THE ALTERNATING CURRENT GENERATOR

BY

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1. Principles of Alternating Currents.

Faraday's discovery that by moving wires across a magnetic field so as to cut lines of force, a current would be induced, suggested the construction of magneto electric machines, drawn by mechanical power.

If a coil of wire be revolved between the poles of a magnetic current a current will be induced in the conductors.

In Fig. 1. a simple coil C of wire is revolved between the poles of a magnet N S each end of this coil is connected to a slip ring A-B. Now suppose the coil to be revolving so that the top of the coil is coming toward one, then the current induced in the wires at that moment will be in the direction indicated by the arrow heads. It will leave by the ring A. and will return from the circuit through B. Now when the coil is turned 180° degrees from the position shown, the E. M. F. will be reversed and now it will leave the ring B. and return through A. Hence in each complete revolution of the coil the E. M. F. rises to a maximum, then falls to 0 and then rises to a maximum in the opposite direction. Then we have the primitive form of the alternator, generating a simple periodical alternating current. In alternating current working, the current is rapidly reversed, rising and falling in a set of pulses, the electrical current being set oscillating, forwards and backwards, through the line and around the circuit with great rapidity under the influence of a rapidly reversing E. M. F.

Now, as seen above, the coil by cutting lines of force of the magnetic field sets up a periodic E. M. F. which changes at every half turn giving rise to alternating gurrents. On each whole revolution there will be an E. M. F which rises to a maximum and then dies away giving a curve such as is represented in Fig. 2. The heights of the curve above the horizontal line represent the momentary values of the E. M. F's; the depths below in the second half of the curve represent the inverse E. M. F's that succeed them. The exact slope of this curve depends upon the arrangement of the iron and the winding of the alternator, and also upon the current that is flowing. Some machines are constructed so that their E. M. F. curve is nearly a sine curve, while in other machines the curves vary and sometimes are very irregular. Each complete operation exhibited by the whole wave above and below the line is called a period, and the number of periods in a second is called the frequency or periodicity of the alternator. The number of revolutions per second times the number of pairs of poles gives the frequency.

Figure 1

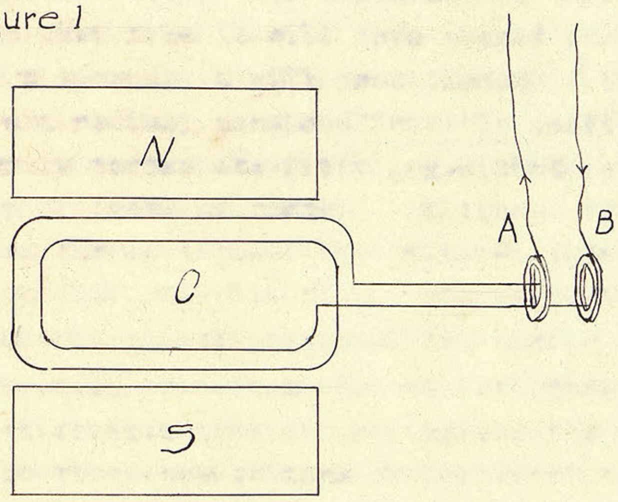
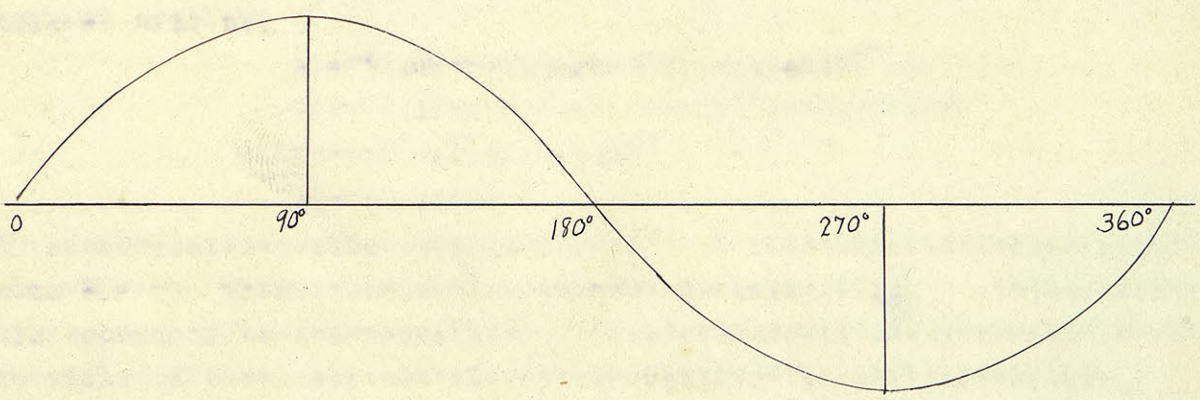


Figure 2.



Let us now consider a two pole machine in which there are N. magnetic lines of force passing through any coil or part of a coil, when it lies across the magnetic field. If the armature makes N. revolutions per second, then in that time it will have passed through $2\pi N$ radius in a second, and in t seconds it will pass through $2\pi n t$ radius. Let the angle of $2\pi n t$ radius, measured from the position of the coil when its plane was squarely across the field, be represented by θ, that is when it encloses the greatest number of lines of force. If there are S spirals in the coil and the coil has turned through the angle θ, then the flux enclosed, varies as S.N. cos θ or S.N. cos $2\pi n t$. Now since the induced volts are proportional to the rate of change of the number of lines of force that are enclosed by the coil, and since the rate of change of the cos is proportional to the sin it follows that we may express the induced E.M.F. by a formula in which there are factors proportional to the sine of the angle, the angular speed, to the number of spirals, and to the maximum flux through the coils The number of lines of force cut by the coil will then be

$$2\pi n S N \sin 2\pi n t \text{ or}$$

$$2\pi n S N \sin \theta$$

Now since one volt is the amount of E.M.F. generated by cutting the magnetic lines at the rate of 10^8 in a second, it follows that the E.M.F. in volts of the armature at the time t, when the coil has passed through the angle θ will be

$$E = 2\pi n S N \sin 2\pi n t \div 10^8 \text{ or}$$

$$E = 2\pi n S N \sin \theta \div 10^8 \text{ and writing}$$

$$D = 2 n \pi S N \div 10^8$$

$$E = D \sin \theta$$

D is the maximum value attained by E. E. reaches its highest value when sine θ = o That is when θ is an odd multiple of $\frac{\pi}{2}$ This maximum value is spoken of as the amplitude. D is the amplitude expressed in volts, and the value of E at any instant can be obtained by multiplying the amplitude by sine θ. The value that sine θ has at any particular instant is obtained by merely filling in the number of seconds or fractions of a second, t, in the expression $2\pi n t$ and reckoning it out numerically by reference to a table of natural sines.

In the simple case of a 2 pole field, such as we have taken, θ is an actual angle through which the armature has turned, but in a multipolar machine yielding an alternating E.M.F. which varies according to the law $E = D \sin \theta$, θ no longer exists as a physical angle. It is the imaginary angle of which we have taken the sign in order to get the instantaneous value of E. The alternating E.M.F. has a constant frequency which we denote by n, that is, there are n complete periods in a second. Each period between one maximum and the next occupies a short interval of time each equal to $\frac{1}{n}$ of a second. This interval is called the periodic time or the period, and measured in seconds is commonly denoted by T. Now we know that the sine of an angle goes through its complete series of changes while the angle goes through 2π or 360°. If, therefore, we are going to express the value of the E. M. F. as a sine function of the time the interval T must correspond to the angle 2π. We take $\theta = 2\pi\frac{t}{T}$ so that when $t = T$ we have $\theta = 2\pi$. and whenever it is a simple multiple of T, θ is a simple multiple of 2π. In fact $2\pi\frac{t}{T}$ gives us an angle which is a fraction of 2π and whose sine varies as the E. M. F. varies. Now as $T = \frac{1}{n}$ we have the more convenient expression $\theta = 2\pi n t$. The angle θ is called the angle of phase. In case of multipolar machines the angle turned through by the armature, which angle we may denote by α is related to θ by the following equation- $p x = \theta$- where p is the number of pairs of poles. It will be seen now that if the number of poles are increased the frequency will be increased. And there may be several different coils upon the armature. In the multipolar machines there are 2π electrical degrees between one N pole and the next N pole. Hence if the generator gives a single phase it will have only one coil and the different convolutions of this coil will be π electrical degrees apart. There will be required two wires to take the current to the external circuit and return. In a two phase there are simply two single phase windings and are placed $\frac{\pi}{2}$ or 90° apart. Hence there are four wires required to take the current to the external circuit. In a three phase machine there are simply three, single phase winding, placed $\frac{\pi}{3}$ or 60° apart. There are different ways of connecting the windings of three phase armatures, which will be spoken of later on. There are required but three wires to the external circuit.

In alternate current work, the ammeters and voltmeters do not read arithmetical average values, but measure what are called vertical volts and amperes. Vertical volts and amperes are the square root of the mean square values. The mean of the squares of the sine is 1/2 hence the square root of the mean square will be $\sqrt{1/2}$ or .707. Hence if the E. M. F. oscillates between +100 and -100 volts the volt-meter will read only 70.7 volts. And if the instrument reads 100 volts or amperes they will oscillate between +141.4 and -1414.

Any conductor, in which there is flowing a current, is surrounded by lines of force, the number depending upon the permissibility of the medium. Now if the conductors are close together the lines from the different conductors will cut across each other, and produce self-induction; and the amount of cutting of these magnetic lines when unit current is turned on or off is called the coefficient of self induction; L and is proportional to the square of the number of spirals reacting; that is L is proportional to S^2. Hence in the external circuit the resistance is not the only factor that must be overcome, but also the inductance which combined with the resistance is called impedance. And the alternate current is governed by the impedance and not by the resistance of the circuit.

When an E. M. F. is applied to a condenser the dielectric becomes charged, and in trying to discharge itself sets up an opposing E. M. F. The effect of this action is to produce a load on phase of the current, that is, the current will reach its maximum ahead of the volts. The action of inductance in the circuit produces a lag of the current. Inductance has another effect which is more important than any retardation of phase. It produces reactions on the E. M. F. choking the current down. While the current is using in strength the reaction of induction tends to prevent it.

The power given out by an alternator cannot be found by simply multiplying volts and amperes together, for if there is any difference in phase the apparent watts will always be in excess of the true watts, because the mean product of two periodic functions is equal to half the product of their maximum values multiplied by the cosine of their phase difference.

The great advantage of alternate current over direct current is in the transmission of power. In the alternate current system of power transmission the voltage can be raised very high, and transmitted a long distance over small wires, with out a very great drop in voltage. Some of the recent power transmission plants employ voltages from 10,000 to 20,000, and some plants even employ voltages as high as 50,000. And in most all electric light plants the voltages used range from 2000 volts and upward. Since the use of high voltage allows the use of small wires, the cost of the transmission lines is not much of a factor in the cost of the plant. When the current is to be used the voltage is lowered by means of step down transformers.

In practice it has been found that it is not safe nor advantageous to use direct current machines at a voltage of from 3000 to 4000; such high pressure causes excessive sparking at the brushes, and the insulation of the commutator will not stand the strain, hence the employment of such voltage is not permissible..

Alternators are simpler in construction than direct current machines, for they have no commutator, having simply slip rings, and for this reason are less liable to get out of order.

There are some objections to alternate currents for power transmission. The maximum pressure with alternate currents is 1.41 times the square root of the mean square, hence a continuous current of equivalent maximum pressure will transmit more power. There is a certain loss in the line aside from the resistance, due to inductance.

Until recently there were no self starting alternate current motors, but this objection has been removed by the introduction of self starting monophase motors of high efficiency, and by the employment of polyphase currents.

The great advantages of alternate current generators over direct current generators, are that no commutator is required, and the pressure can be transformed from high to low or from low to high voltages.

Some of the very earliest alternators had revolving multipoler field magnets, and external stationary armature, but most of the earlier machines were of the revolving armature type.

The Ferranti Alternator may be taken as an illustration of the earlier types. In this machine wave windings were substituted for coils. The field magnets consisted of two crowns of alternate poles, and the armature consisted of strip copper bent into a "wavy" star form, consisting of eight loops, and on each side there were sixteen magnet poles. The copper strip was wound around on itself with insulation between, in many layers. The limbs of the star were held in place by insulated bolts passing through star shaped face plates. The advantage of the armature of zigzag copper was supposed to lie in its strength and simplicity of construction.

When the project of utilizing the water power of Niagara by Turbins was taking shape the Cataract Construction Company invited many different manufacturers of both Europe and America to submit plans. The machines were to be of 5000 horse power, driven by turbins at 250 revolutions per minute. While many good designs were submitted from Europe it was decided to have the machines built in America, owing to the high tariff and cost of transportation.

The machines were designed for an externally revolving umbrella field magnet with inwardly pointing poles held together by an external annulus

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of steel as possessing both great strength and a large fly wheel action. The first designs were for a two phase machine, having a frequency of 16 2/3 periods per second, and with eight poles. The frequency was changed to 25 and the armatures were wound for 2000 volts. The field magnet consists of a nickel-steel ring forged with out a weld, toward the interior of which project twelve pole cores. This is supported by an umbrella shaped driver fixed to the top of the shaft. There are 187 slots in the armature with two conductors in each slot. Each conductor is 1 11/32 inches by 1/16 in section, with slightly rounded edges. The armature winding is of the wave form.

Construction of Alternators.

Alternate current generators may be classified in three groups.

1. Those having stationary fields and rotating armature.
2. Those having rotating fields and stationary armatures.
3. Those having both field and armature stationary, the magnetic induction being caused to vary or alternate by the revolution of appropriate masses of iron called inductors.

Alternators may also be classified as single phase and polyphase, according as to whether their coils are arranged so that the currents in them will be in or out of phase with each other.

The field may either be stationary or rotating. They are excited from some external source, or may be self exciting, or may be partly self exciting and partly separate excited. Of the two kinds of fields the rotating field is now universally used, and especially in large machines.

As a rule most alternate current generators have iron clad armatures, while some will be found of the disc armature type. They may either be wound on ring coils, or drums. The coils may be smooth or slotted, but the latter is used in all recent machines.

The stationary armature has the advantage over the rotating armature, on account of the high insulation that can be secured.

The armature windings of all polyphase generators may be considered as consisting of two or three or more single phase windings grouped so as to have proper phase relations. All the polyphase armatures now in use may be regarded as developed from one or two generic single phase forms, namely (a) those having armature windings concentrated in large slots or coils having one large tooth per pole: (b) those having the windings distributed uniformly over the surface of the armature. They may either be on the face or may be sunk between iron teeth more numerous than the poles.

In Fig. 3 is illustrated an example of concentrated winding where the coils are sunk between large teeth. The six coils if joined successively in series so as to add the E. M. F's, must be joined up so that the currents that circulate in one sense around any one tooth, shall circulate in the reverse sense around the next, being wound or connected alternately.

In Fig. 4 is illustrated distributive winding with a simple ring winding

Another method of winding is to wind the whole number of wires on half the poles, and the armature coils on half the slots, that is making each twice as large, as illustrated in Fig. 5. Such a winding is called hemitropic. This winding is used in both armature and field and is employed in some of our modern machines. It has a particular value in polyphase armatures in reducing the undesirable overlapping of coils at the ends of the armature.

The monotooth construction with concentrated winding can be modified so as to produce a two phase relation. The number of slots can be doubled, by cutting another slot between each of the others, thus making twelve slots. Now in this set of slots another single phase winding can be laid, as illustrated in Fig. 6.

This may also be wound without overlapping, as shown in Fig. 7.

In the foregoing there was but one tooth per pole per phase. Now we can have two teeth per phase per pole by simply doubling the number of slots, making 24 and in this case each slot carries only half as many conductors as before, that is by keeping the output the same. This is illustrated in Fig. 8.

Now by again doubling the number of slots, making 48, making them half as large and each carries half as many conductors, as shown in Fig. 9.

Winding, like the last illustration, is an excellent plan and in nearly all of the modern machines with stationary armatures this style is used. In this plan the windings are better distributed over the periphery of the armature.

The hemitropic modification lends itself readily to two phase grouping..

Now in Fig. 1 if two sets of three coils displace the one set we obtain the result as illustrated by Fig. 10.

And now by displacing the second set of coils through a distance equal to 1 1/2 instead of 1/2 times the pole pitch, we have a winding without overlaps, as illustrated in Fig. 11

These constructions are suitable only for machines having an odd

Figure 3

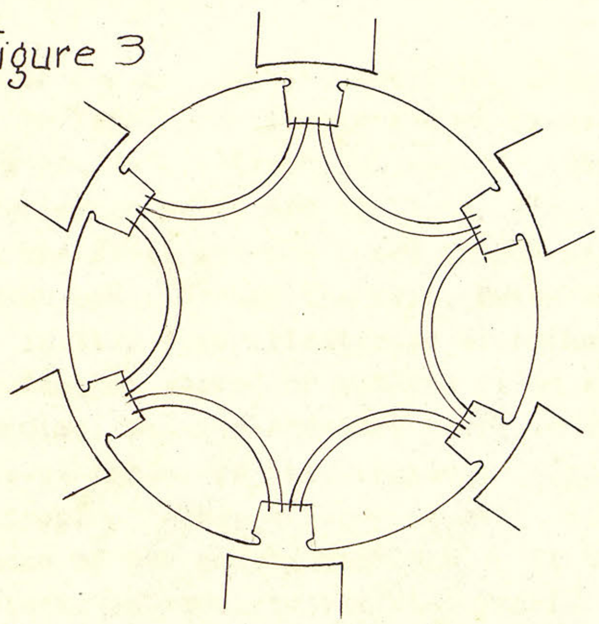


Figure 4

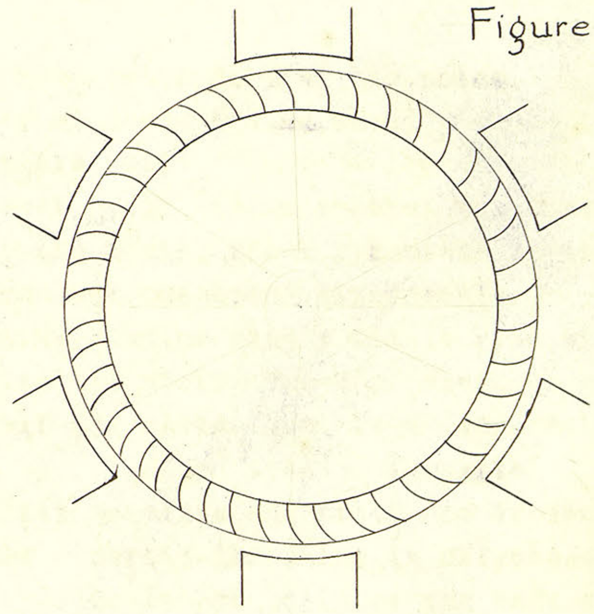


Figure 5

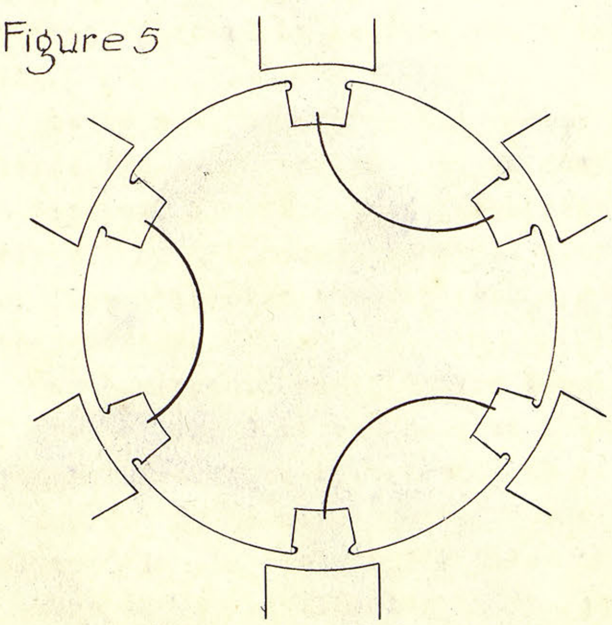


Figure 6

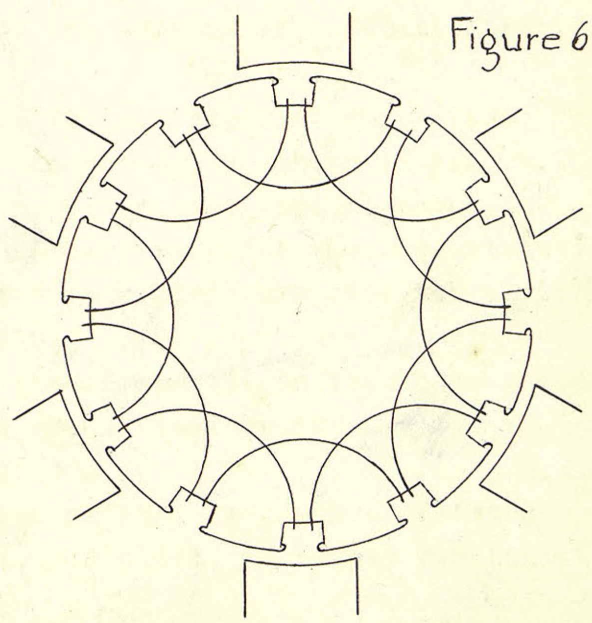


Figure 7

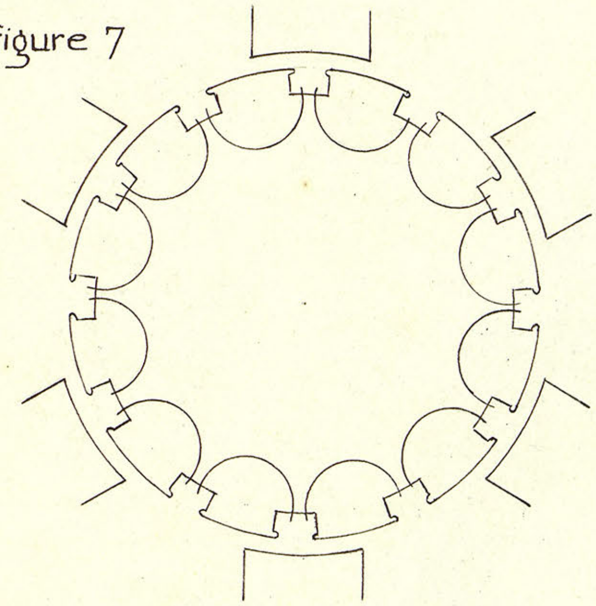


Figure 8

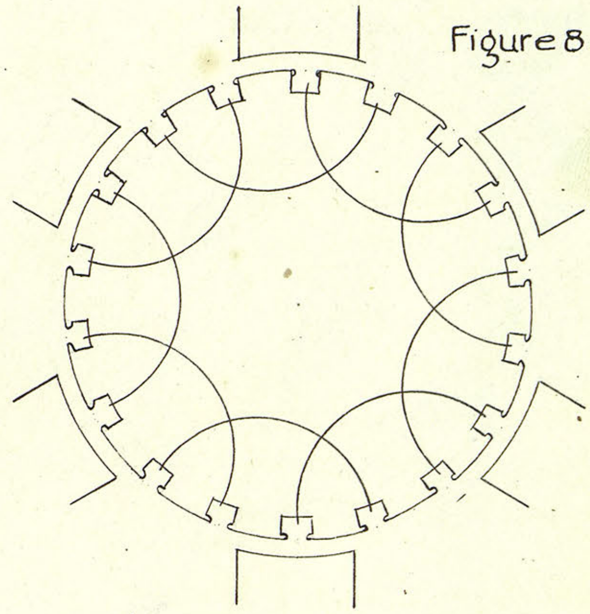


Figure 9

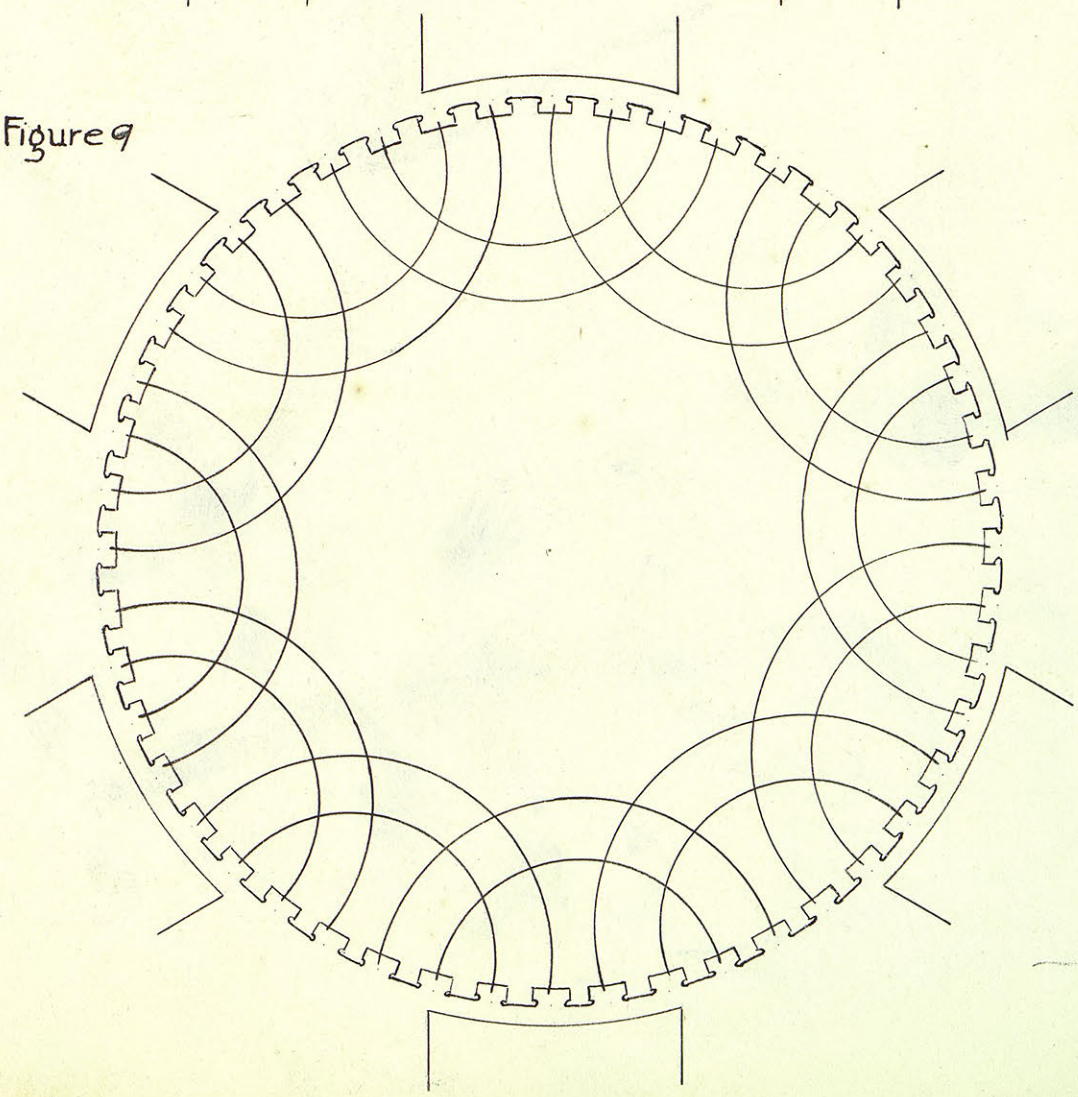


Figure 10

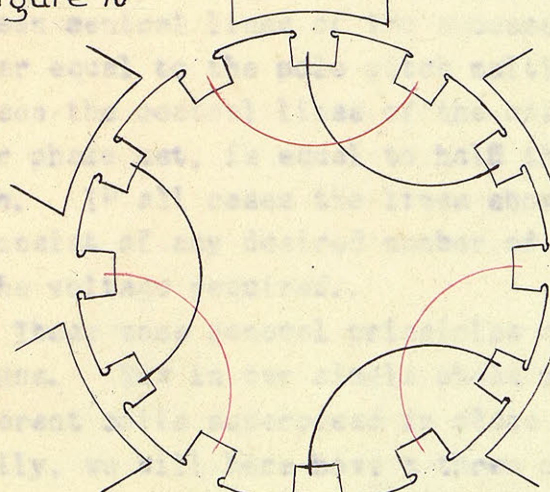


Figure 11

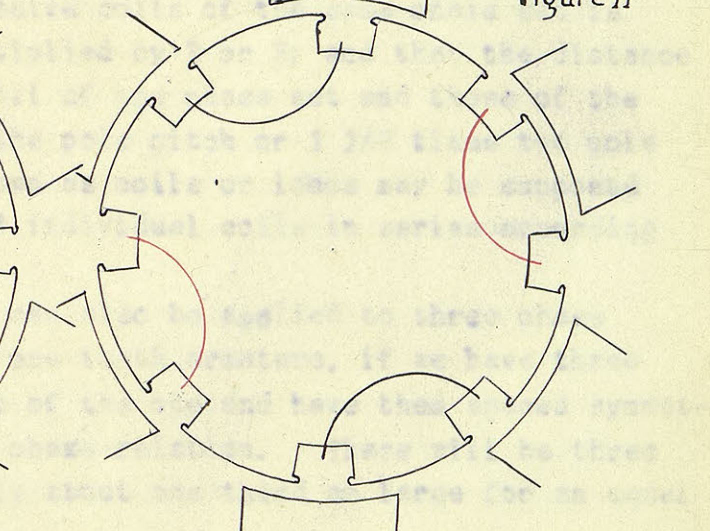


Figure 12

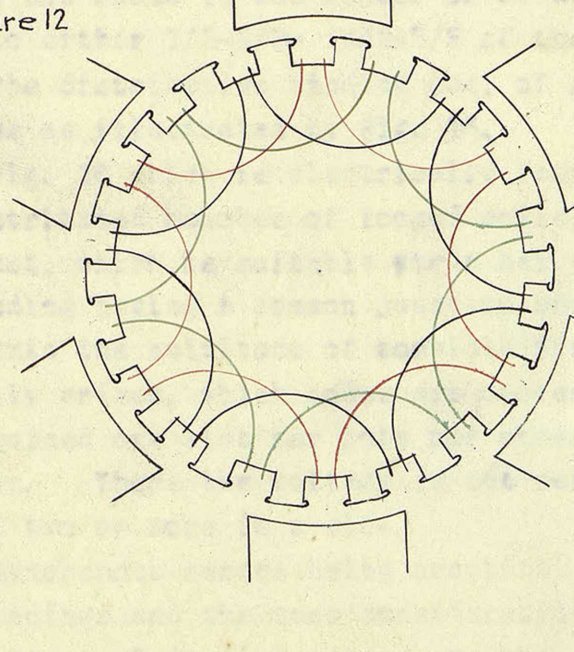
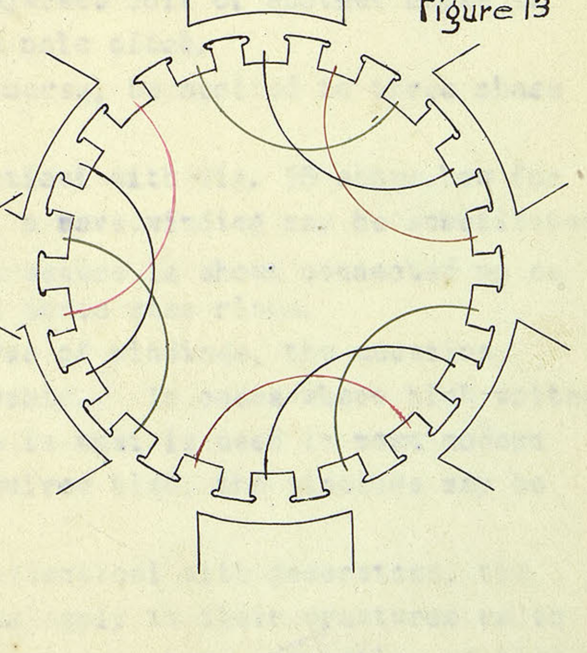


Figure 13



number of pairs of poles. In all cases it will be seen that the distance between central lines of two successive coils of the same phase set is either equal to the pole pitch multiplied by 2 or 3; and that the distance between the central lines of the coil of one phase set and those of the other phase set, is equal to half the pole pitch or 1 1/2 times the pole pitch. In all cases the lines shown as coils or loops may be supposed to consist of any desired number of individual coils in series according to the voltage required..

These same general principles can also be applied to three phase designs. Now in our single phase one tooth armature, if we have three different coils superposed in place of the one and have them spaced symmetrically, we will here have a three phase relation. There will be three times as many sl ts but will be only about one third as large for an equal out put, as illustrated in Fig. 12.

Now by hemitropic winding we can have the three phase winding as illustrated in Fig. 13.

And also this can be used to take the form as illustrated in Fig. 14.

It will be observed that in all three phase windings the angular distance from the central part of one coil to the central part of the next coil of the same phase is equal either to the pole pitch or to the pole pitch multiplied by two or three, while the distance from the center of any coil of one phase to the center of an adjacent coil of another phase is equal to either 1/3-2/3- 4/3-5/3 of the pole pitch.

The distributive winding can, of course, be applied to three phase machines as illustrated by Fig. 15.

Fig. 16 which is electrically identical with Fig. 15 shows how for the distributed bunches of looped coils, a wave winding may be substituted. This last, which is suitable for a bar armature is shown connected up as a Y winding having a common junction and three step rings.

Amid the multitude of possible forms of windings, the question naturally arises, which modes are preferable. In cases where high voltages are required one slot per pole per phase is what is used in most modern machines. Where the voltage is not required high, the windings may be grouped two or more in a slot.

Synchronous motors being practically identical with generators, the same windings and the same considerations apply to their armatures as to generators. Induction motors, on the contrary, have properties of their own which render it desirable, as far as possible, to suppress all reactions

Figure 14

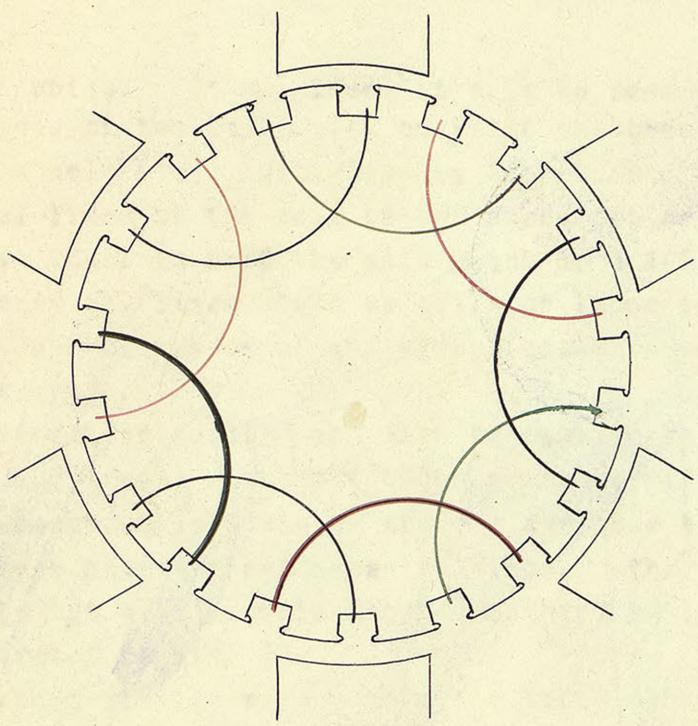


Figure 15

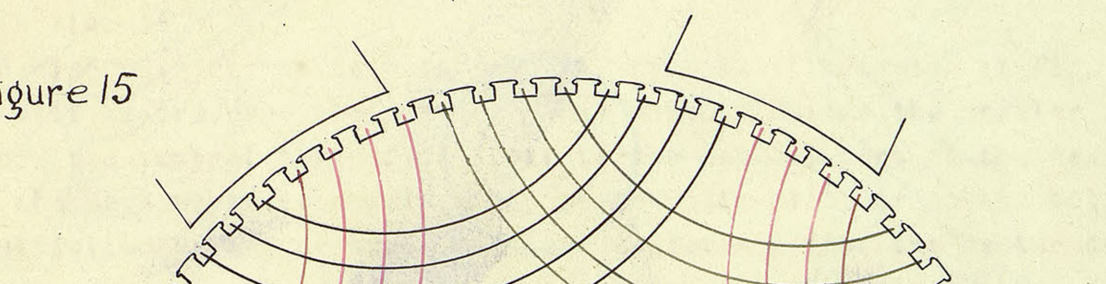
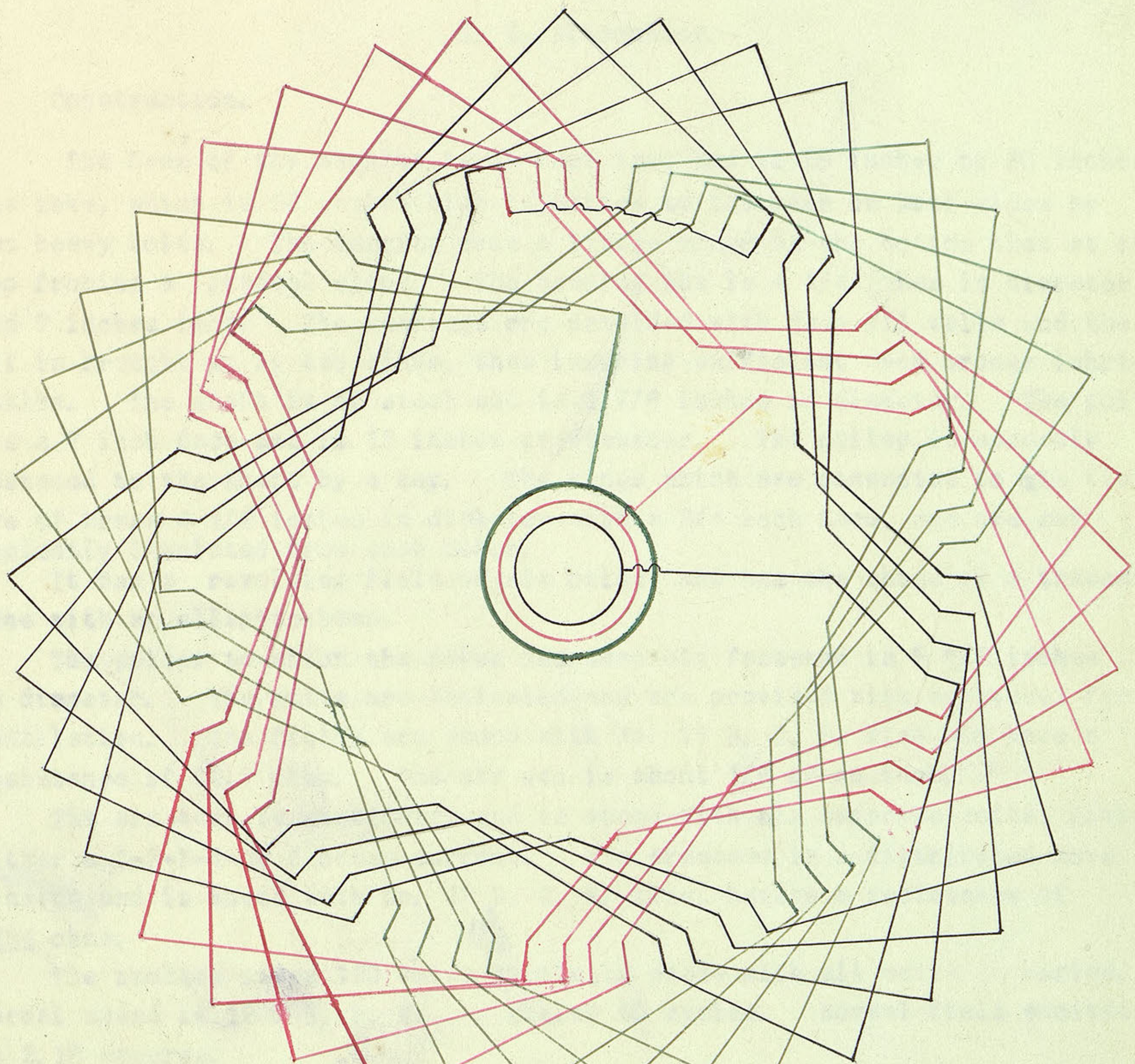


Figure 16



that might arise from an unequal distribution of conductors around the periphery. Hence it is very seldom in the stator of an induction motor, are any of the forms employed in which the windings are concentrated in a few slots, but every effort appears to be made to distribute the windings.

G. E. Alternator.

Construction.

The base of the machine is of cast iron and is 28 inches by 30 inches. The yoke, which is 28 inches high is bolted to the base on both sides by two heavy bolts. The bearing arms a little wider at the bottom than at the top froming a gradual slope. The bearing box is 4 1/4 inches in diameter and 7 inches long. The bearings are provided with deep oil wells and the oil is brought up by two rings, thus insuring sufficient and proper lubrication. The shaft is of steel and is 1 7/8 inches in diameter. The pulley has a 7 inch face and is 13 inches in diameter. The pulley is securely fastened to the shaft by a key. The rings which are connected to the fields are of brass 4 1/2 inches in diameter with a 3/4 inch face, and are sufficiently insulated from each other.

It has a revolving field of six poles, and has the shape of a truncated cone with an elliptic base.

The spider to which the poles are securely fastened is 8 1/2 inches in diameter. The poles are laminated and are provided with apertures for ventilation. The fields are wound with No. 15 B. C. S. wire and have a resistance of 14.2 ohms. The air gap is about 1/8 of an inch.

The armature is stationary and is wound with six separate coils, giving either a 1-2-3-4-or 6 phase current. The armature is a distributed wave winding and is wound with No. 13 B. C. S. wire, having a resistance of .234 ohms.

The machine gives 120 volts as single phase with all coils in series. The Normal speed is 1200 R. P. M. giving 60 cycles. Normal field excitation is 2.18 amperes.

The armature coils are grouped six in parallel and are insulated from each other as three turns. There are 36 single coils in all and there are 4 turns in series per coil. There are 36 slots and there are 8 conductors per slot. The armature coils are built up of thin iron sheets insulated from each other by mica. These sheets have a thickness of about .05 inches.

There are 432 turns per pole in the field and all are connected in series The poles are laminated, being built up of thin iron stampings, insulated from each other by mica and firmly bolted together.

When operated at a speed of 1200 R. P. M. it gives at full load 120 volts and 69 amperes.

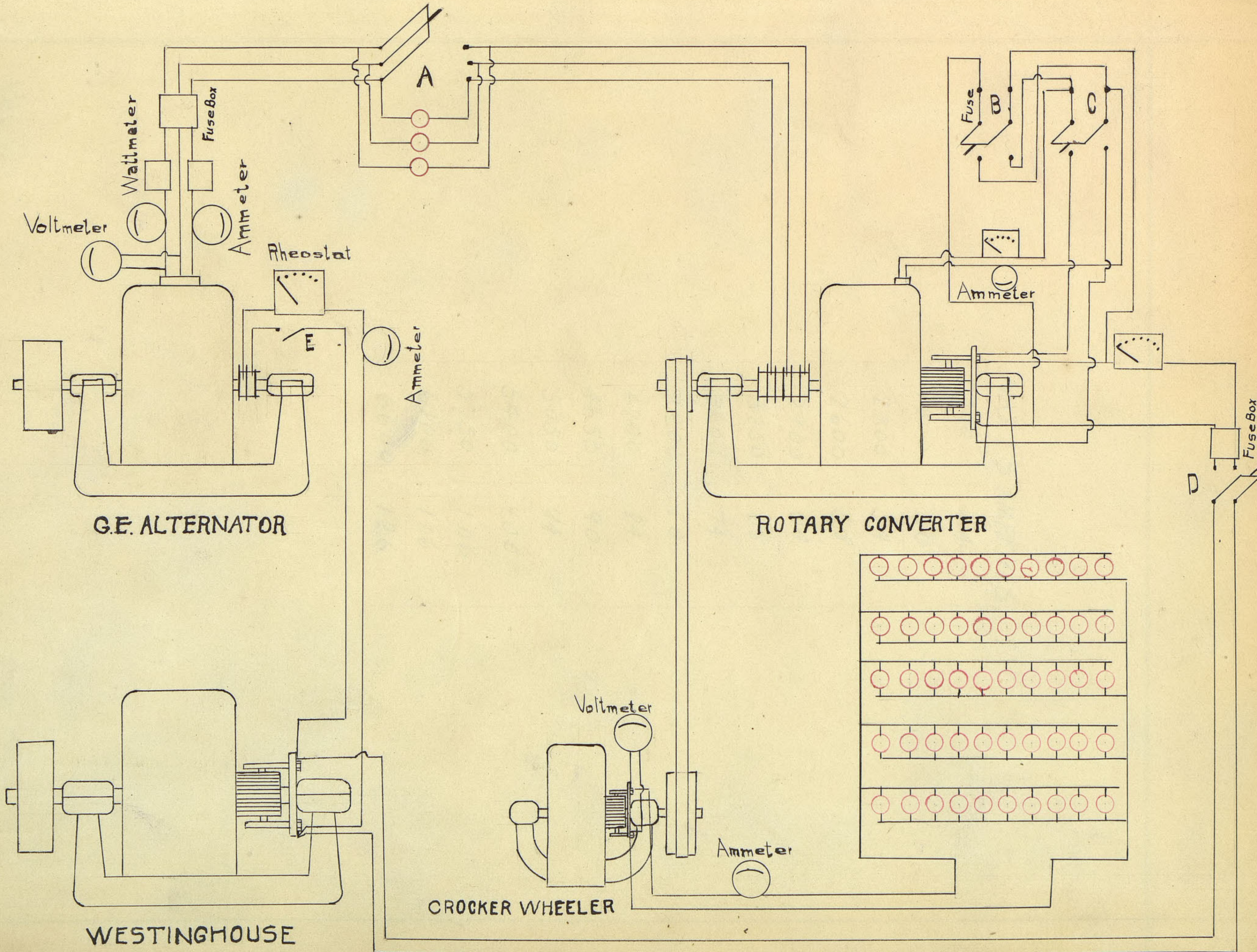
THREE PHASE INDUCTIVE LOAD.

In this experiment the rotary converter was operated as a three phase synchronous motor, and thus working the alternator on an inductive load. The laternator was operated as a three phase delta connected machine and throughout the experiment the voltage and speed were kept constant, the voltage at 68 and the speed at 1120 R. P. M. The rotary converter was at first operated as a shunt motor until it was in synchronism with the alternator, when it was switched directly on to the alternator mains. The method of bringing the rotary converter up to synchronism will be explained with reference to the Figure. The rotary converter was connected directly to the Westinghouse dynamo, and in this circuit was placed a switch, a fuse box and a starting box. When the switch B is closed the fields of the converter are separately excited, and by closing C and opening B it becomes self exciting. The switch D was closed and the converter was started by means of the starting box F. The switch B was closed and the converter was operating as a shunt motor with separate excitation, and was brought up to a speed of 1760 R. P. M. The switch C was now closed and B opened and it now excites itself. In the self exciting field circuit was placed a rheostat G to regulate the current, and an ammeter. The lamp at A would now become bright and then dim, and by regulating the field current in the alternator and converter, the lamp would become bright and then die down and become dark. When the lamps became dark the two machines were in synchronism. Now the switch A was closed and D opened and the rotary converter was operated as a three phase synchromous motor driven by the alternator. The field of the alternator was excited from the Westinghouse machine. The small Crocker Wheeler dynamo was belted to the rotary converter and was connected to a bank of lamps. A load was thrown on the Crocker Wheeler dynamo, thus increasing the load on the rotary converter. The Crocker Wheeler dynamo was started on open circuit and then the load on it was gradually increased to its normal output 36 amperes.

It required 44 amperes to run the two machines when the Crocker Wheeler was not loaded.

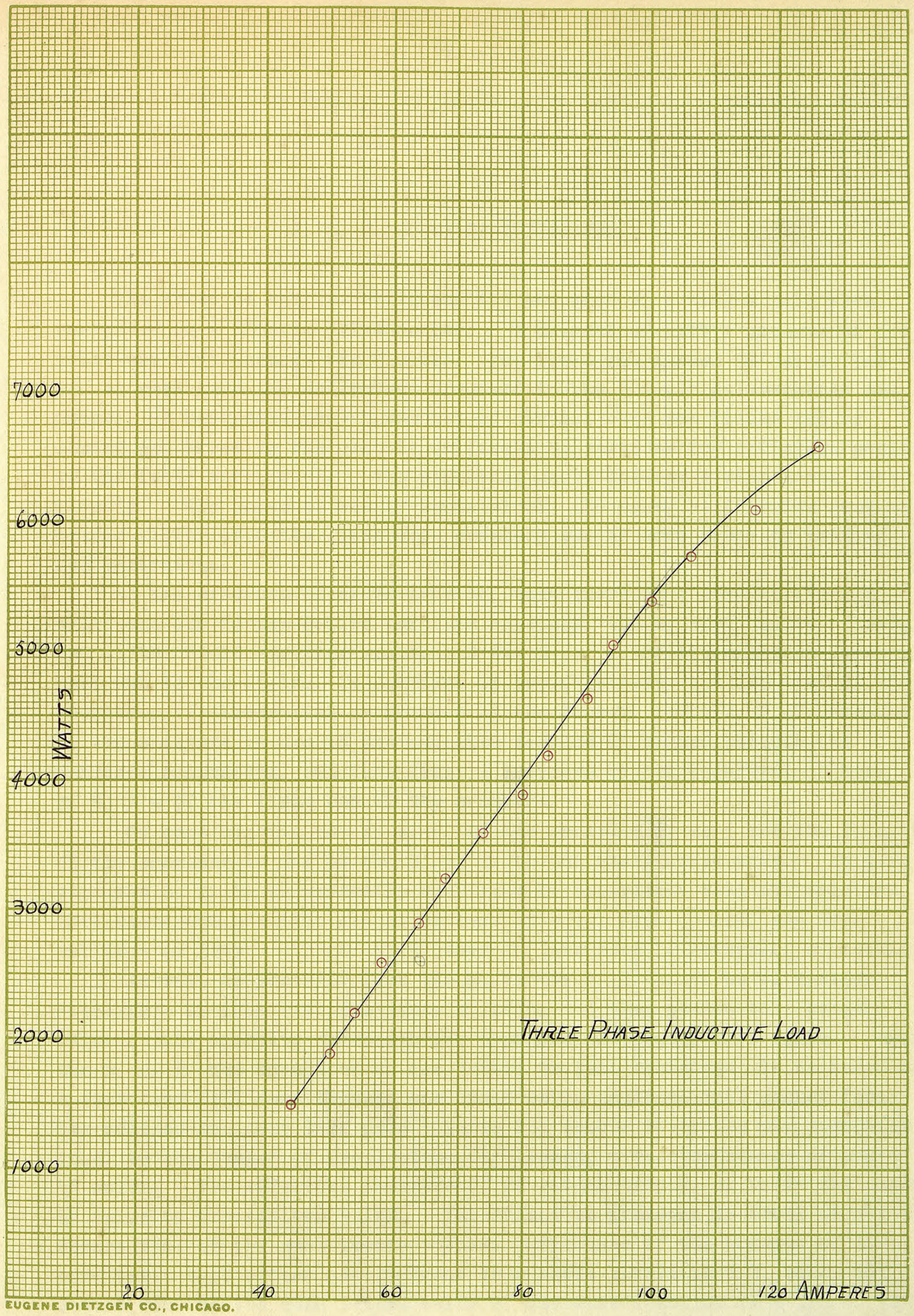
The rotary converter is a four pole machine having six armature coils and six step rings so connected as to give a single or polyphase current. At the other end often is a commutator which either delivers or takes in a direct current.

A synchronous motor for a polyphase system may consist of an ordinary alternator connected across any two of the mains, but preferably it is identical in construction to the polyphase generators and connected to all the lines. They differ from a synchronous motor mainly in the fact that instead of a motor it has a field magnet separately excited by means of a continuous current.



A
Fuse Box
Wattmeter
Ammeter
Voltmeter
Rheostat
E
Ammeter
G.E. ALTERNATOR
Fuse
B
C
Ammeter
Fuse Box
D
ROTARY CONVERTER
Voltmeter
Ammeter
WESTINGHOUSE
CROCKER WHEELER

WATTS	AMPERES
1500	44
1900	50
2200	54
2600	58
2900	64
3250	68
3600	74
3900	80
4200	84
4650	90
5050	94
5400	100
5750	106
6100	116
6600	126



EUGENE DIETZGEN CO., CHICAGO.

E. M. F. CURVE OF ALTERNATOR.

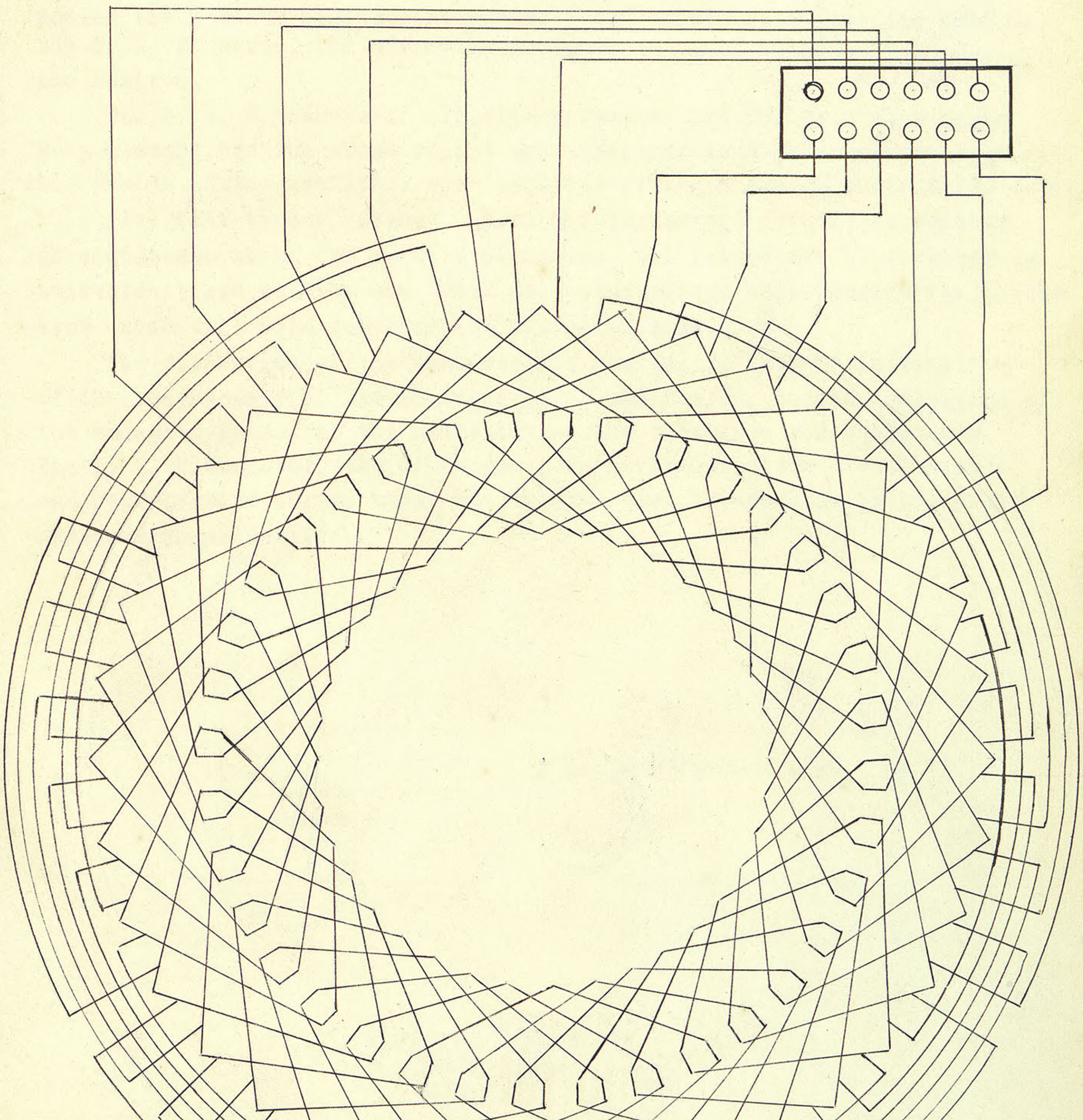
The Armature has six coils and the two ends of a single coil were connected to a ballistic galvanometer. A current of .07775 amperes at 4 v volts was sent through the fields. The field was turned 10° at a time and at each turn the deflection produced in the ballistic galvanometer was noted. A reversing switch was put in circuit with the fields and by making and breaking the circuit different deflections for different positions of the field were noted. The resulting curve follows a sine curve very closely. The curve is nearly symmetrical, the upper half rising just a trifle higher than the lower one, probably due to some error in reading the instrument.

In the armature of an alternator, when there is a current flowing, there are two forces acting upon the armature; the M. M. F. of the fields, due to the field exciting spools and the M. M. F. of the armature current. That due to the fields, is constant or approximately so, while that of the armature, is alternating in respect to the former. The E. M. F. induced in the armature is due to the magnetic flux as it passes through the armature conductors, and thus flux is produced by the resultant of both M. M. F's of the field and of the armature.

On open circuit the M. M. F. of the armature is zero and the E. M. F. of the armature is due to the M. M. F. of the field coils only. In this case the E. M. F. is generally a maximum at the moment when the armature coil faces the position midway between adjacent field coils, and thus encloses no flux. The E. M. F. wave in this case is generally symmetrical.

As will be observed from the curve the E. M. F. of an alternator rises to a maximum then dies away to zero, and then passes to a maximum value in the opposite direction and then passes through zero again. When the E. M. F. has completed an operation as just explained, it is known as a cycle and will pass through one cycle as an armature coil passes from one pole to the next like pole Hence the number of cycles per second is equal to the number of revolutions per second, times the number of pairs of poles. The effective pressure of an alternating E. M. F. is not equal in value to the maximum value. The effective pressure is equal to the square root of the mean square values. The mean of the squares of the sine taken over either one quadrant or a whole circle is 1/2, hence the square root of the mean square value of the same function is $\sqrt{1/2} = .707$.

DIAGRAM OF ARMATURE WINDING

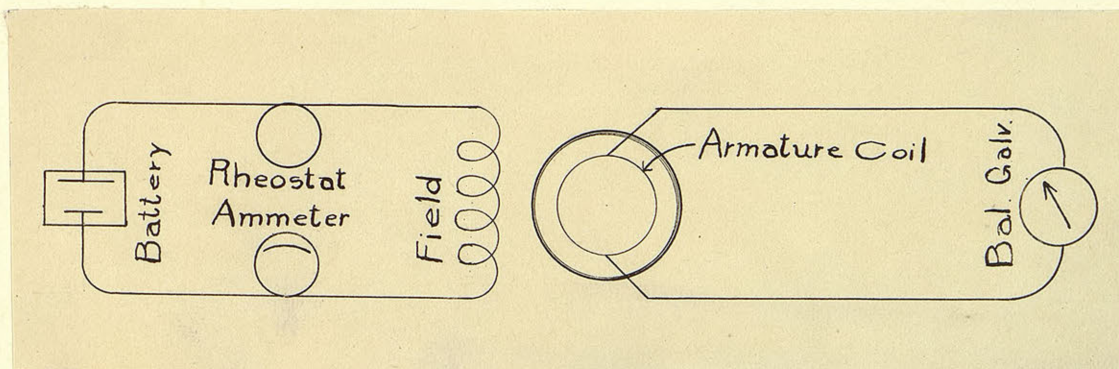


618

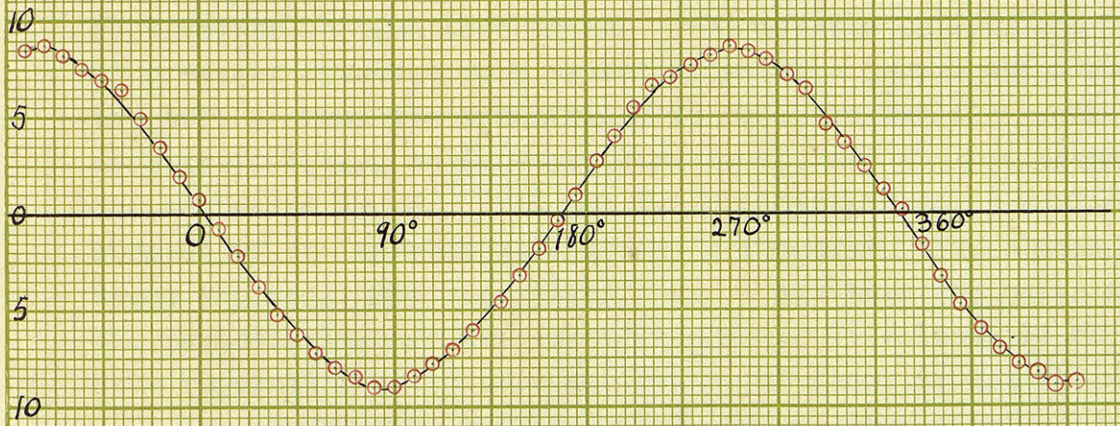
Taking the maximum ordinate at 90° as 1 and considering just one half of the E. M. F. curve, the effective pressure is equal to $\sqrt{\frac{0^2 + 1^2}{2}}$ = .707 of the maximum.

The E. M. F. curves of all alternators do not follow a sine curve very closely, as the shape of the curve depends to a great extent upon the design of the machine., some machines giving a peaked curve while others give flat topped curves. Also the curves are not always regular. In most cases where the wave is distorted, the values can be replaced by equivalent sine values, and hence the calculations made considering a true sine curve will hold good for the distorted curves.

The distortion of the sine wave is due to the lack of uniformity of the arrangement of the armature coils and fields, and the pulsation of the magnetic flux, and the pulsation of the reostance and resistance. The G. E. Alternator, the one under consideration, gives a very smooth and regular sine curve, hence we conclude that the machine is uniformly balanced magnetically.



DEFLECTIONS		
7.9	8.9	8.6
8.5	8.85	8
8.6	8.3	7.25
8.2	7.65	6.6
7.6	7.05	4.85
7.15	6.05	3.7
6.55	4.5	2.5
4.9	3.1	1.2
3.5	1.6	.2
2.1	.3	1.5
.7	+ 1.1	3.3
− 8	2.8	4.6
2.2	4.05	6.05
3.7	5.5	7.
5.2	6.65	7.7
6.4	7.2	8.45
7.2	7.75	9.
7.8	8.45	8.95
8.4	8.8	



E.M.F. Curve

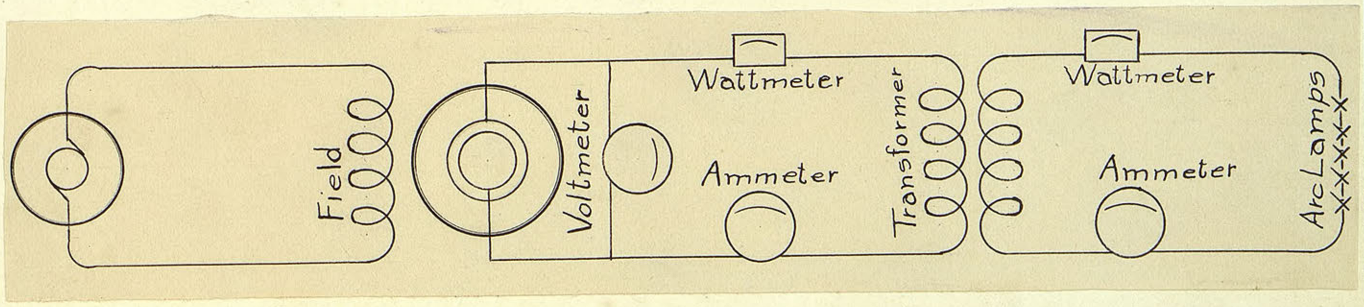
ALTERNATOR ON ARC LAMP LOAD.

The alternator was operated as a single phase machine, at a speed of 1200 R. P. M., and the voltage was kept constant at 120 during the experiment. A constant current transformer was connected across the radius of the alternator. The arc lamps were connected in series to the secondaries of the transformers The lamps were then thrown in circuit, one at a time, until five lamps were in. As the different lamps were thrown in circuit simultaneous readings of the different instruments were taken.

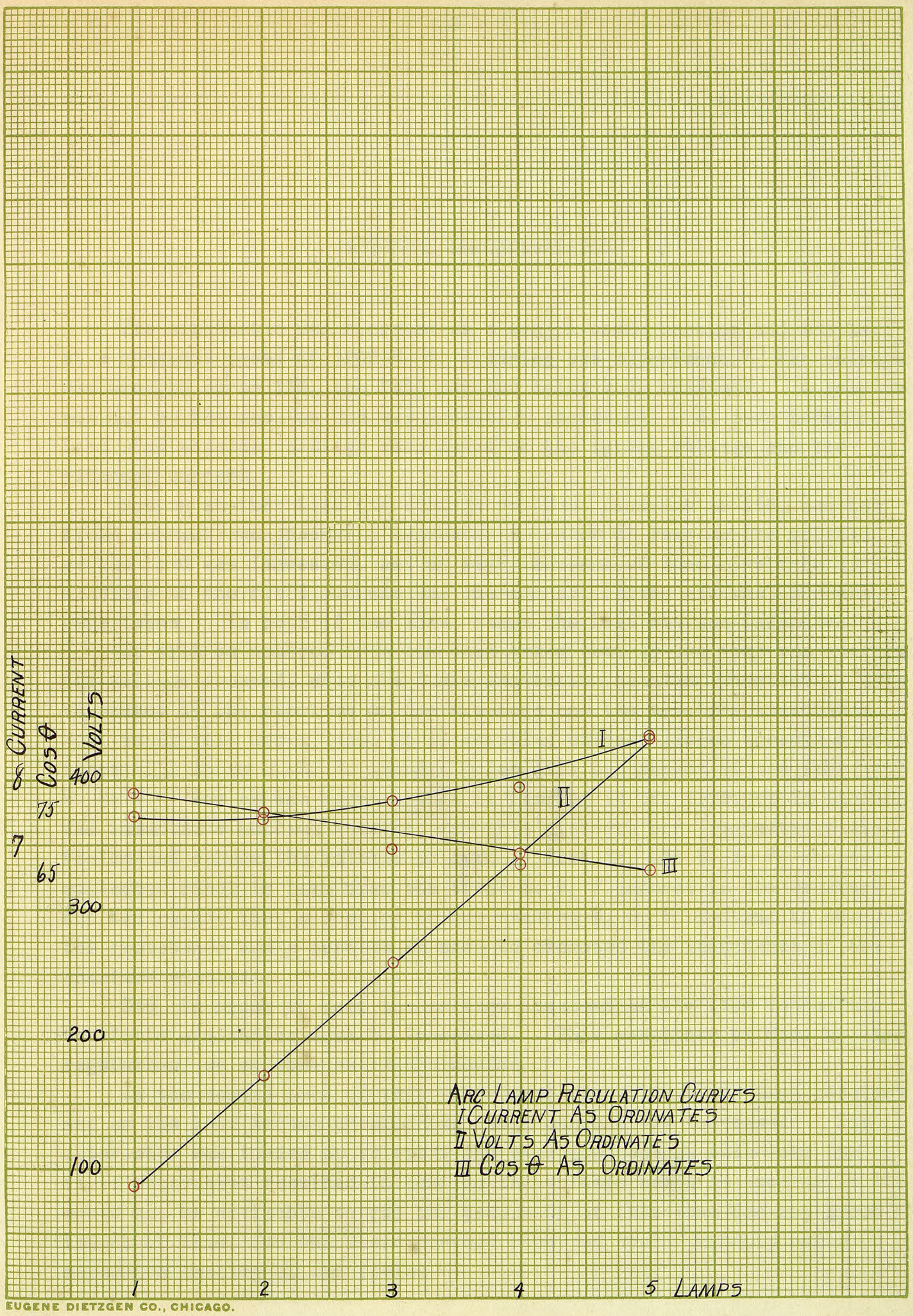
When series arc lamps are to be run on a constant potential alternating current system, it is necessary to use some devise whereby the current in the lamp circuit may be kept constant, irrespective of the number of lamps in operation. One way in which this may be accomplished is by the use of a constant current transformer, a transformer which when supplied with constant potential will deliver a constant current.

The G. E. constant current transformer, the one used in this experiment, consists of two coils, one fixed and one movable. The fixed coil is the primary and the movable coil is the secondary. A laminated iron core passes through both coils. The movable coil is regulated by means of a weight attached to a system of movable levers which raise or lower the coil. When the transformer is fully loaded the movable coil rests upon the primary, or is very close to it, and the transformer is giving its maximum E. M. F.. If the load is diminished by cutting out lamps the current in the movable coil tends to increase, thus causing a repulsion between the coils and separating them. Now when the coils become separated the magnetic leakage between them results in a lowering of the E. M. F., thus regulating it to suit the number of lamps in operation.

The transformer was regulated for one lamp giving 7 1/2 amperes, but the current increased somewhat, for maximum current,



TOTAL CIRCUIT			LAMP CIRCUIT			
CURRENT	VOLTS	WATTS	WATTS	CURRENT	VOLTS	Cos θ
38	120	640	486	7.45	86.5	78
38	120	1080	920	7.4	173	75
39	120	1550	1400	7.7	259.5	69.9
40.5	120	2050	1800	7.9	346	67
45.5	120	3000	2600	8.7	432	66



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EXTERNAL CHARACTERISTIC.

The alternator was operated as a single phase machine and was kept at a constant speed of 1200 R. P. M. during the experiment. The voltage was brought up to 110, the full current being kept constant. A load was now put on the machine and was gradually increased. At each increase of load simultaneous readings were taken of the dynamo voltage and the external curremt.

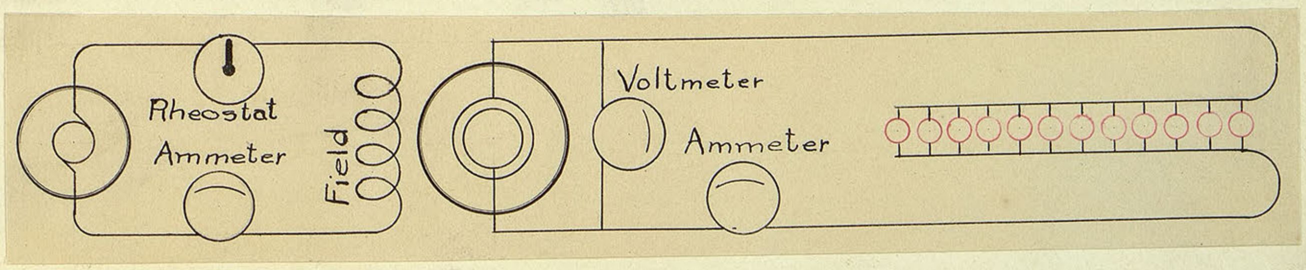
Now on another test the voltage was kept constant at 110, and the field current was gradually increased in order to keep up the voltage as the load was increased, and at each increase of load simultaneous readings of the field current and the curremt in the external circuit were taken. In both of the above cases the load was non-inductive.

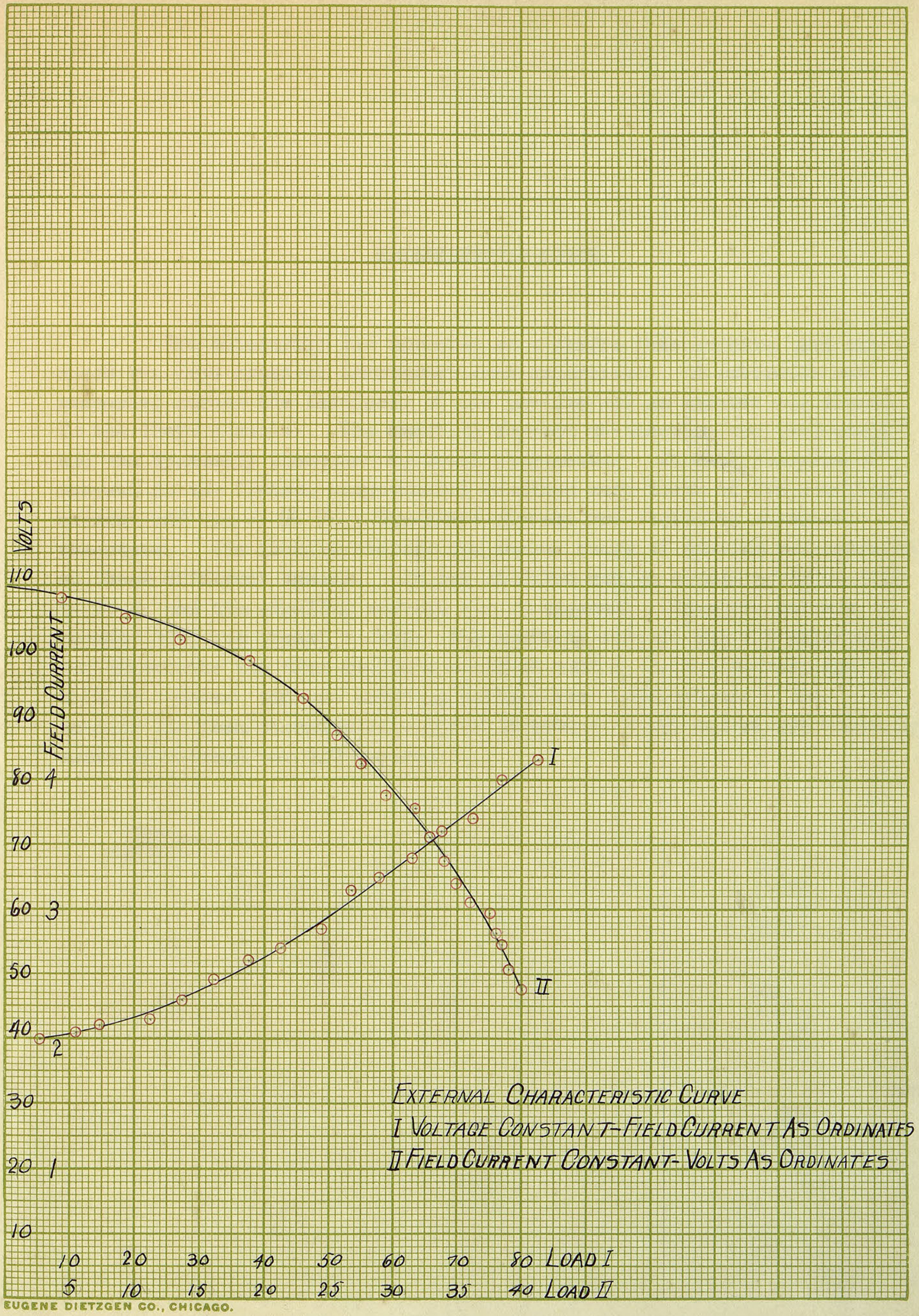
It will be noticed from the data taken that as the load was increased the voltage dropped, when the field excitation remained constant. This is caused by the reaction of the armature and the armature inductance. Now, as is well known, when an alternating current passes through a coil, there will be an E. M. F. induced which will be opposed to the impressed E. M. F. Now as the current that is flowing in the armature is increased, the inductance becomes greater, and this distorts and demagnetizes the fields and causes the voltage to drop. That is, the E. M. F. at the collector rings is less than the total E. M. F. induced in the armature, for the reason that a portion of the induced E. M. F. is used to overcome the resistance and a portion is used to overcome the inductance of the armature windings.

Now, in order to keep the voltage constant as the load increases, the field excitation must be increased. This caneither be done by hand regulation, or by some automatic device.

In the second part of this experiment the voltage was kept constant and as the load became greater the field current was increased. The alternator was loaded up to about 15% over load and at this load the field excitation required to keep up the voltage was 4.15 amperes. It would not be advisable to run the generator at this load for any great length of time, for the field current required would probably cause excessive heating of the fields.

FIELD CURRENT "K"		VOLTS "K"	
VOLTS	LOAD	LOAD	FIELD CUR.
110	0	5.65	2.
108	4.4	11.	2.05
105	9.4	14.9	2.1
101.5	13.6	22.25	2.15
98.5	19.	27.4	2.3
92.4	23	32.5	2.45
87	25.5	37.75	2.6
82.5	27.5	42.5	2.7
77.75	29.5	49	2.85
75.5	31.75	53.5	3.15
71	32.8	58	3.25
67.5	34	63	3.4
64	35	67.5	3.6
61	36	72.5	3.7
59.5	37.5	77.	4.0
56.5	38	82.5	4.15
54.5	38.5		
50.5	39		
47.75	40		

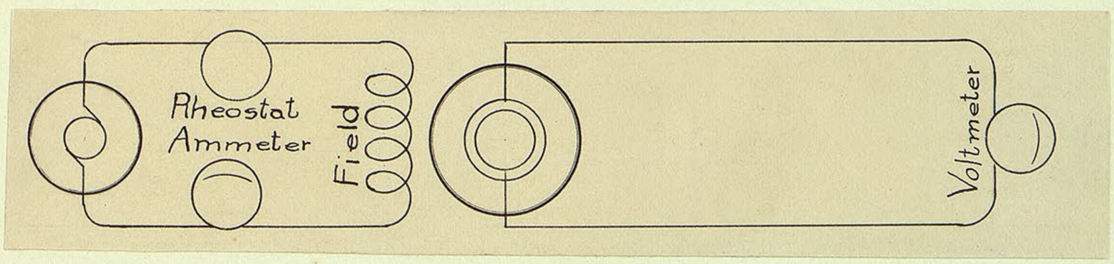




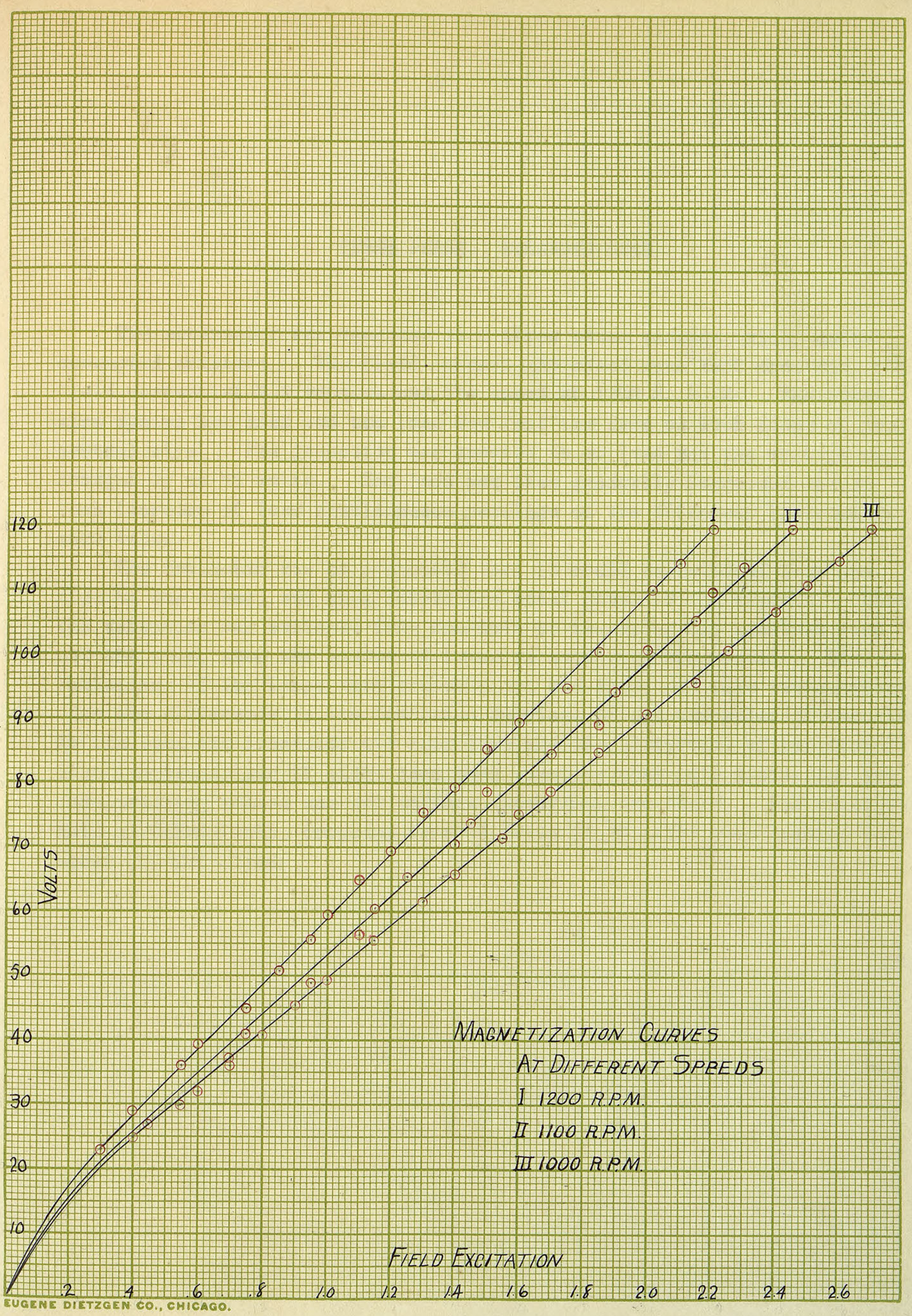
VOLTS
FIELD CURRENT
110
100
90
80 4
70
60 3
50
40 2
30
20 1
10
I
II
EXTERNAL CHARACTERISTIC CURVE
I VOLTAGE CONSTANT - FIELD CURRENT AS ORDINATES
II FIELD CURRENT CONSTANT - VOLTS AS ORDINATES
10 20 30 40 50 60 70 80 LOAD I
5 10 15 20 25 30 35 40 LOAD II

MAGNETIZATION CURVE.

The alternator was operated as a single phse machine, and the speed was kept constant throughout each experiment. A voltmeter was connected across the terminals of the machine and an ammeter was placed in the field circuit. The exciting current at starting was very small and was gradually increased by small increments. At each increase of current in the fields, simyltaneous readings were taken of the exciting current and the E. M. F. The field current was varied by means of rheostats. The machine through its normal range of voltage was operated at three different speeds. It was at first run at normal speed at 1200 R. P. M. and the exciting current was .3 amperes. When the voltage reached 120, its normal voltage, the exciting current was 2.2 amperes. The alternator was then run at a speed of 1100 R. P. M. and when the voltage reached 120 the exciting current was 2.45 amperes. The machine was then operated at a speed of 1000 R. P. M. and at 120 volts the exciting current was 2.7 amperes.



SPEED 1200 R.P.M.		SPEED 1100 R.P.M.		SPEED 1000 R.P.M.	
FIELD CUR.	VOLTS	FIELD CUR.	VOLTS	FIELD CUR.	VOLTS
.3	23	.3	23	.4	25
.4	28	.45	27	.55	30
.55	36	.6	32	.7	36
.6	39.5	.7	37.5	.8	40.75
.75	45	.75	41	.9	45.4
.85	50.75	.95	49	1.0	49.5
.95	55.5	1.1	56.5	1.15	55.5
1.0	59.75	1.15	60.5	1.3	61.75
1.1	65	1.25	65.5	1.4	66
1.2	69.5	1.4	71.5	1.55	71.5
1.3	75.5	1.45	74	1.6	75.5
1.4	79.75	1.5	79	1.7	79
1.5	85.5	1.7	84.9	1.85	85
1.6	89.75	1.85	89.5	2.	91
1.75	95	1.9	94.5	2.15	96
1.85	100.5	2.0	101	2.25	101
2.0	107	2.15	105.5	2.4	107
2.05	100.5	2.2	110	2.5	111
2.1	114.5	2.3	114	2.6	115
2.2	120	2.45	120	2.7	120



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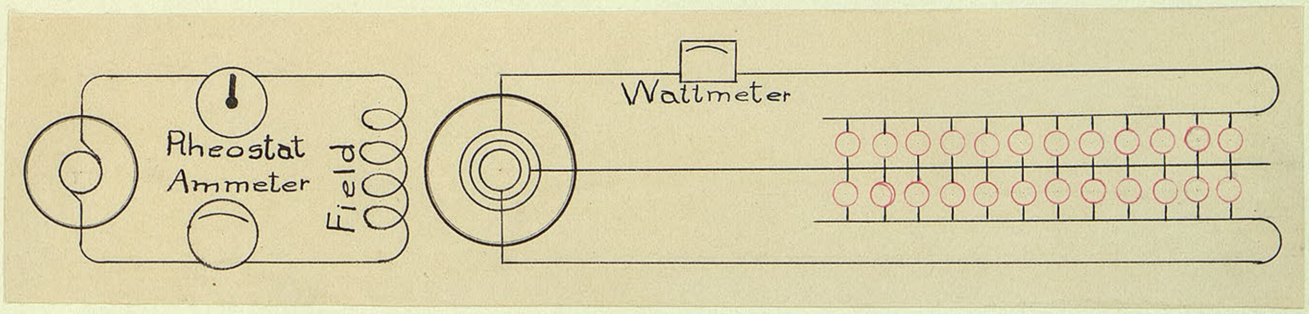
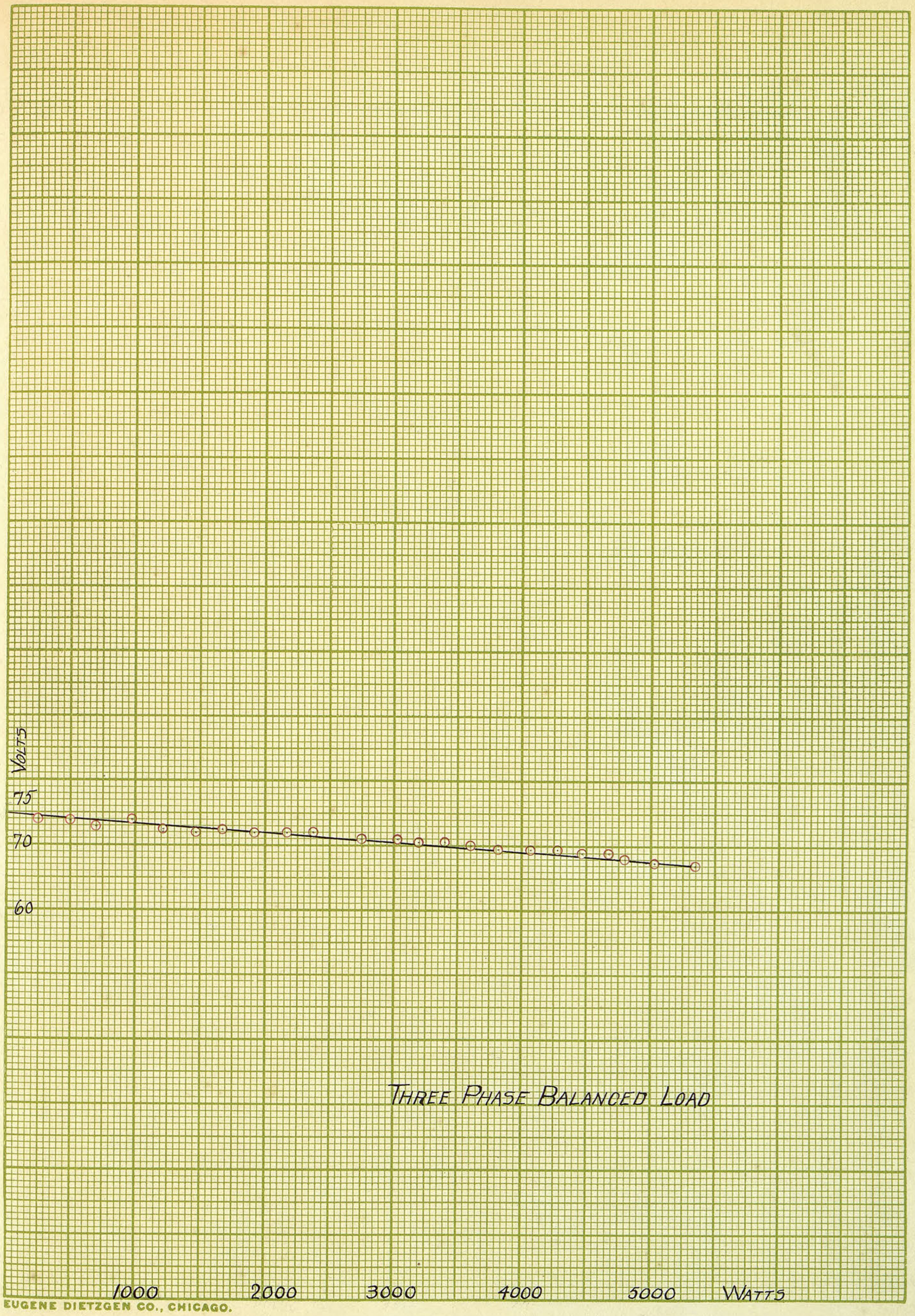
THREE PHASE- BALANCED LOAD.

The alternator was operated as a three phase machine, with delta connected armature. The field current and speed were kept constant, the field current at 2.8 amperes and the speed at 1200 R. P. M. The three wire system was used and the load was kept the same on both sides of the neutral wire. The generator was started at no load and the voltage was brought up to 75 volts. The laod was then gradually increased and at each increase of load simultaneous readings of the different instruments were taken.

The wattmeter was so connected that it could be switched from one side to the other, and thus obtain the total power in the circuit. When the wattmeter was switched from one main to the other the readings were not the same, when the number of lamps on each side were equal. The resistance of the lamps were probably not the same, and this would account for the difference in the indicated readings on the two sides of the line. As the load was increased the reactions and the distortion of the fields also increased, and it might have been possible that this distorting and demagnetizing action was not uniform throughout the field. The voltage held up fairly well, dropping from 75 volts to 67 volts when working on about 35% full load.



VOLTS	WATTS
75	0
74	250
74	508
73	740
74	980
72.5	1215
72	1470
72.5	1685
72	1920
72	2160
72	2380
71	2750
71	3030
70.5	3200
70.5	3400
70	3600
69.5	3825
69.5	4070
69.5	4270
69	4475
69	4680
68	4840
67.5	5035
67	5350



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