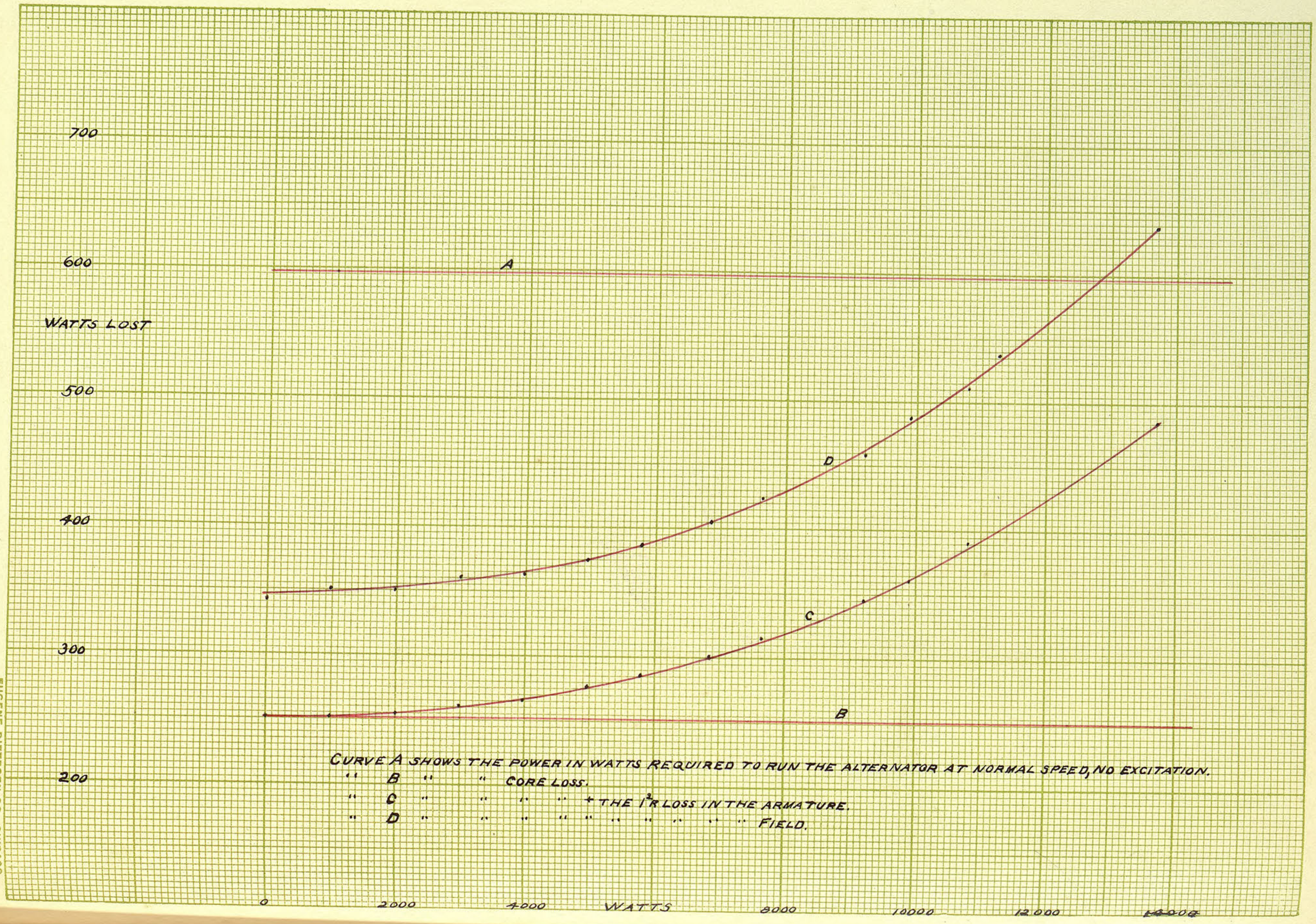
Results computed from the previous data.

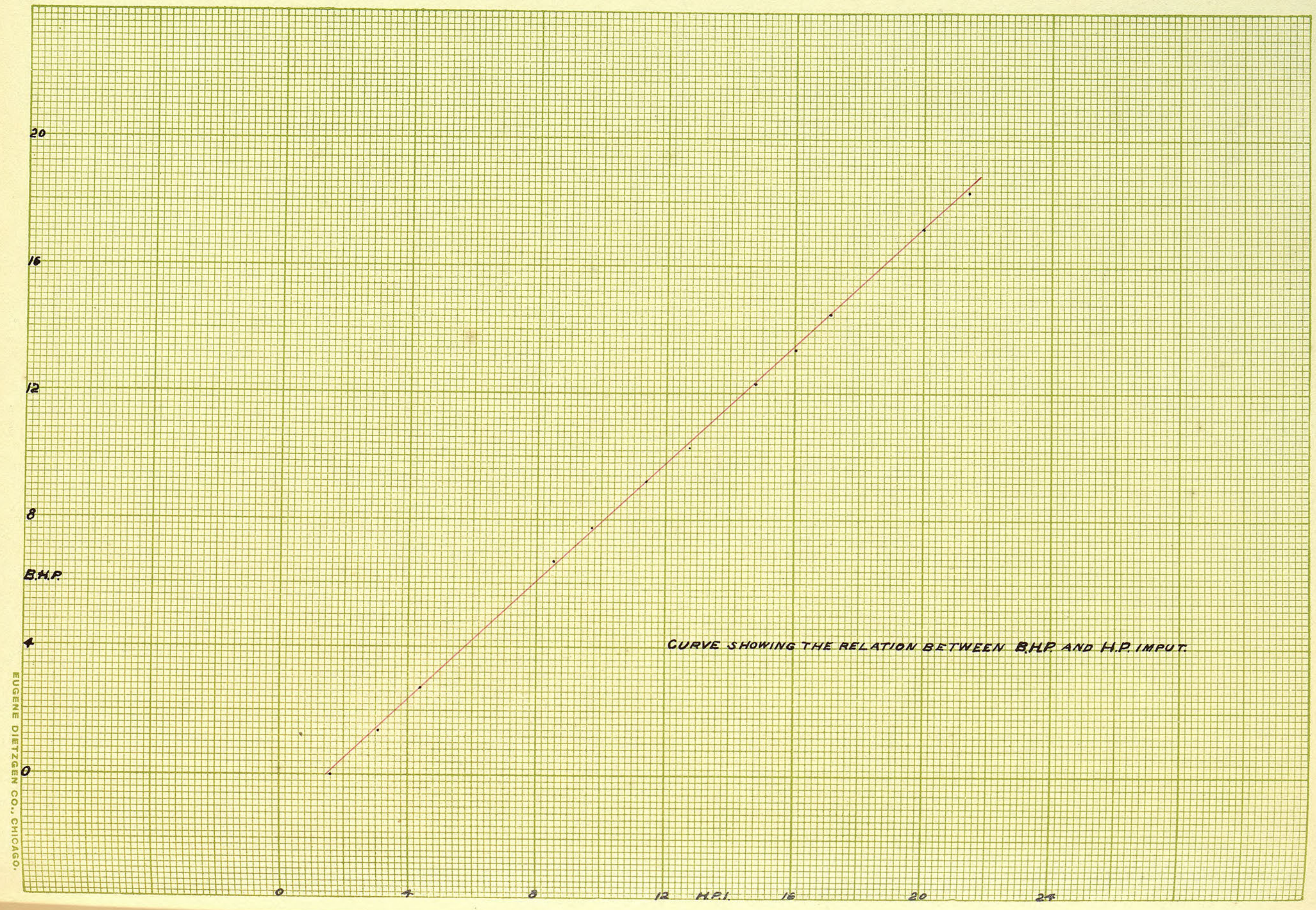
Watts Input.	Watts Output	%Eff	HP output	HP to drive	1^2 r Fld	1^2 r Arm.
1306.6	0	0	0	1.62	92.6	0.
2431.8	990	36.5	1.32	3.12	100.8	.99
3459.8	2000	57.9	2.68	4.40	100.8	3.94
					109.4	
4366.4	2980	68.3	3.99	5.71	112.9	9.90
5455.9	3990	73.2	5.34	7.80	123	16.3
6441	4940	76.6	6.62	8.46	135.2	24.3
7387.2	5790	78.9	7.76	9.72	153.3	35.24
8566.3	6850	79.9	9.18	11.27	172.5	49.1
9692.5	7640	80.7	10.23	12.74	207	63.1
11243	9200	82	12.31	14.79	236	93.44
12208	9900	81.1	13.27	16.04	259	109.93
13078	10800	82.5	14.34	17.18	285.6	139.
13618.6	11270	82.8	15.10	17.87	367.2	175.9
16410.2	13600	82.9	18.23	21.50	386.5	213.3
16520.5	13700	82.9	18.36	21.62		234.4

The resistance of any one circuit of the alternator Y connected is .0197 ohms.(hot)


100
80
60
% EFF.
40
20
0
0
2000
4000
6000 WATTS IMPUT TO MOTOR 10000
12000
14000
16000
EFFICIENCY CURVE OF (C&W) 26 H.P. MOTOR.


80
60
%EFF.
40
20
0
EFFICIENCY CURVE (G.E. ALTERNATOR) 15 K.W.
0
2.69 H.P. OUTPUT 5.38
8.07
10.76
13.45
16.14
18.8
0
2000
4000
6000
WATTS OUTPUT
10000
12000
14000
EUGENE DIETZGEN CO., CHICAGO.


WATTS LOST
700
600
500
400
300
200
A
B
C
D
CURVE A SHOWS THE POWER IN WATTS REQUIRED TO RUN THE ALTERNATOR AT NORMAL SPEED, NO EXCITATION.
" B " " CORE LOSS.
" C " " " " + THE I²R LOSS IN THE ARMATURE.
" D " " " " " " " " " " FIELD.
0
2000
4000
WATTS
8000
10000
12000
EUGENE DIETZGEN CO., CHICAGO.



20
16
12
8
B.H.P.
4
0
0
4
8
12
H.P.I.
16
20
24
CURVE SHOWING THE RELATION BETWEEN B.H.P. AND H.P. IMPUT.
EUGENE DIETZGEN CO., CHICAGO.

The efficiency curve of the alternator shows an efficiency of 80.8% for half load and 82.9% efficiency at full load, which is a little above the average for a small machine. The curve A on page 36 shows that the power required to run the alternator at normal speed, 1200 R.P.M., with no field excitation is 590 watts. This power is consumed in bearing friction and windage. The power required to run the alternator at normal speed with the f fields excited to give 110 volts is 1144 watts. The difference, 1144-590= 552, is the core loss, composed of magnetic friction and eddy currents losses in the iron and copper parts of the armature. The curves C and D show the copper losses, for different loads, in the armature and fields respectively. The last two curves resemble each other, but show that the loss in the field exceeds the armature losses, and increase more rapidly with increase of load.

The data for the efficiency shows that the increase of field current that kept the voltage of one leg constant, as the load increased, did not keep the other voltage up, but it decreased with increase of load. This was undoubtedly due to the inductance of the machine, for with all three legs loaded using a neutral wire, the voltage was the same over each bank of lamps.

This alternator is especially adapted for laboratory purposes. The ends of the coils are carried out to a terminal block on top of the frame. By means of these ends connections may be made to secure any phase desired.