

A TEST AND ANALYSIS OF THE  
BURKE  
SYNCHRONOUS MOTOR-GENERATOR SET  
LOCATED IN THE ALTERNATING  
CURRENT LABORATORY OF  
MICHIGAN STATE COLLEGE

THESIS FOR THE DEGREE OF B. S.

A. K. Walton      E. W. Warnock  
1930



THESIS

Dynamos



Electrical engineering



A TEST AND ANALYSIS  
OF THE  
BURKE SYNCHRONOUS MOTOR-GENERATOR SET  
LOCATED IN THE  
ALTERNATING CURRENT LABORATORY  
OF  
MICHIGAN STATE COLLEGE

A THESIS  
SUBMITTED TO THE FACULTY  
OF  
MICHIGAN STATE COLLEGE  
BY  
A.K. WALTON                      E.W. WARNOCK

CANDIDATES FOR DEGREE OF  
BACHELOR OF SCIENCE

JUNE, 1930



**THESIS**

## INTRODUCTION

The parallel operation of alternators has been of great practical and theoretical interest for about forty years. To enable the electrical engineering students at Michigan State College to more thoroly study this subject, a special motor-generator set was lately purchased from the Burke Electric Company of Erie, Pa. While this set has been used in various ways no complete test has been made of it. The authors of this thesis have undertaken to make such a test and some of the fruits of their labors are presented in the following pages.

Preliminary to the laboratory work a survey was made of the theory and practice of the operation of alternators in parallel. All data was then secured with great care, and it is believed that the results are reliable.

We extend our thanks to the Staff of the Electrical Engineering Department and to others who helped us in our undertaking.



## CONTENTS

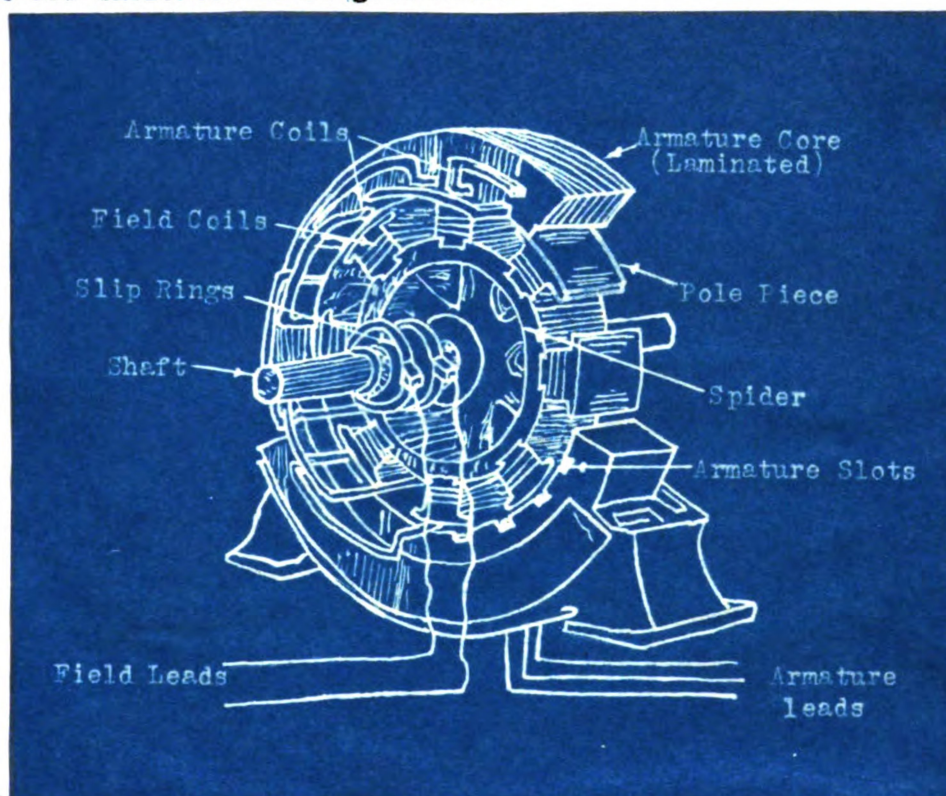
|                                                 |          |
|-------------------------------------------------|----------|
| CHAPT. I.                                       | Page 1.  |
| Theory of alternating current machinery.        |          |
| CHAPT. II.                                      | Page 9.  |
| Theoretical discussion of synchronous machines. |          |
| CHAPT. III.                                     | Page 20. |
| Description and pictures of the Burke M-G Set.  |          |
| CHAPT. IV.                                      | Page 26. |
| Methods of procedure.                           |          |
| CHAPT. V.                                       | Page 38. |
| Performance of the Burke Set.                   |          |
| CHAPT. VI.                                      | Page 61. |
| Parallel operation.                             |          |
| CHAPT. VII.                                     | Page 71. |
| Regulation.                                     |          |
| CHAPT. VIII.                                    | Page 80. |
| Wave forms.                                     |          |
| Test data.                                      | Page 85. |

---

## CHAPTER 1.

### **ALTERNATORS:**

In general it may be said that an alternator is an electric generator for producing alternating current or currents by a relative motion of conductors and a magnetic field. More particularly, a synchronous alternator is one in which the magnetic field is excited by direct current. This is the most general type of alternator in use at the present time and the essential parts of such a synchronous machine are indicated in Diagram No.1.



**Diagram No.1.- Essential Parts of Synchronous Alternator.**

The stationary armature core consists of soft steel laminations held together in a cast iron frame. These laminations are slotted, and the armature coils placed in these slots are held there by suitable wedges. In low speed machines, the revolving spider is made of cast iron, and in high speed machines, of steel of greater tensile strength.



Each pole piece is fastened to this spider, and in turn is provided with a field coil. The field, ~~excited~~<sup>x</sup> with direct current, is so wound and connected, that the opposite magnetic polarity is produced in adjacent pole pieces. The direct current is conducted to the field coils by two slip rings as indicated.

The alternator shown in diagram No.1. is an eight pole three phase machine; it has four armature coils per phase, or one coil side per pole. A schematic sketch of the armature winding and field poles is shown in diagram No.2. partly developed for purposes of explanation.

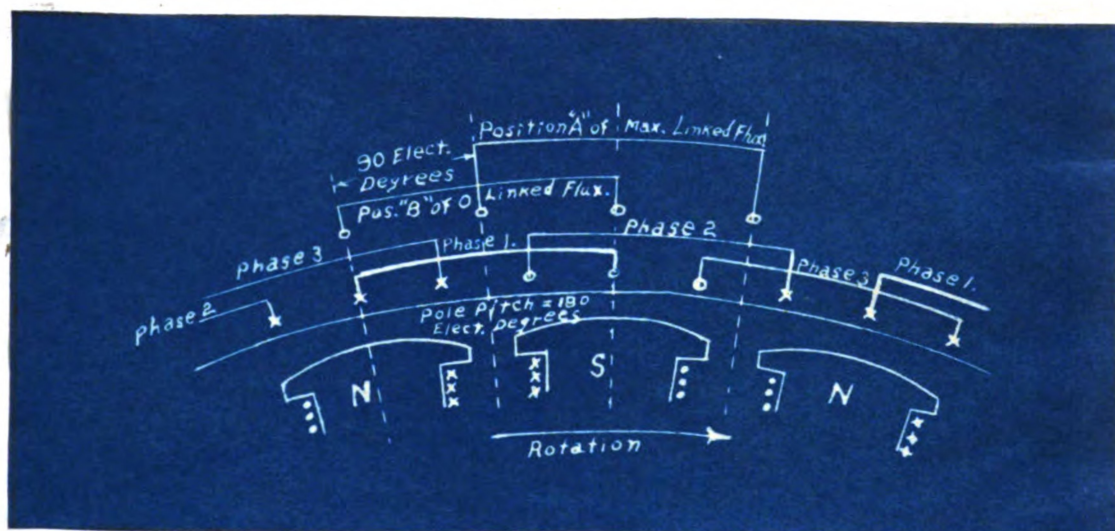


Diagram No.2.- Armature Winding and Field Poles of Alternator.

The armature conductors which are electrically connected in series, belong to phase one, and are under the centers of the poles at the instant shown. Hence, the voltages induced in these conductors are a maximum, because they are cut by the most dense portion of the magnetic field. The respective directions of the induced voltages together with those of the exciting current are shown conventionally with crosses indicating current flowing toward the page, and a dot accordingly designating the opposite direction. As the poles move on in the direction of rotation, the voltages induced in this phase, decrease to zero and then increase in the opposite direction, to



reach an opposing maximum after the poles have moved one complete pole pitch. Thus a complete alternation occurs in the interval of time which elapses as the pole moves one pole pitch.

The coils of phase two are the same as those of phase one, but are displaced from them two thirds of a pole pitch measured along the periphery of the armature structure, in the direction of the rotation of the poles. A pole pitch equals one hundred eighty electrical degrees, therefore, the second phase is displaced one hundred twenty electrical degrees in the direction of field rotation, from the first. Since phase two is the same as phase one, the same voltage is induced in it as was induced in phase one, one third of a cycle later. Thus the wave or the vector of the voltage induced in phase two lags behind that of phase one by one hundred twenty electrical degrees. Correspondingly the coils of phase three are so arranged that the voltage induced in them leads that of phase one by one hundred twenty electrical degrees.

The arrangement indicated above is called a three phase winding and the voltage resulting from each of the three phases may be used either singly or in combination. This type of machine with three phases is the commonest now in use in power and lighting systems. Likewise machines of the type shown in diagram No. 1, are also most common. The reason for the use of this type is that the armature is from a comparative standpoint, easily wound for fairly high voltages and the stationary structure is more easily insulated and more easily supervised in operation.

An alternator is not only capable of converting mechanical energy into electrical energy, but it is likewise capable of converting an electrical energy input into mechanical energy at the shaft thus operating as a motor. Thus utilized the machine is called a synchronous motor. The material to follow, concerns synchronous machines in general and their operation both as motors and as generators.

If a machine similar to the one shown in diagram No.1. is driven by a steam turbine, a water turbine, or some other suitable device, and at the same time if the field is excited by a suitable direct current source, an alternating voltage will appear at the terminals of each phase. The frequency of this voltage is obviously a function of the speed of the driving machine, hence it is necessary in order that a standard frequency of generation be maintained, that the drivers be held almost exactly at the required speed by suitable governing devices.

The relationship between the number of poles,  $p$ , of an alternator, the speed or rotation,  $n$ , in r.p.m. and the frequency,  $f$ , of the induced voltage in cycles per second, is as follows: At  $f$  cycles per second, the induced voltage has a frequency of  $60f$  or  $120$  alternations per minute, because each cycle corresponds to two alternations. During one revolution of the machine,  $p$  poles pass under each group of conductors thus inducing  $p$  alternations. Consequently the number of alternations per minute is  $pn$ , and  $120 f$  equals  $pn$ . Likewise with a fixed source frequency, the synchronous speed of a machine operating as a motor equals  $120f/p$ .

In order to understand clearly the mode of operation of a synchronous machine it is essential to be familiar with the production and properties of rotating m.m.f.s. Hence a discussion of the principles involved in this consideration follows.

#### REVOLVING FIELDS:

A gliding magnetic field produced by means of three phase currents is shown in diagram No.3. The machine considered is of the type of diagram No.1. is connected to a source of three phase A.C. The rotor for the purpose of explanation is supposed to be removed, but the rotor core actually serves as a path for the lines of force. The cylindrical

inner surface of the stator is shown reduced to the plane S-T. For the sake of simplicity and clearness, only one coil per pole per phase is indicated in the sketch. Actually the winding is distributed over a comparatively large number of slots per pole. The flux density in space due to current in one phase only may be assumed to be nearly sinusoidal at any and every instant. This is indicated by the waves at X-X, R-R, and V-V.

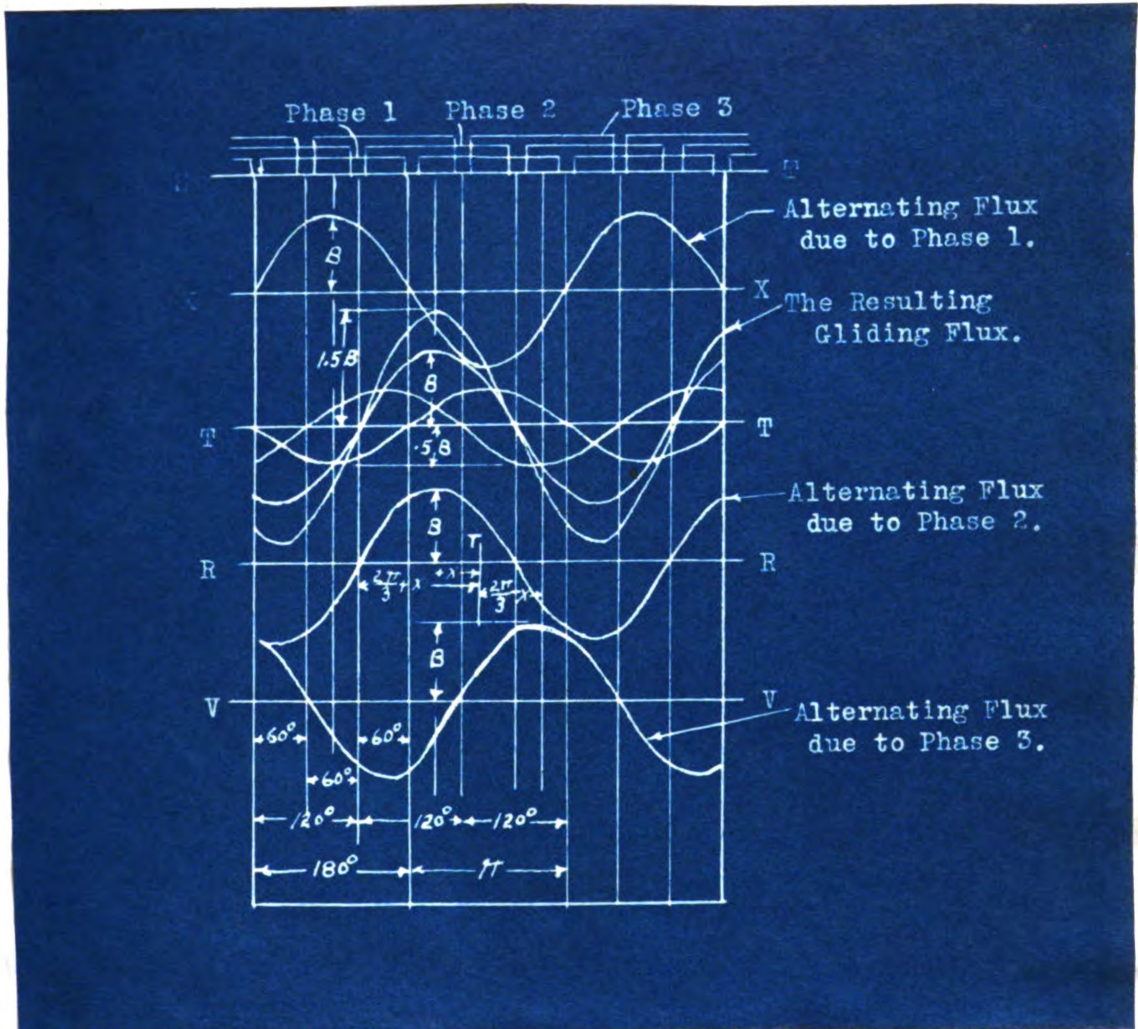


Diagram No. 3.-Gliding Magnetic Field by three phase currents.

As the stator currents vary from instant to instant, the corresponding flux densities also change accordingly, but each flux remains distributed sinusoidally in space. Each of the three waves retain their positions, but during a cycle of alternating current, all of the ordinates decrease, pass thru zero, reach an opposite maximum, and return to



the original values.

We shall suppose that the current in phase two leads that in phase three and lags behind that of phase one; also that the current in phase two reaches its positive maximum when  $t$  equals zero and that the windings two and three are displaced one hundred twenty electrical degrees to the right of winding one. The expressions for the current are.

$$i_1 \text{ equals } I (\cos \omega t \text{ plus } 2\pi/3)$$

$$i_2 \text{ equals } I (\cos \omega t \text{ plus } 0)$$

$$i_3 \text{ equals } I (\cos \omega t - 2\pi/3)$$

where  $I$  is the amplitude of each current wave. The curves at  $X$ ,  $R$ , and  $V$  are drawn for the instants when the corresponding currents reach their maximum.

Consider the instant when the current in phase two is a maximum that is to say, the instant when  $t$  equals zero. The component distributions of flux density at this instant are plotted on the axis  $T$ . The distribution due to phase two is the same as the curve at  $R$ . For phase one,  $i_1$  equals  $I \cos 2\pi/3$  equals  $-.5 I$ . Therefore the curve 1-1 is shown as of amplitude  $.5 B$  and reversed with respect to the curve at  $X$ . Similarly  $i_3$  equals  $I \cos (-2\pi/3)$  equals  $-.5I$ , and the corresponding  $B$  curve is shown accordingly. By adding these three curves point by point, the resultant flux density distribution  $r-r$ , is obtained.

By assuming different values of  $t$ , and constructing the according sine waves, of flux distribution, the resultant distribution may be determined at any instant. It will be found that its amplitude is equal to  $1.5 B$  at all times, and that it glides synchronously from the leading to the lagging phase always having its maximum over the phase in which the current at that instant is a maximum. However, such a point-by-point addition is exceedingly tedious, and the same

result may be obtained analytically as follows:

At a certain point T, along the air gap of diagram No.3, let the flux density resulting from the current in phase two be  $B \cos \omega t \cos x$ . The angle  $x$  is measured from the point V at which the flux in phase two reaches its maximum in space. The magnetic field at the point T due to the other two phases is obtained by changing the time angle  $\omega t$ , and the space angle  $x$ , by the amounts plus or minus  $2\pi/3$ . Thus the resultant magnetic flux T, due to all three phases is:-

$$B(x,t) \text{ equals } (B \cos \omega t \cos x) \text{ plus } (B \cos (\omega t \text{ plus } 2\pi/3) \cos (x \text{ plus } 2\pi/3)) \text{ plus } B \cos (\omega t - 2\pi/3) \cos (x - 2\pi/3).$$

In the above expression, each cosine of the sum or of the difference of two angles may be replaced by its expansion according to the familiar trigonometric formula:

$$\cos(x \text{ plus or minus } y) \text{ equals } \cos x \cos y \text{ minus or plus } \sin x \sin y$$

After multiplication and reduction we get:

$$B(x,t) \text{ equals } 1.5 B (\cos \omega t \cos x \text{ plus } \sin \omega t \sin x)$$

which reduces finally to

$$B(x,t) \text{ equals } 1.5 B \cos (\omega t - x)$$

It may be seen, that a sinusoidal wave of amplitude B synchronously gliding from left to right satisfies the required conditions of the equation.

This means that the instantaneous flux density will be found to be constant at any point and moving to the right at the velocity  $w$ . Since  $w$  equals  $2\pi f$ , which value is the electric angular velocity of the exciting currents, all points for which flux density remains constant, move along the air gap at synchronous velocity.

Thus with the stator of a synchronous machine connected as indicated in the above general discussion, to a multiphase source, a rotating magnetic field is produced traveling in a sense, about the

periphery of the inside of the stator. Now the rotor is excited with direct current as already indicated, and the same is designed so that when it is rotating at the same speed as the revolving field, each pole, of fixed polarity, will be under a stator magnetic pole of exactly opposite polarity. Thus since unlike magnetic poles attract each other, under the above conditions, the stator with its rotating field tends to drag the rotor around with ~~the same~~ <sup>it</sup> at synchronous speed as determined by the rotation of the field. The machine resists any effort tending to pull the rotor out of step with a counter torque, and thus we have typical motor action. The greater the load, the greater will be the corresponding torque, and the greater the current supplied to the stator.

From the above discussion it may be seen, the synchronous motor is thus a constant speed machine the speed of which is fixed by the standard frequency of the source and the number of poles of the machine. This particular feature makes such machines desirable for constant speed service, though the lack of starting torque frequently prohibits their use for any traction service.

When a synchronous machine is being used as a motor, it is obviously necessary to bring the rotor up to the speed of the rotating field before any power can be developed when the the rotating m.m.f. and armature m.m.f. are locked together, into synchronism. Several methods of accomplishing this result are in common use, though the commonest method, because of its simplicity, is to provide the rotor with a squirrel cage winding so that the machine may be started as an induction motor. The methods of bringing synchronous motors up to speed are discussed in greater detail at a later point.



CHAPTER 2.**THEORETICAL DISCUSSION OF SYNCHRONOUS MACHINES:**

For the sake of explanation consider two identical alternators connected to the same bus bar as indicated in diagram No.4. From the bus between the machines; with the machines M and G running in synchronism with equal field excitation, the voltages are vectorially 180 degrees apart, and there is consequently no current flowing in the series circuit. This condition is indicated vectorially in diagram

No.5.

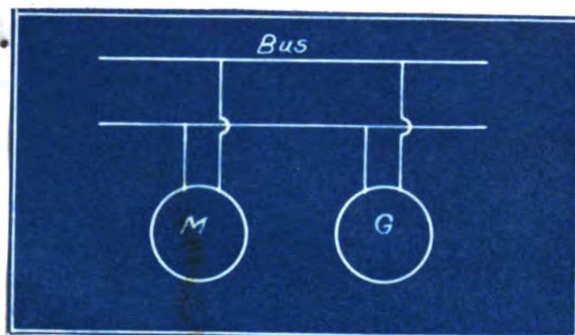


Diagram No.4.



Diagram No.5.

If now the power supply of the machine M is reduced, the voltage vector  $E_M$  lags behind the first position relative to the voltage  $E_G$  by an angle as shown in diagram No.6. The voltage  $E_g$ , the vector sum of  $E$  and  $E_M$  is then effective in producing a circulating current  $I_M$  between the two machines thru their impedances. Thus power is transmitted from G to M. If the supply of external power is completely removed from M, the same will continue to run being driven as a motor, and receiving the necessary power from the generator G. When in addition, the machine M is loaded mechanically, more power will be transmitted from G to M and more current will flow in the series circuit between the machines. The application of the mechanical load results in a difference in phase position of  $E_M$  in respect to  $E_G$  resulting in an increase of  $E_g$  which causes the increase in current already noted. Despite the change in phase angle, the machines will continue to operate in synchronism, provided of course, the pull out torque of the motor is not exceeded.

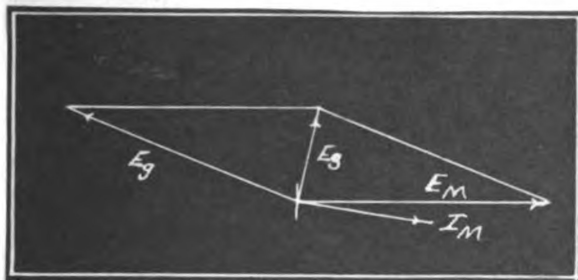


Diagram No. 6.

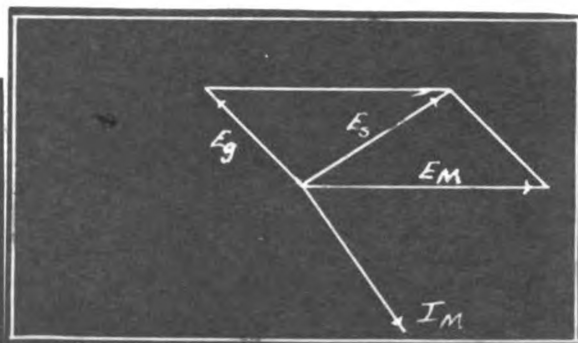


Diagram No. 7.

All of the above discussion is based on identical excitation of identical machines. Hence,  $E_m$ , the induced motor voltage, and  $E_g$ , the induced generator voltage ~~were~~ <sup>are</sup> in each instance equal in magnitude. If, however, the excitation of either the motor or the generator is changed, the phase angle of the voltage for a given motor load will also be changed. Diagram No. 7. shows a decreased excitation for the generator with the same excitation for the motor. The generator thus delivers a leading current to the line, while the motor takes a lagging current  $I_m$  as shown. Accordingly for changes of field excitation of the motor and for different phase positions of the motor voltage  $E_m$  in respect to the generator voltage  $E_g$ . The resultant voltage  $E_s$  changes in both magnitude and in phase position. Likewise the current which results from  $E_s$  changes in both magnitude and phase position under the above conditions.

#### SYNCHRONIZING CURRENT:

When two alternators are operating in parallel, the vector sum of their induced voltages results in a voltage which produces a synchronizing current which lags behind  $E_s$ , the vector sum, by an angle depending upon the total resistance and reactance of the series circuit, therefore, including the total resistance and reactance of the two armatures. Thus one machine supplies power to the series circuit, while the other receives power from it. The

machine which gives off power tends to drive the machine receiving power even though they may be both operating from the external standpoint as alternators on a common load. This flow of synchronizing current results in a tendency to retard the machine supplying the power coupled with a tendency to accelerate the one receiving the same. Thus the synchronizing current tends to keep the two machines in synchronism.

When there is synchronizing current flowing in the series circuit between two machines, the difference between the power supplied by the one machine and that received by the other, is equal to the power lost in the series circuit.

If several alternators are connected to one set of bus-bars the synchronizing current as already ~~suggested~~ <sup>indicated</sup>, tends to keep them in step. If the prime mover of any one machine tends to decrease its speed, the machine lags behind, and receives power by the synchronizing current which accelerates the lagging alternator thus tending to keep it in synchronism. If on the other hand, the prime mover of any one machine tends to increase its speed, a resultant voltage is generated causing a synchronizing current to flow. The machine that leads, delivers power, is thus retarded, and thereby is held in synchronism.

#### METHODS OF SYNCHRONIZING:

Two direct current machines may be connected in parallel as seen as their voltages are approximately equal provided the proper polarity is observed in connecting them together. However, before two alternators can be switched in parallel, three conditions must be fulfilled: their terminal voltages must be:

(1) of the same magnitude,

- (2) of the same frequency,
- (3) in phase with each other.

Unless all of these conditions are met, there will be a circulating current between the two machines when they are connected together.

When the terminal voltages of the two alternators are equal and opposite at all instants, the above conditions will be met. The process of adjusting a machine to be connected to a bus bar or to another machine, so that the above conditions will be met is known as synchronising the machine in question. Literally the term synchronising means "bringing into step".

Let us consider what would happen if two alternators were connected to the same bus bars without having all of the above stated conditions fulfilled.

(1) If the two machines are so excited as to give different voltages the other two conditions being fulfilled, a reactive current will circulate between the machines, leading in the machine excited lower, and lagging in the machine excited higher. This results in a strengthening of the field at the first machine, and a weakening of that at the second, the resultant voltage at the bus will be somewhere between the voltages of the two machines. The set may still work satisfactorily providing the reactive current is not too heavy. However, such a circulating current does not help the operation, and results in an unnecessary  $I^2 R$  loss in the armatures of the two machines. Should this current become sufficiently large, it may cause a dangerous temperature rise in the armature windings, or open a circuit breaker even though the external load is not excessive.

(2) If the two machines are not in phase with each other, even though



they are of the same frequency and magnitude, an energy current will circulate between them. This current tends to bring the two machines into step and it may be quite large if the difference in phase is considerable. If the torque due to the synchronising current is large enough to bring the two machines into phase promptly, the surge of current will be of short duration and will not damage the machines. Otherwise the armature windings may be overheated, and the insulation damaged.

(3) If coupling without synchronism is attempted when the two frequencies differ from each other by a few percent, the conditions are approximately the same as described in (2) above. If two sine waves of nearly the same frequency are drawn this condition may easily be shown. It will be found that at some instants the waves are in phase with each other, then they are in phase quadrature, in phase opposition, and after a number of cycles in phase again. Unless the energy component of the circulating current is sufficient to pull the lagging machine into step promptly, and to hold it there, one of the machines may be injured by the inrush of current.

An ordinary oil type circuit breaker is much too slow to protect an alternator against excessive transient currents due to short circuit or to faulty synchronising. Therefore, it is necessary that great care be exercised when synchronising a large machine for the first time.

After the correct speed of an alternator to be synchronised to the bus has been approximately obtained thereby meeting the frequency requirements, the field currents are so adjusted as to give about the same voltage as that of the bus to which <sup>the</sup> machine is to be connected. It only remains to bring the machines into phase with the bus. This is done with the aid of synchronising lamps, or a commercial synchroscope.

## STARTING METHODS:

A motor of which one member (say the stator) is excited with alternating current and the other (the rotor) with direct current, possesses no starting torque because the direction of attraction between the two members is reversed with each alternation of the supply voltage. For the same reason, the machine has no torque for speeds other than synchronous. It is only when poles alternate under a given armature coil at the same rate at which the current in the coil itself changes direction, that a unidirectional tangential effort will result. For this reason a synchronous motor has to be brought up to speed either by means of another machine or by temporarily converting it into an induction motor. The following methods of starting are among these most commonly used.

(1) When a synchronous motor is part of a motor generator set the other machine being a direct current or an induction generator, the generator may sometimes be converted into a motor for starting when the proper source is available. The machine may be thus started and synchronised by means of the motor on the same shaft.

(2) A small induction motor or A.C. commutator motor can be used to bring a synchronous motor up to speed, provided that the latter can be synchronised before the load is applied. When directly connected, the starting induction motor should have a smaller number of poles than the synchronous machine in order to be able to bring the latter up to synchronous speed.

(3) The field structure of the synchronous motor is provided with a squirrel cage winding of sufficient resistance to give the required starting torque. This is at the present time, the most common method of starting synchronous motors.

(4) A cylindrical three phase wound rotor like that of an induction motor of this type is sometimes used. This winding is closed on a resistance for starting and is excited with direct current for operation.

(5) A friction clutch is sometimes interposed between the synchronous motor and its load, to reduce the required starting current and the size of the machine. The stator itself may be used as such a clutch. It is then mounted on auxiliary bearings which are used during the starting period. A brake is provided of such proportions as to bring the stator quickly from synchronous speed to a stop. A high starting torque is thus obtained by virtue of the fact that no torque whatever is exerted on the load until the stator has come up to synchronous speed and full excitation has been applied. Thus the torque which is available as the rotor speeds up and as the stator retards is the maximum load torque, or what is known as "pull out torque".

#### HUNTING:

In a synchronous motor, torque is a function of the relative phase position of the rotor and the impressed stator voltage. Therefore, when the load changes on a synchronous motor, the rotor is required to change its relative phase position without change of speed. It is obvious that these two conditions are not strictly compatible - hence the result is effected in a series of oscillatory changes which may produce serious disturbances in the system. If the load of such a motor is decreased, the torque is in excess of that required for the decreased load hence an acceleration of the armature follows. Then due to this acceleration together with inertia of the comparatively heavy armature, the speed of the same increases to some value slightly in excess of synchronous. Subsequently due to this new change of phase

position, the torque decreases and becomes less than that required by the load and this difference must be adjusted by the subsequent deceleration of the armature. When once more the armature has reached synchronous speed, its phase position is such as to give less torque than required by the load. The deceleration thus continues and the phase position is retraced until the torque again balances the load. However, the armature speed is by this time less than synchronous and again passes the desired position. The change in kinetic energy of the rotating mass thus causes the armature to oscillate around the desired position which is fixed by the torque just sufficient to equal the load.

#### DAMPING:

The results of this oscillatory action may in some instances be cumulative so that each successive oscillation increases in magnitude until the machine finally drops out of synchronism. The commonest and most effecting method of reducing this oscillatory action known as hunting, is the use of amortisseur windings. This winding consists simply of a short circuited grid similar to the squirrel cage winding of an induction motor, placed in slots along the periphery of the field iron core. With such windings, the hunting oscillations of the armature cause a corresponding change of flux interlinkages of the windings thus causing a current to flow in the same, the magnetic effect of which according to the elementary law as stated by Lenz, acts as a brake on the armature oscillations. The squirrel cage winding provided on some machines for starting as an induction motor, effects in addition the purpose of acting as an amortisseur winding. When the machine is running in synchronism no lines of force cut the squirrel cage structure



hence under normal operating conditions the presence of this winding does not affect the operation of the machine. The winding provides a means for gradual adjustment of the motor phase positions for changes of load, and thus tends to eliminate troublesome surging or hunting of the synchronous machine.

#### SYNCHRONOUS CONDENSERS:

Let a polyphase synchronous motor be brought up to speed, synchronized, and placed on the line at no load. If during the process of synchronization, the field current of the machine has been so adjusted that the induced e.m.f. of the motor is approximately equal to the line voltage, the machine takes only a small current necessary to overcome the no load losses. If the field current then be somewhat decreased, the motor adjusts itself to the new conditions by taking a lagging current from the line or delivering a leading component to the line which amounts to the same thing. This reactive current causes an armature m.m.f. which strengthens the field although not quite to the value corresponding to the line voltage. The bus voltage exceeds the motor counter voltage by an amount equal to the reactance drop in the armature. The counter voltage may be thought of as consisting of a voltage induced by the weakened field, and a voltage due to armature reaction. Of course the field m.m.f. and the armature m.m.f. combined into one effective m.m.f. . At no load, and with a machine with salient poles, the field excitation may be reduced almost to zero without the machine's dropping out of step. Some motors may continue to run even without any excitation operating as "reactance machines".

On the other hand, if the excitation is increased above normal the machine will draw a leading current from the line. In this case, the resulting armature reaction reduces the field. The more the machine is overexcited, the larger will be the leading current which it will

draw from the line. This effect is demonstrated in further detail in a later discussion of current loci.

The property of the synchronous motor which enables it to draw either leading or a lagging current from the line at no load, is utilized when it is desired to draw such a current; for example, for voltage regulation, for ~~poor~~ power factor correction etc. To obtain this effect, a synchronous motor is connected across the line at the desired point and is run idle with the proper excitation. The field current may be controlled either by hand or by an automatic regulator for a desired performance. A synchronous machine used at no load for the purpose of regulation is called a "synchronous condenser". A better name is "phase adjuster" since at times the machine may be called upon to draw a lagging instead of a leading current.

#### ARMATURE REACTION

There are three component causes of the difference between no load voltage and voltage under load with the same field current and speed in an alternator. They are, armature resistance, armature leakage reactance, and armature reaction. The latter cause is the one in which we are <sup>now</sup> interested at this point of discussion.

When a current is flowing thru the armature winding it becomes a source of magnetomotive force which is combined with that of the field winding, weakening (or strengthening) and distorting the field flux. The flux having thus been modified, the e.m.f. induced by it in the armature windings is different from that induced by the original flux at no load. The actual effect of the armature reaction is quite complicated, but for practical purposes the magnetomotive force of the armature may be resolved into two components;

(a) Direct armature reaction, whose ampere turns can be directly subtracted (or added to) those of the field winding.

(b) Transverse armature reaction, whose effect in a generator is to shift the field flux against the direction of rotation of the poles, and in a synchronous motor in the direction of rotation of the poles.

The armature reaction is simpler in a polyphase machine than in a single one, because in a polyphase machine the magnetomotive forces of the individual phases are combined into one resultant magnetomotive force which glides along the air gap at the same angular velocity as the field poles. Therefore, the relative position of the field and armature m.m.f.s remains unchanged with the time.

CHAPTER No.3.THE BURKE M-G SET

---

The Burke motor-generator set now installed in the alternating current laboratory of Michigan State College was manufactured by the Burke Electric Company of Erie, Pennsylvania according to approximate specifications furnished by the Michigan State College Electrical Department.

The design of the set was supervised by Mr. Burke, of the Burke Company.

The set consists of three units mounted on a common shaft; a 2200 volt synchronous motor together with two 220-240 volt synchronous generators. The stator structure of one of the 220 volt machines has been so designed that its position in respect to the rotor may be adjusted by means of a hand operated, worm gear drive. Since all of the machines are on the same shaft, it has merely been necessary to arrange the 220 volt armatures in identical positions relative to their respective stators in order that the two machines may at all times satisfy the phase and frequency requirements for parallel operation with the movable stator set, of course, at a fixed zero position.

Thus by shifting the adjustable stator's position numerous parallel operation conditions may be obtained for study using the 2200 volt machine as a prime mover and testing the two 220 volt machines in parallel. The effect of an effort to increase the speed of the prime mover of the one machine may also be effected by merely shifting the phase adjusting device in the proper manner.

Photographic diagram No.8. indicates the general layout of the set showing also its relative location in the laboratory.

The switch board shown in the foreground of Diagram No.8, is provided with circuit terminals of the armatures of both small machines so that meters may be conveniently inserted in these circuits for test purposes. Also an opening in the field circuit of each of the machines is provided for the insertion of field ammeters or additional field resistance units when desired. There are also mounted on the board, field rheostats and switches for the small machines.

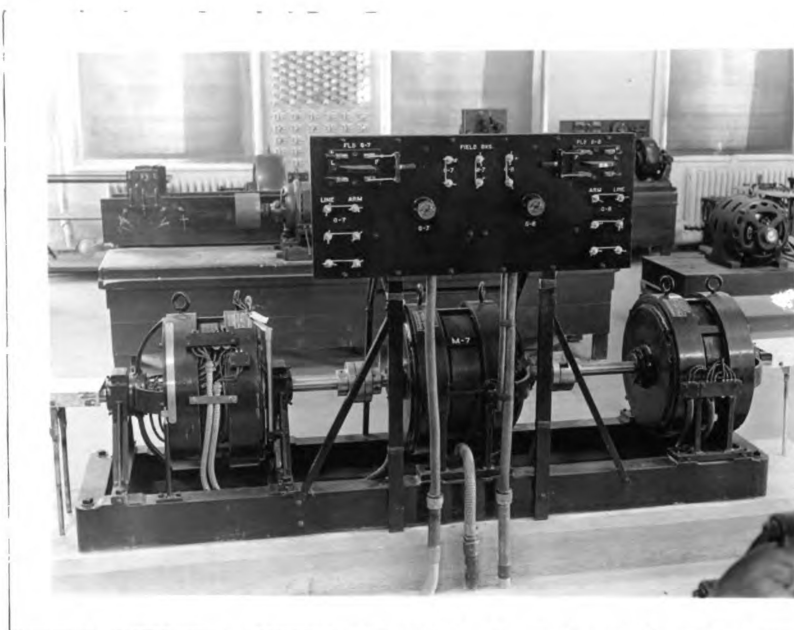


Diagram No.8- Burke Motor-Generator Set

The connections of the 2200 volt machine are permanently installed though there is a fuse box on the opposite side of the set from the one shown in diagram No.8. in which connections may be made for high voltage tests of the large <sup>motor</sup> machine.

Diagram No.9. indicates the General Electric Starting Compasator which is permanently connected to the 2200 volt machine. The field switch may be seen in the upper right corner with the field rheostat



immediately below it. Resistance units are provided thru which the field windings are shorted during the process of starting until the armature has reached synchronous speed. An armature ammeter and line voltmeter are also installed on the main board though they are out of the range of vision included in diagram No.9. Diagram No.10, shows the connection details of the hand starting compensator.

The armature connections of both small machines together with their field terminals lead to the main board where they may be conveniently connected for various experiments.

Diagrams No. 11 and 12 indicate other views of the set. The hand phase rotation adjuster may be seen on the left hand machine in each instance.

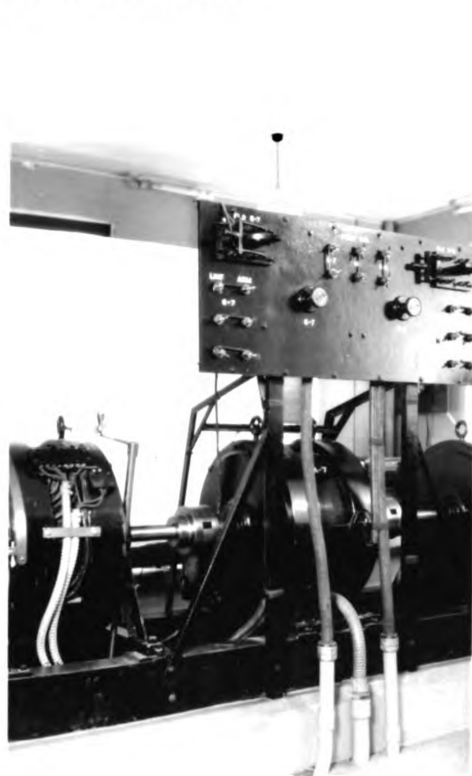


Diagram No.11.



Diagram No.13.

Diagram No.13, is a close-up of the machine with the moveable

stator. The scale indicating electrical degrees phase rotation may be seen in the foreground of the view. The salient pole structure may also be seen.

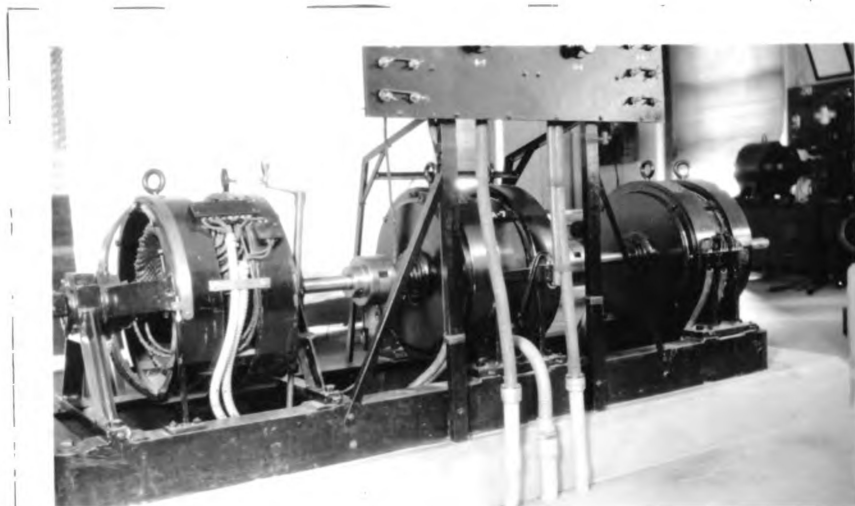


Diagram No.12- Overall view of Burke Set

Each machine is provided with a squirrel cage winding which serves to prevent hunting and also may be used for starting as an induction motor.

The name plate specifications as furnished by the manufacturer are given on the following page, for each machine.



Diagram No.9.

MANUFACTURERS SPECIFICATIONS.G-2

---

**Manufactured by:****Burke Electric Company, Erie Pa.****Serial No. 138264 Type A.C. 85****Alternating Current Generator**

| K.V.A. - | R.P.M. | Volts   | Amps    | Cy | Ph |
|----------|--------|---------|---------|----|----|
| 7.5      | 1800   | 240-220 | 18-19.7 | 60 | 3  |

---

G-7**Serial No. 138686 Type A.C. 85**

| K.V.A. | R.P.M. | Volts   | Amps    | Cy | Ph |
|--------|--------|---------|---------|----|----|
| 7.5    | 1800   | 240-220 | 18-19.7 | 60 | 3  |

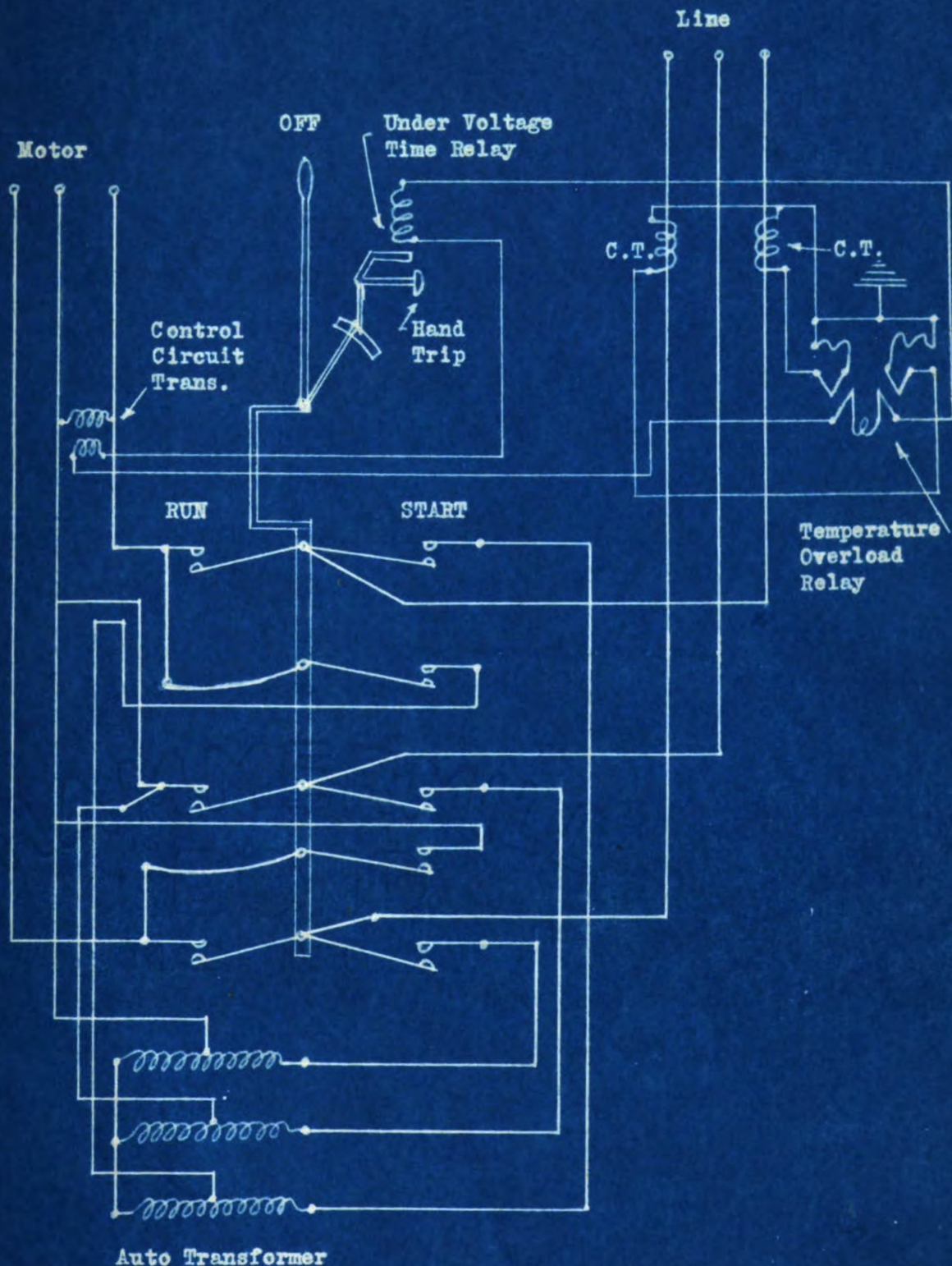
---

H-7**Manufactured by:****Burke Electric Company, Erie Pa.****Serial No. 138609 Type 138609 Rating Continuous T emp 0°-40**Synchronous Motor

| K.V.A. | H.P. | R.P.M. | Volts | Amps | Cy | Ph |
|--------|------|--------|-------|------|----|----|
| 21.0   | 25.0 | 1800   | 2200  | 5.5  | 60 | 3  |

**P.F. 100 Field amps 3.8 Exciter Volts 220.**

---



Connection Diagram of the G.E. CR1034-K17 Hand Starting Compensator

Diagram  
No.10.



CHAPTER NO. 4.METHODS OF PROCEDURE.**NO LOAD LOSSES:**

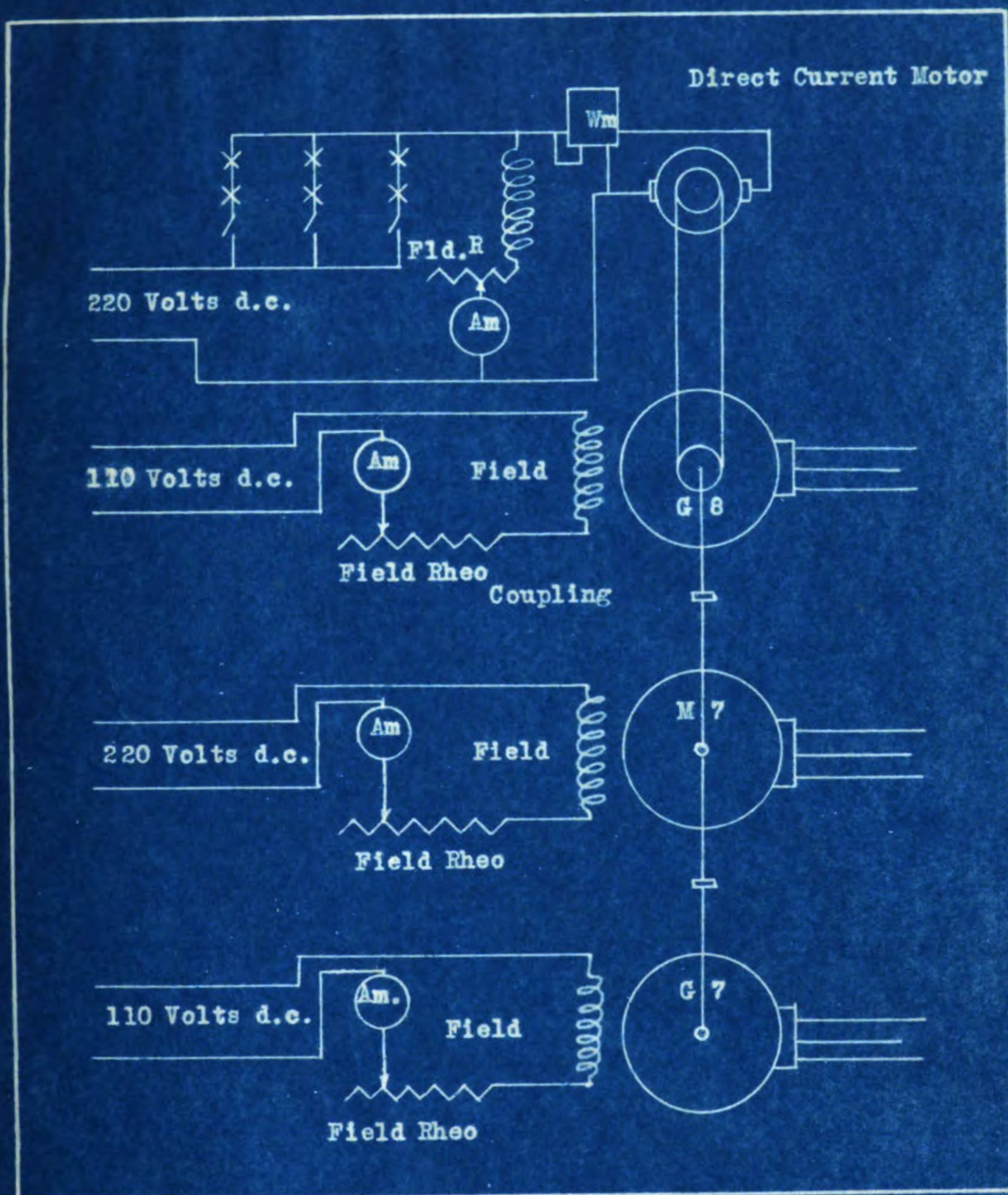
The first test conducted in the laboratory was that of determining all no load losses. For this purpose, a direct current motor was arranged to drive the set as indicated in diagram No.14. Since no accurately calibrated d.c. machine was available, it was first necessary to calibrate this machine by determining its no load losses together with the corresponding field and armature current at the speed of 1800 r.p.m., the synchronous speed of the set. A lamp bank was provided in series with the d.c. armature to conveniently vary the terminal voltage. In the following tests, the armature reaction of the d.c. machine is ignored and iron loss is regarded as substantially constant for a constant field excitation.

After determining the no load losses of the direct current machine, belt friction in the drive was estimated at 1800 r.p.m.

The direct current machine was then started, driving all three alternators. Keeping the field current constant at the no load value already determined, the speed was adjusted to 1800 r.p.m. with no excitation on the alternators. The power input of the d.c. machine was then noted and recorded together with the armature current value.

Then the field of M-7 was excited from the d.c. source. The direct current machine's power input and armature current values were then noted for each of a series of field excitations of M-7, thereby obtaining data for iron loss at various excitations of M-7.





Determination of No Load Losses for All Machines

Diagram

No. 14.

This same procedure was repeated for G-7 and G-8.

The coupling between G-7 and M-7 was next removed and power with direct current input noted for the driving machine without excitation of M-7 and G-8. The G-8-- M-7 coupling was then removed noting again the input to the direct current machine without excitation of G-8. Thus data was obtained for computing all losses.

#### OPEN CIRCUIT TESTS:

G-7 and G-8 were connected for open circuit test as shown schematically in diagram No.15. The driving motor M-7 was started and connected to the line source. Then beginning with very small field current values for G-7 and G-8, their respective excitations were increased in small steps noting for each step the corresponding field currents and terminal voltages.

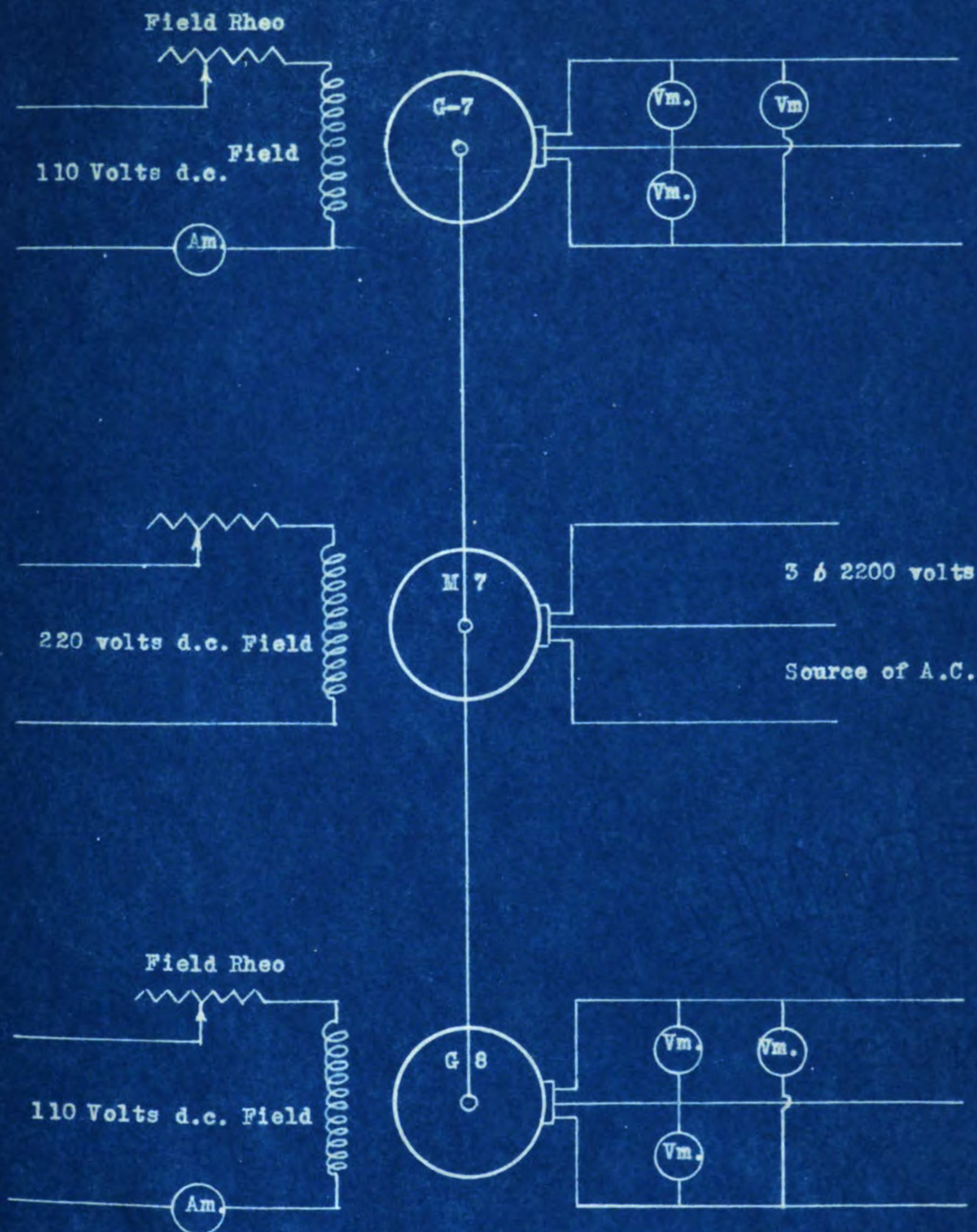
#### SHORT CIRCUIT TESTS:

The armature terminals of G-7 and G-8 were connected in a shorted Y with an ammeter in each branch as shown in diagram No.16. The driving motor M-7 was started and connected to the line. The field currents of G-7 and G-8 were then increased, starting with very small values, in convenient steps noting in each instance the current value in the field and in the armature.

#### "V" Curves for M-7:

For this test G-7 and G-8 were provided with a variable resistance load as shown in diagram No.17. "V" curve data was obtained for each of a series of loads of M-7 indirectly provided by G-7 and G-8. Full load was regarded as such load as required rated current at unity power factor. With this in view G-7 and G-8 were uncoupled for no load data. Then starting with a small value

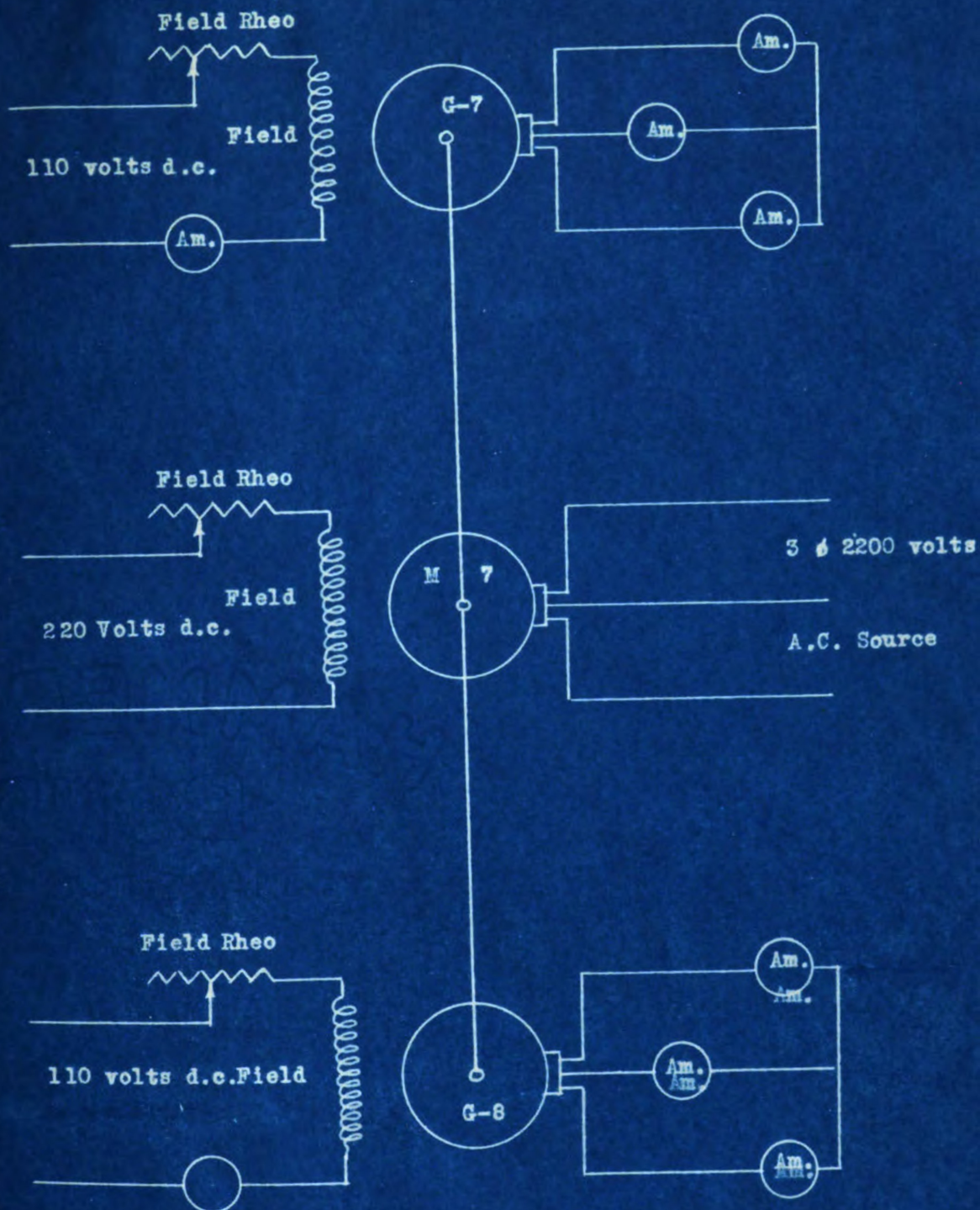




Open Circuit Test

Diagram  
No.15.



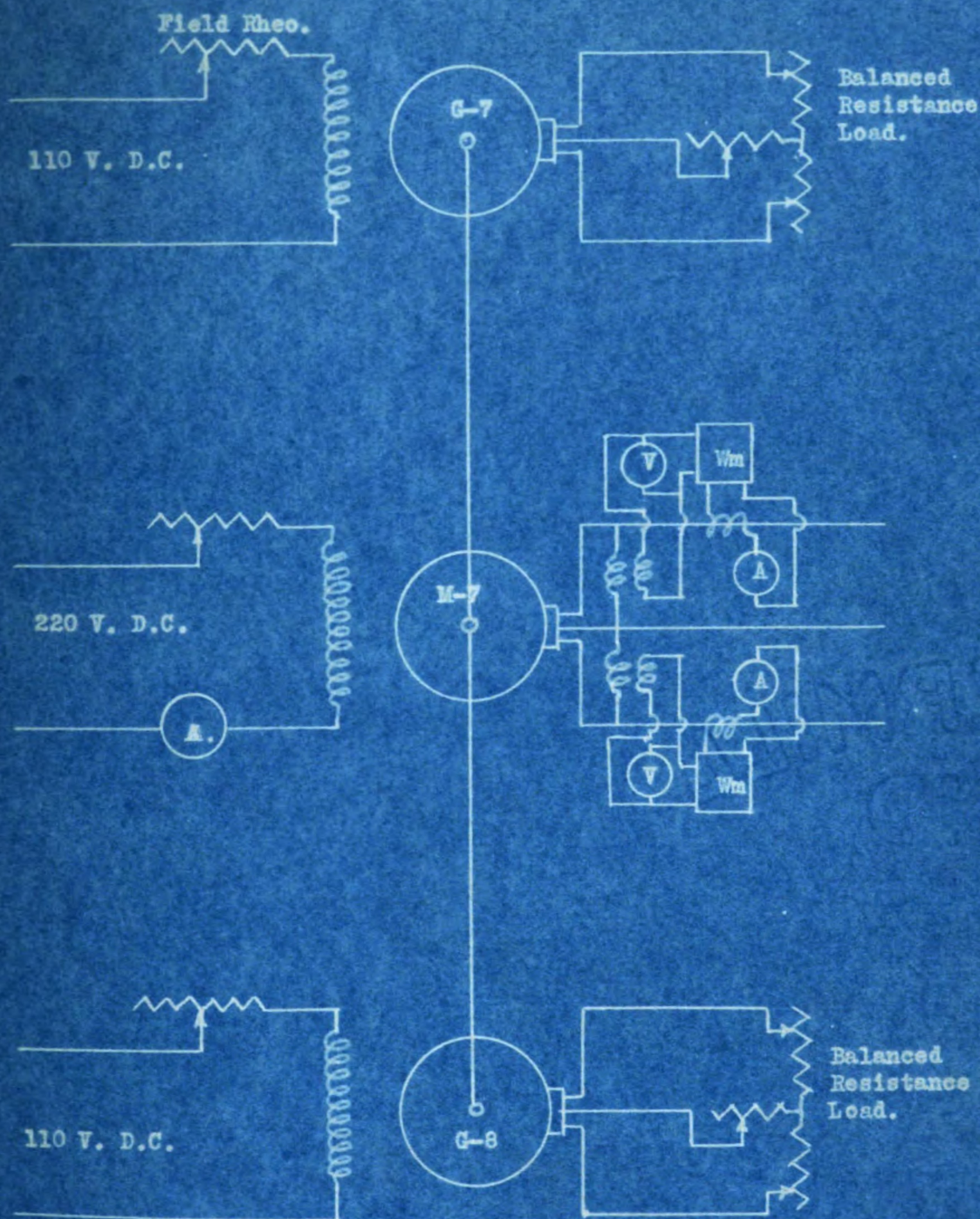


Short Circuit Test

Diagram

No.16.



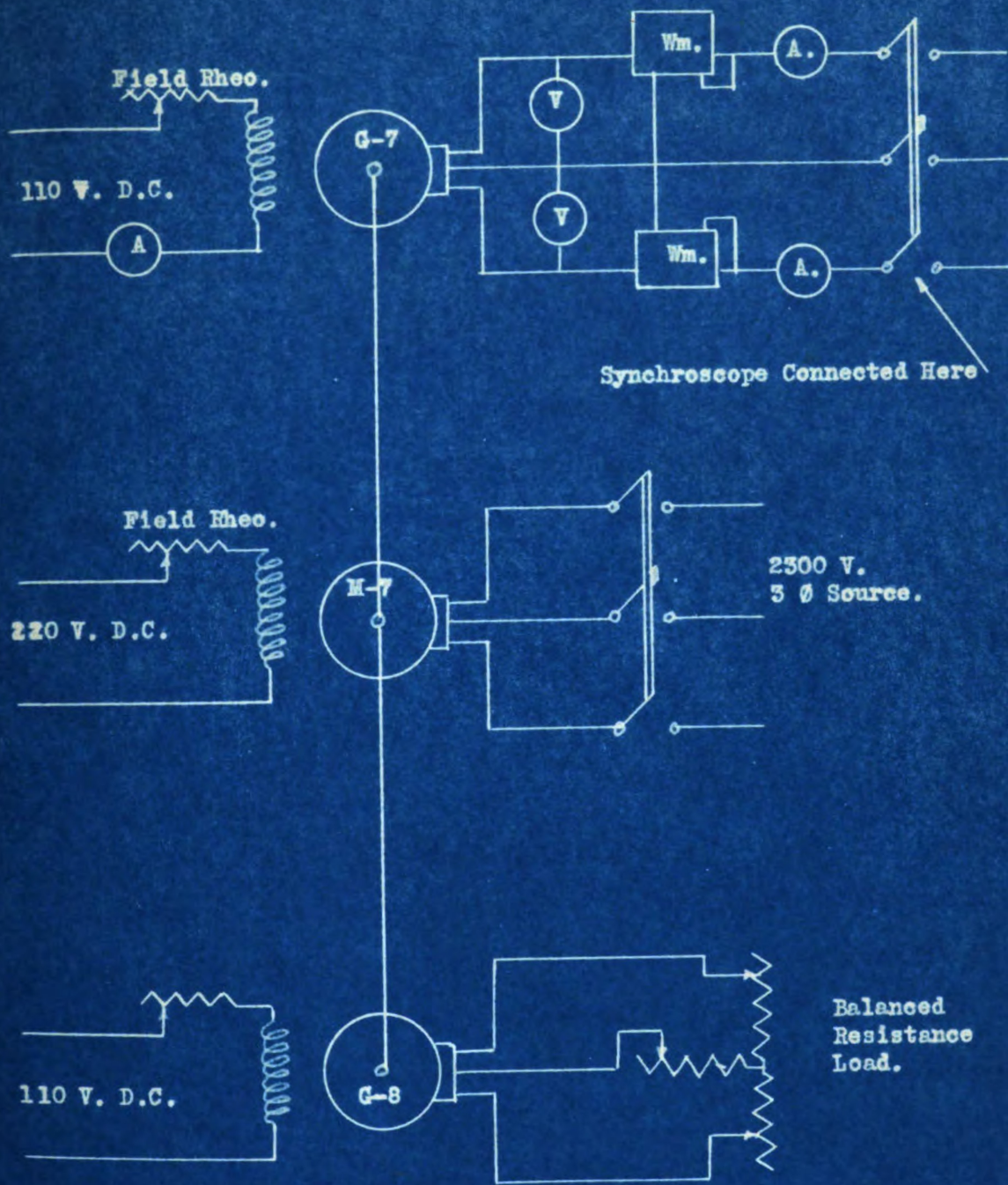


Connection Diagram for "V" Curve Test

Of M-7

Diagram  
No.17.





Connection Diagram for "V" Curve Test  
Of G-7

Diagram  
No.18.

of field current for M-7, the excitation was increased in steps noting in each instance corresponding values of field current, armature, power, current, and voltage. The point at which the two wattmeters recorded identical values was particularly noted as that of unity power factor. Thus values were likewise obtained for a series of loads by recoupling G-7 and G-8 and loading them as already indicated.

For determining the "V" curve data for G-7 and G-8 the alternate machine was respectively loaded. Diagram No.18 indicates the set up for G-7 "V" curves. The same general procedure as noted for M-7p was followed. This procedure was again repeated for G-8 with G-7 loaded.

#### REGULATION:

The percent regulation of G-7 and G-8 was determined in the laboratory for unity power factor, .7 lag and .7 lead. The connection diagram for this determination is No.19. To provide a means of varying the power factor G-7 was loaded with a synchronous motor which in turn was arranged to drive a d.c. machine. This d.c. machine was used for starting and synchronizing with G-7, and was later used as a generator to load the synchronous motor. The load was first adjusted for unity power factor and the excitation of G-7 was so adjusted that rated current at rated voltage was obtained. This rated voltage value was noted, and the load switch was subsequently opened. The new no load voltage value of G-7 was then again noted and recorded.

Now power input to the load (or synchronous motor) remains substantially constant (but for copper loss) regardless of the excitation of the machine. Hence the required wattmeter readings



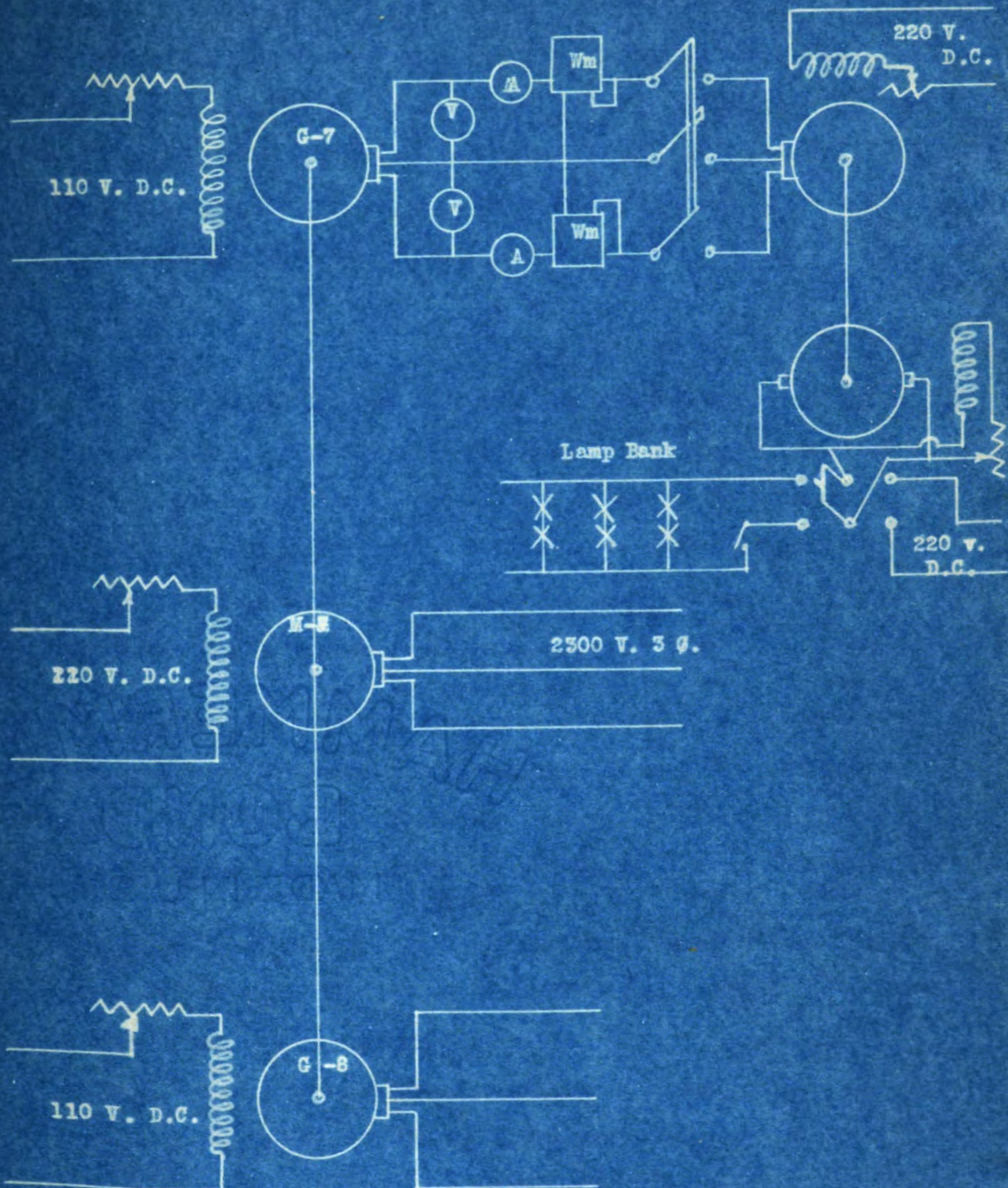


Diagram of the Circuit Used In the Determination Of Regulation

Diagram

No.19.

28



for rated current and .7 (lead) power factor were computed. The load and the machine G-7 were then so adjusted that rated current was obtained at rated voltage with a power factor of .7 leading. The load was then again thrown off noting the new voltage at the terminals. This procedure was then repeated for a power factor of .7(lag ). The same scheme was utilized in this test of G-8.

#### PARALLEL OPERATION:

The two machine were connected for parallel operation on a common load as indicated in diagram No.20. The voltage of each machine was adjusted to rated value and the switch between them was closed leaving the load switch open. The phase angle of G-7 was then shifted in increments of five electrical degrees noting for each setting of the G-7 stator, all currents, voltages and power values.

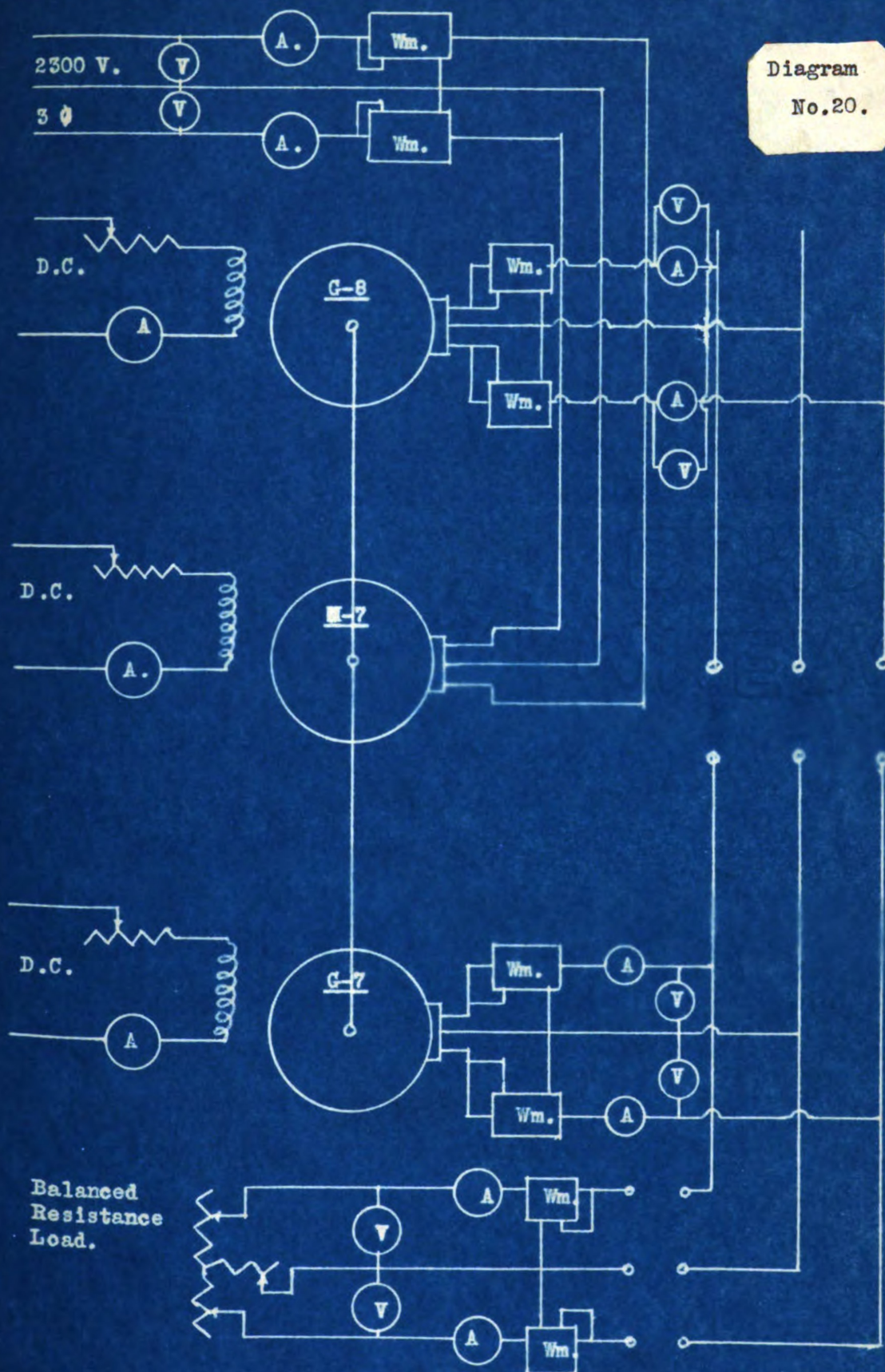
A load was then applied by closing the load switch and adjusting the lamp bank resistance. Then starting again with the zero position of G-7, the phase was again shifted in the same increments noting the same meter readings keeping the bus voltage constant as rated.

The phase shifter of G-7 was then again returned to the zero position. The excitation of G-7 was increased and that of G-8 decreased simultaneously in convenient steps maintaining rated bus voltage and consequently constant resistance load. All meter readings were noted for each setting of the field rheostats.

#### OSCILLOGRAMS:

Oscillograms were obtained of the voltage waves of G-7 and G-8 equal and in phase, and equal but 180 degrees out of phase.

Diagram  
No. 20.



Parallel Operation

To reveal harmonic oscillograms of the current for each machine under a heavy condensive load were also obtained.

A three phase voltage wave was photographed with a resistance load on each phase so balanced as to give equal voltage values.

Starting armature current, field current, and armature voltage wave forms were also studied and a photograph was obtained of each of these during the process of starting M-7.

#### RESISTANCES:

Cold resistance values were measured for each phase by the drop-of-potential method using direct current. These values were checked by means of a portable wheatstone bridge.

#### GENERAL PROCEDURE:

The general characteristics of the set were observed during all tests. The effectiveness of the damper windings on each machine was noted, as a prevention of hunting action. All of the individual peculiarities of the set which were noted during the procedure were recorded.

#### PERFORMANCE CURVES:

In obtaining the data for performance curves, the same connections were used as for "V" curves as indicated in diagrams No. 17 and 18. For various field excitations of each machine respectively, the load was varried in convenient steps noting for each step, the corresponding current and power input to the machine under test keeping the voltage of that machine constant as rated.



CHAPTER NO. 5.PERFORMANCE

---

**PERFORMANCE CURVES:**

It is probable that the performance curves included in this chapter are good indices of the actual performance of the machines under test. Much time has been devoted to their completion to as great a degree of accuracy as has been possible.

The first diagrams shown, No's. 21 and 22 respectively, indicate the iron loss at no load for the machine G-7; G-8 and M-7.

In obtaining performance curve data in the laboratory, current and power input readings to each machine, together with terminal voltages, were obtained in respective order for different loads. From the input values for each load  $I^2R$  losses, together with friction, windage and iron losses were subtracted to secure corresponding output values. Then efficiency was calculated as equal to input/output. All performance curves are plotted against K. W. output of the particular machine under consideration. Current values are plotted directly as obtained in the above mentioned procedure while power factor values were calculated in each instance, as equal to  $\text{Power}/\sqrt{3} EI$ . Losses were also plotted as computed for various loads. A set of curves are included for various excitation of each machine.

The shape of the efficiency and power factor curves is typical. In general, starting from zero they reach a maximum to fall <sup>ing</sup> off slightly beyond rated load. For a given power output it is evident it is evident that for any excitation other than that for unity power factor, more current must flow, hence there is more  $I^2R$  loss and lower efficiency. Likewise the power factor decreases. Hence this general shape of performance curves for different excitations is explained on a theoretical basis.

The obvious flaw in the determination of these performance curves is that the curves of diagram Nos. 21 and 22 are not accurate indications of iron loss under load because they do not allow for armature reaction. However, since it is very difficult to determine the magnitude of armature reaction, the method here used is justifiable. The results here indicated are in all probability very close to those of actual loading. An input-output test might have been used had a machine been available which had been accurately calibrated, taking account of its armature reaction.

A consideration of the shapes of the curves of diagram Nos. 21 and 22 leads to the conclusion that within the normal operating conditions of the machines their fields are not saturated. If they were these curves would slant sharply upward and to the right. Most modern machines are designed to operate under normal conditions with a saturated field because this results in greater stability. In spite of this observation the machines of the Burke Set are comparatively stable in operation.

Another interesting thing to be observed in connection with general performance is that the friction loss of G-7 is somewhat larger than that of G-8 despite the fact that each of the parts are of

identical dimensions. This is due to the fact that the moveable stator of G-7 is suspended directly from the shaft. This is further ~~connected~~ <sup>explained</sup> by the fact that the bearings of machine No.7. tend to run hotter than those of G-8 and M-7.

It is to be noted that friction, windage and iron losses are practically constant as shown on the performance curves, for a given excitation. Here again armature reaction would tend to alter iron loss though friction and windage are actually constant since they are functions of speed and the structure of the rotating parts only.

#### "V" CURVES:

V curves are a plot of field current against armature current for a given load on a synchronous motor. A complete set of these curves differing by steps of 20% of rated load are included up to 100% load. These curves are shown in diagram Nos. 23-24-25. For a fixed load on a synchronous motor it is evident that for any excitation other than that for unity power factor a greater current must flow than at unity. Thus at unity power factor, the current is a minimum for a synchronous motor with a fixed load. The smaller the field current below that for unity power factor, the greater will be the armature current. Likewise for excitations above that of unity power factor, the current increases with an increase of excitation. Overexcitation, as already explained, results in a leading current, while under excitation results in a lagging current. Normal excitation of 100% is regarded as that excitation which will give unity power factor at rated load.

#### CURRENT LOCI:

The "V" curves may be <sup>better</sup> ~~more~~ thoroughly understood if the current



loss for one machine (say G-8) be considered. Diagram No. 26 is a plot of such loss for actual value obtained from G-8. The loss of voltages and Motor Current for different field excitations are indicated.

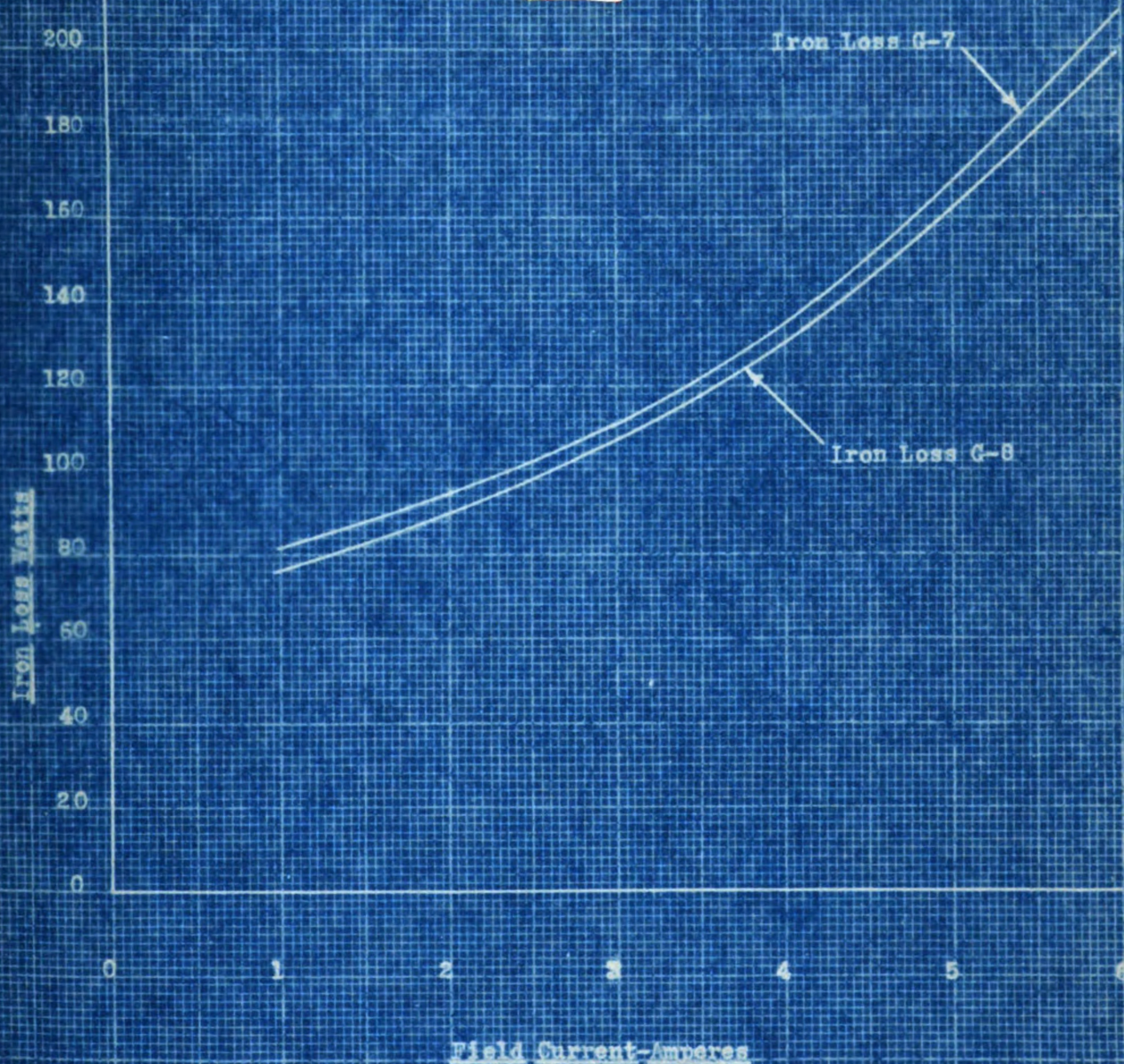
Diagrams No. 27 to 39 are the performance curves already discussed.

It was noted that the damper windings of each machine were effective in preventing "hunting action" with the machines operating as motors.



Plot of Field Current vs Iron Loss for  
Synchronous Generators G-7; G-8

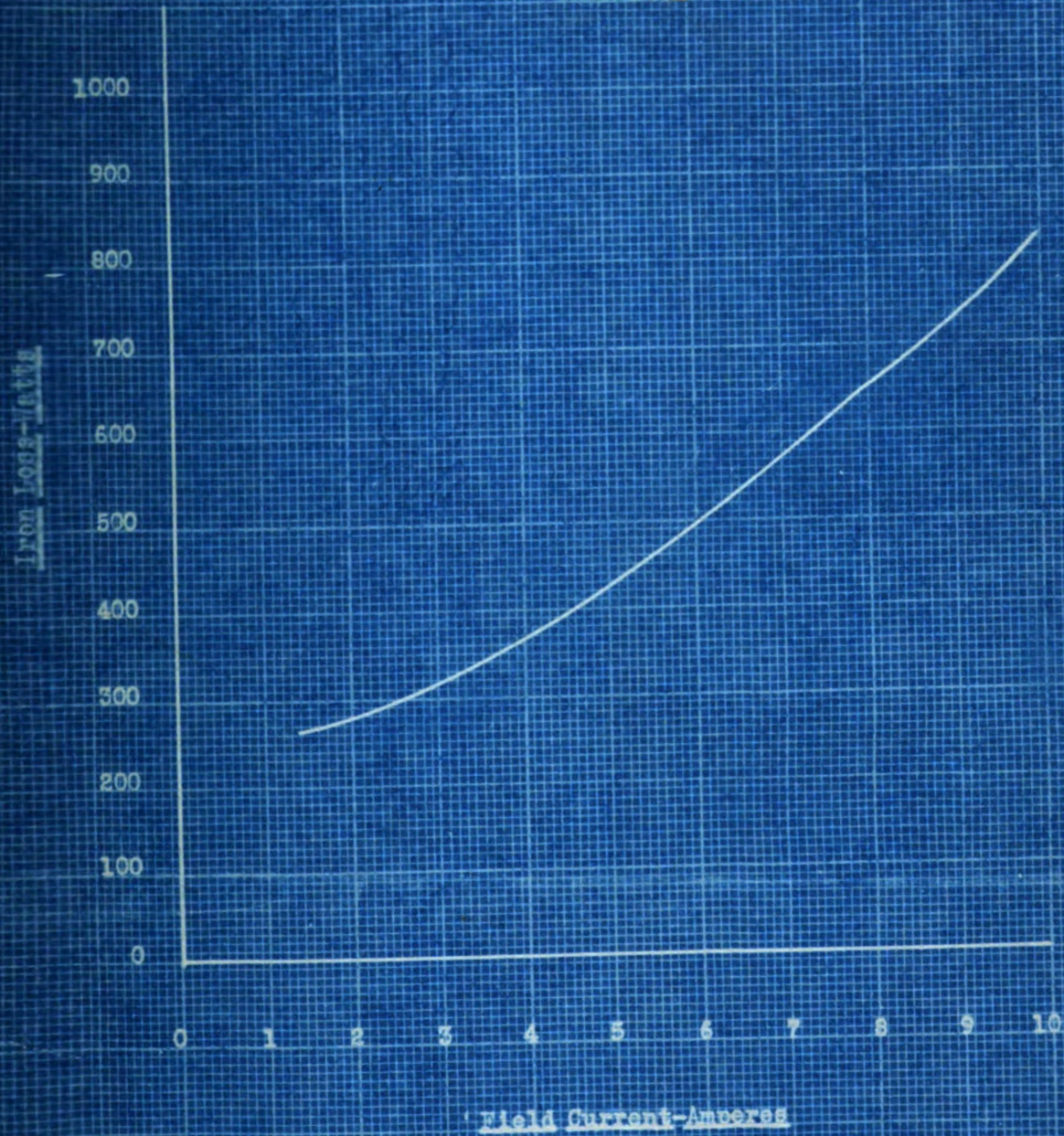
Diagram  
No. 21.



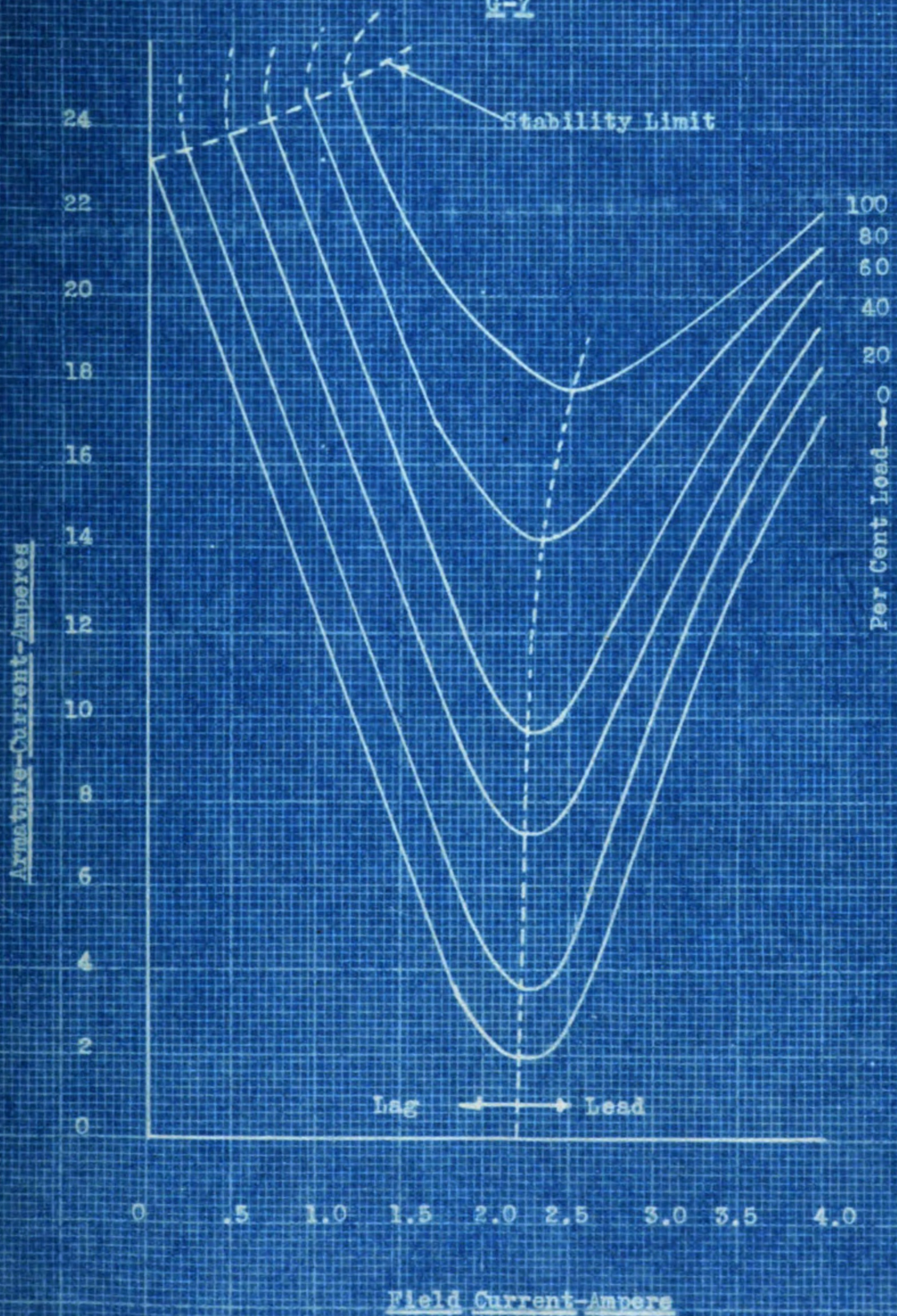


Iron Loss vs Field Current  
for M-Z

Diagram  
No.22.





"V" CurvesFor 220 Volt Synchronous MachineE-Z

Diagram

No.23.



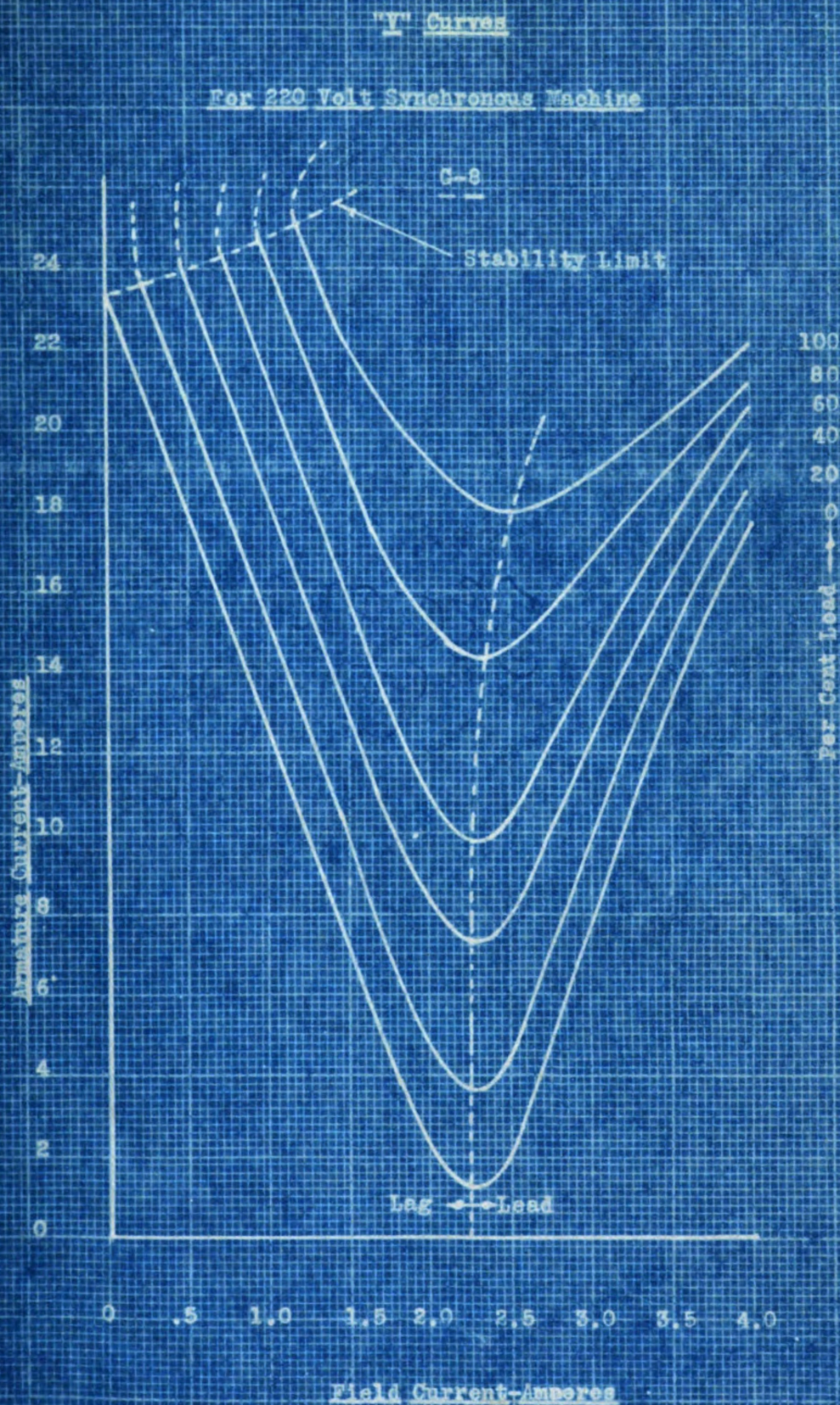
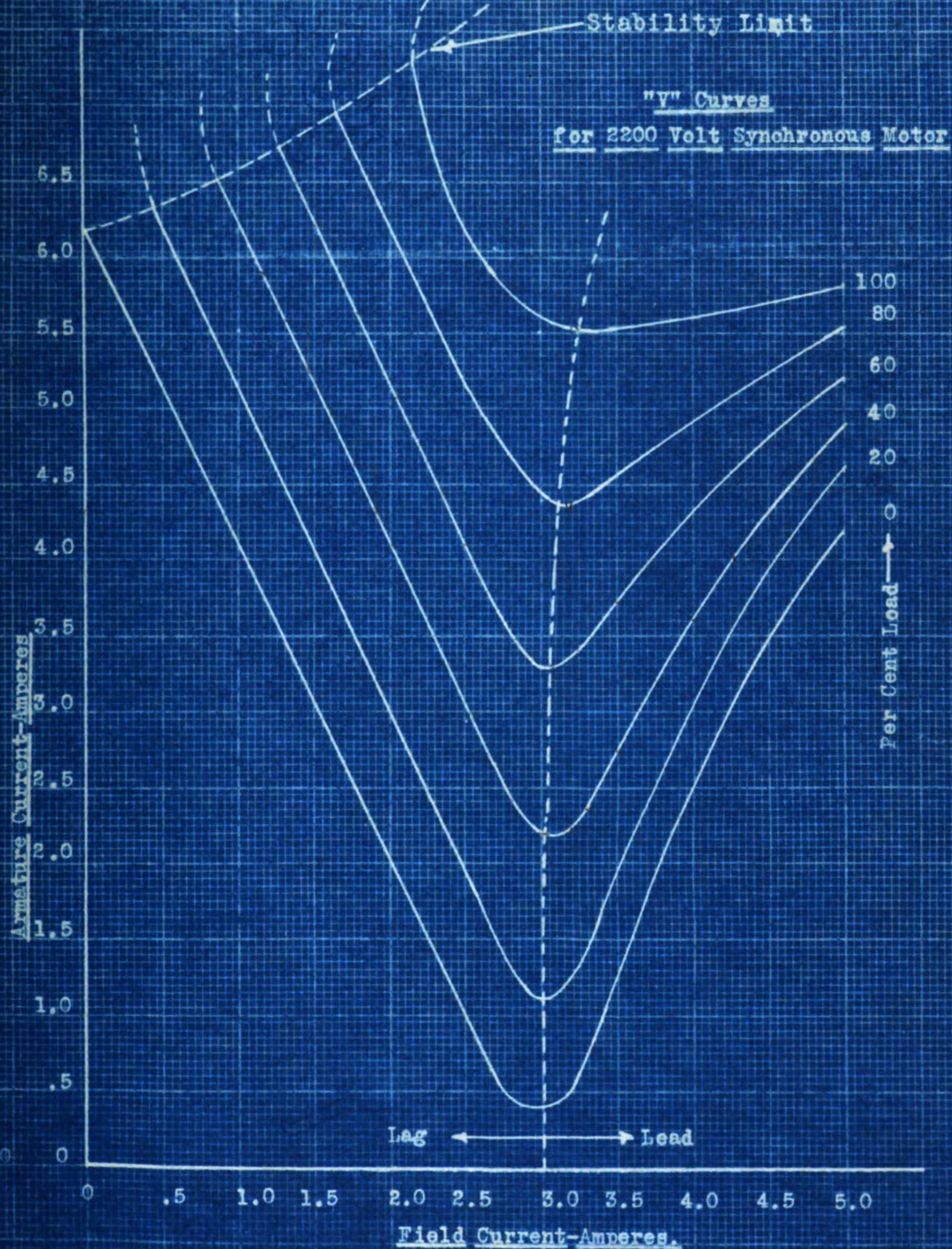


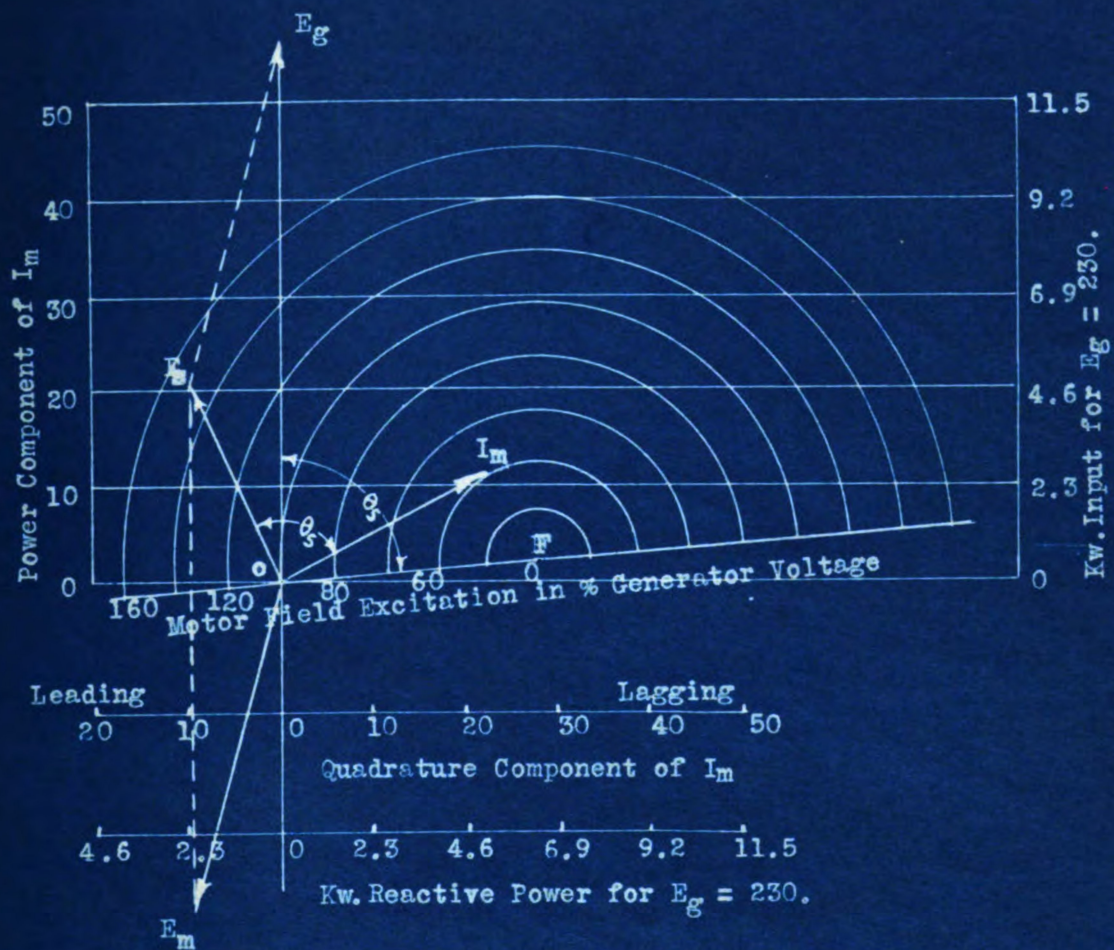
Diagram  
No. 24.



Diagram  
No.25.







The Loci of the Voltages and Motor Current for Different  
Field Excitations

Diagram  
No. 26.



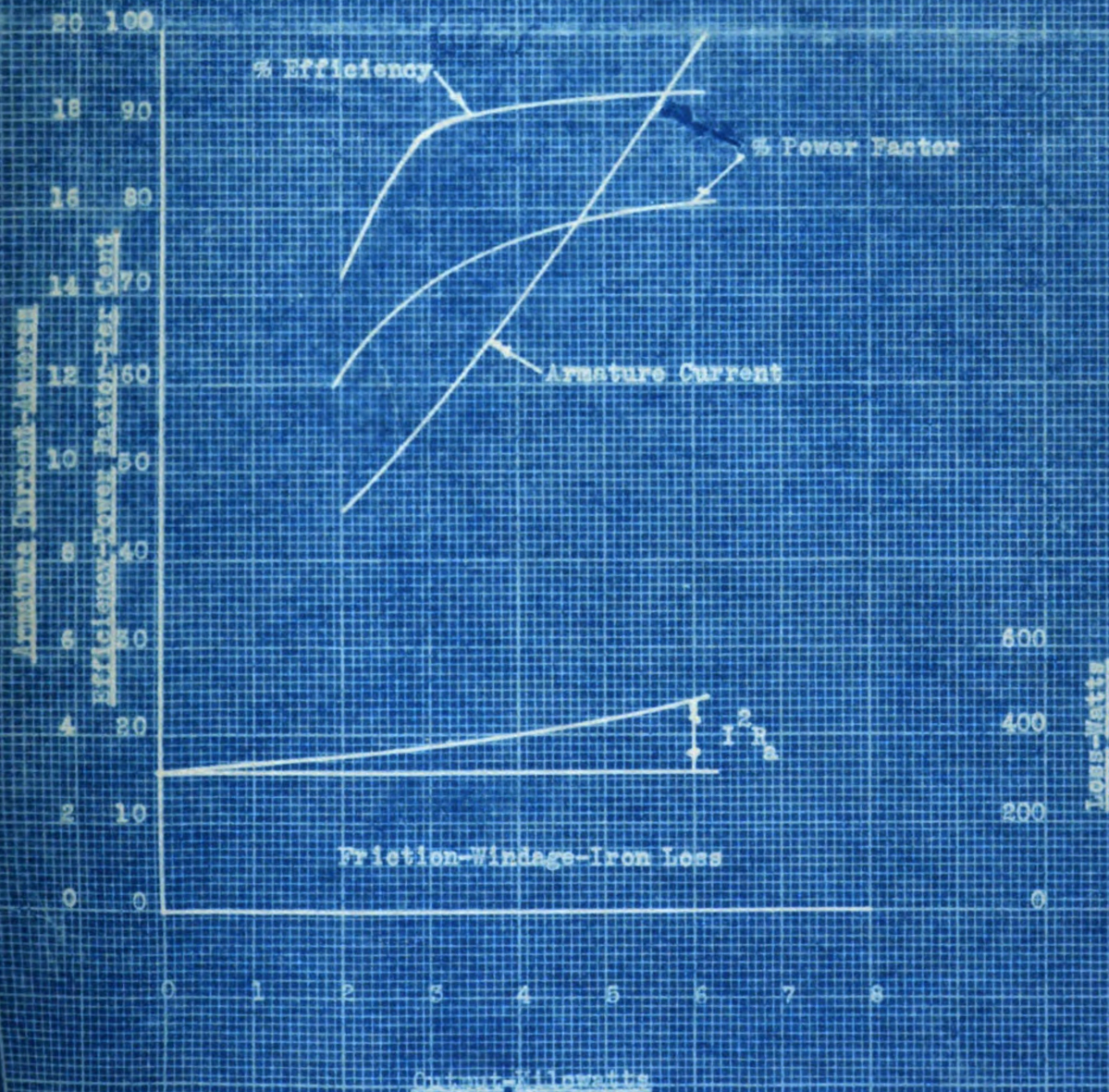
## Performance Curves

for S-2

Excitation = 40%

Diagram

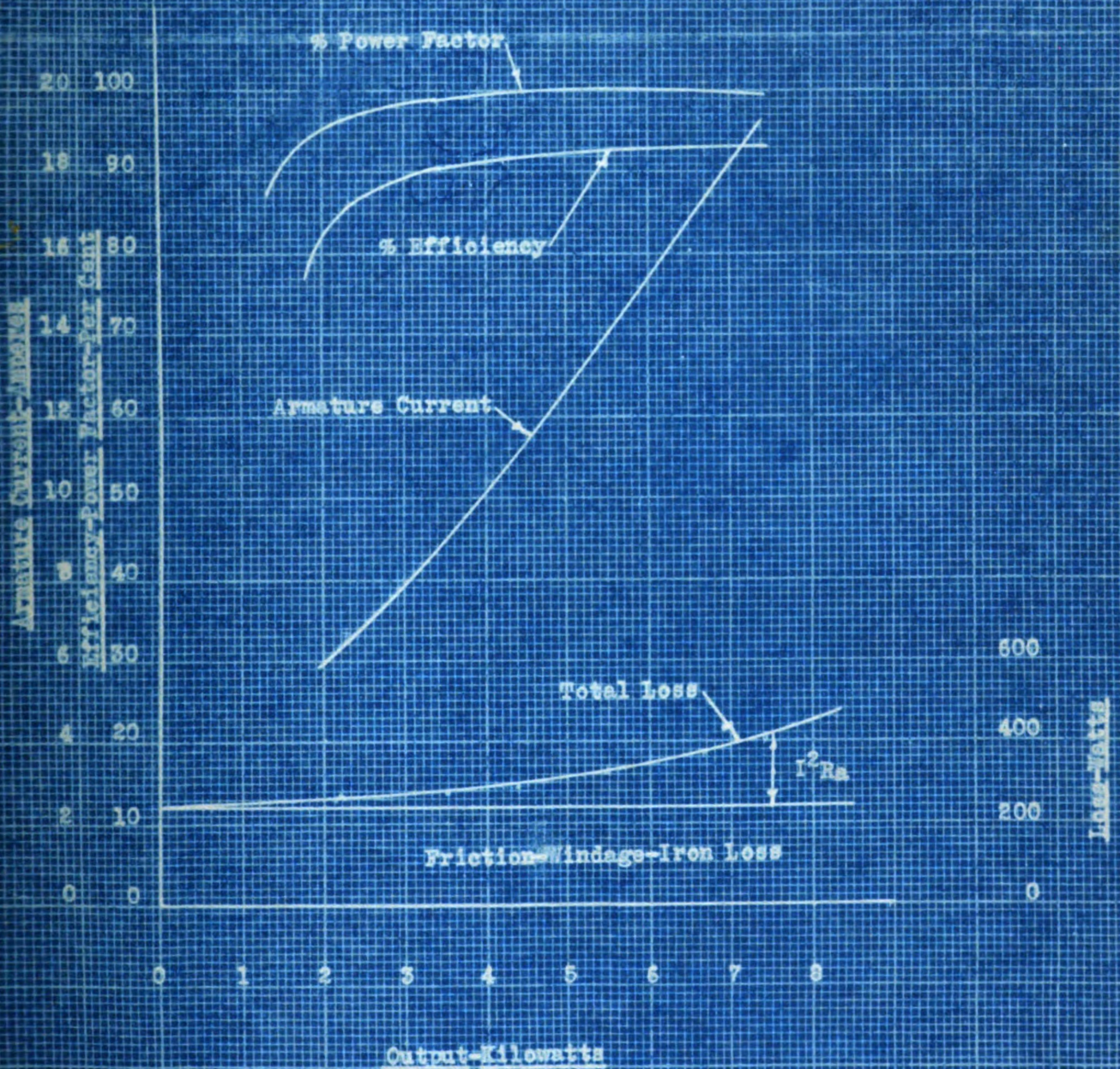
No. 27.





Performance Curves  
for G-8  
Excitation = 100%

Diagram  
No. 28.





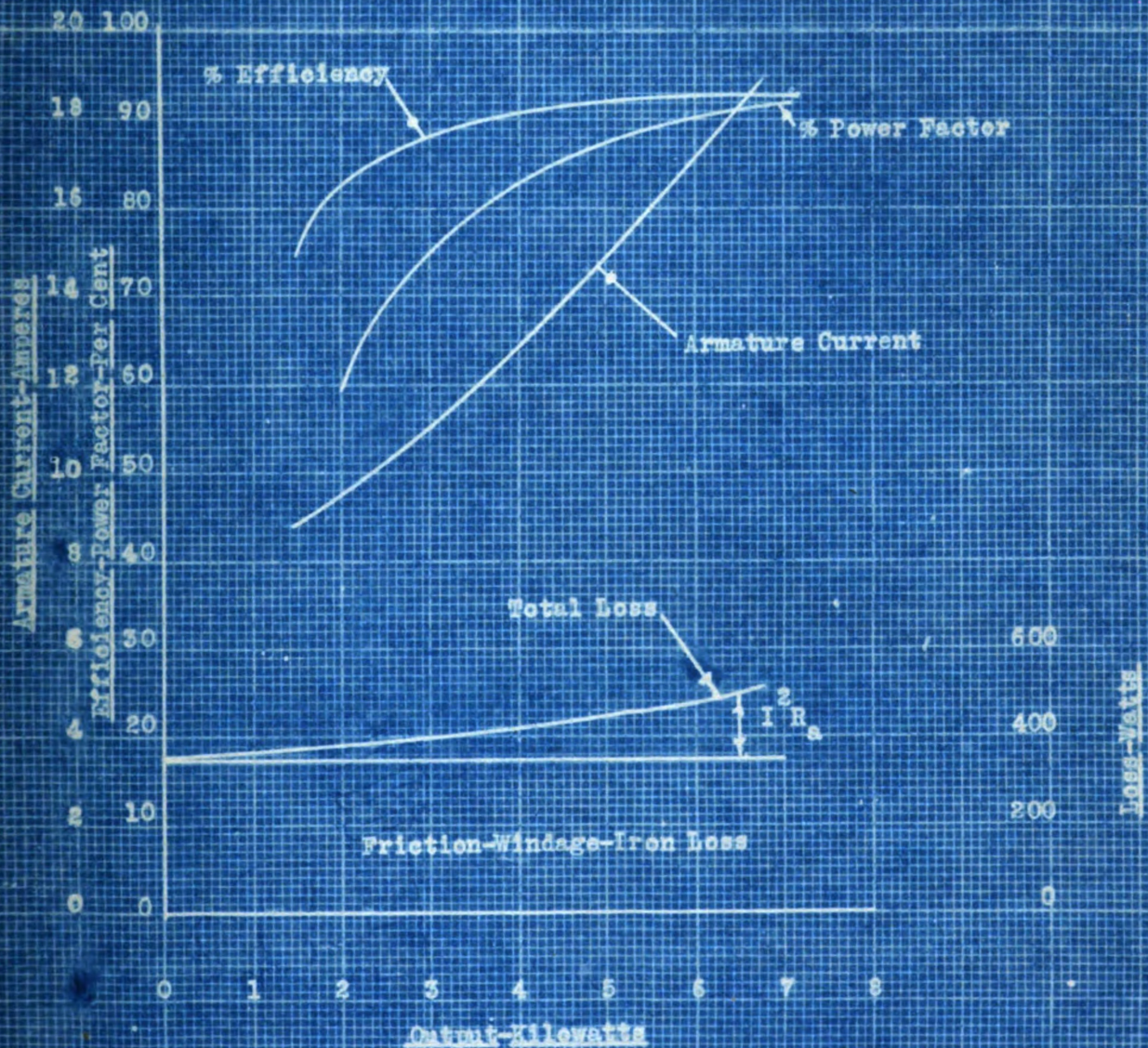
## Performance Curves

for G-8

Excitation = 120%

Diagram

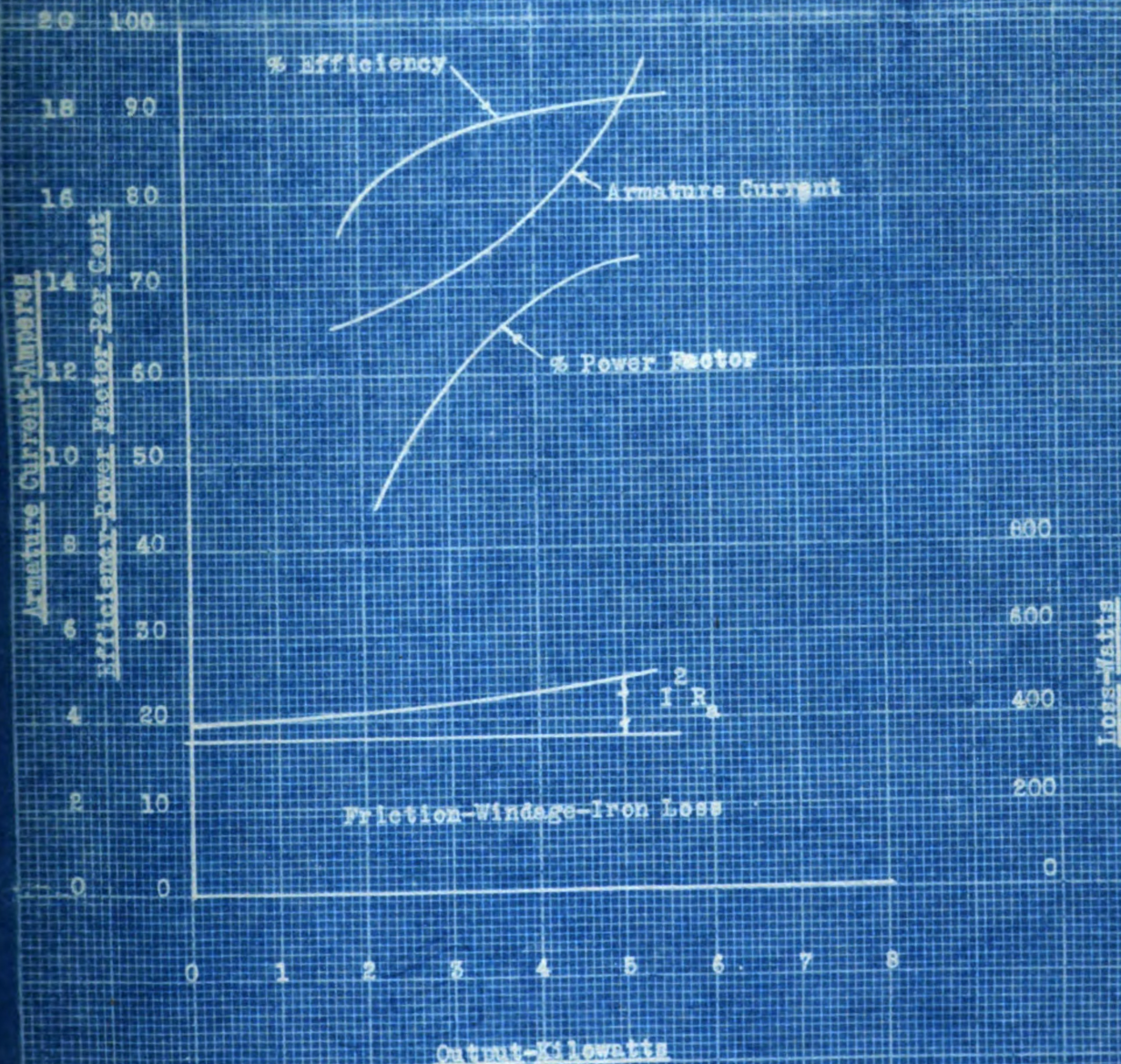
No. 29.





Performance Curves

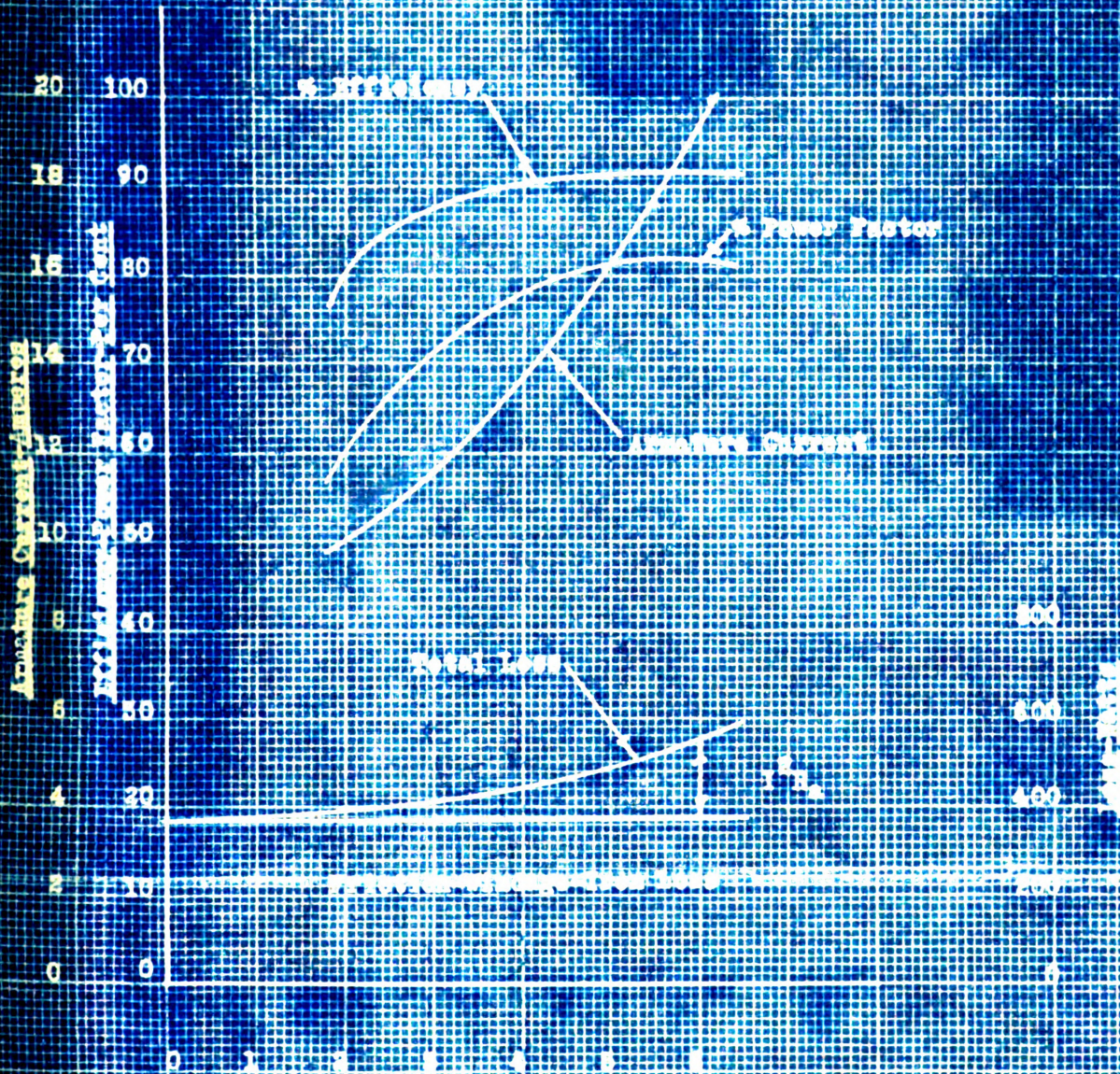
for G-8

Excitation = 100%Diagram  
No. 30.



Performance Curves  
for 2-1  
Rotation - 60%

Diagram  
No. 31.

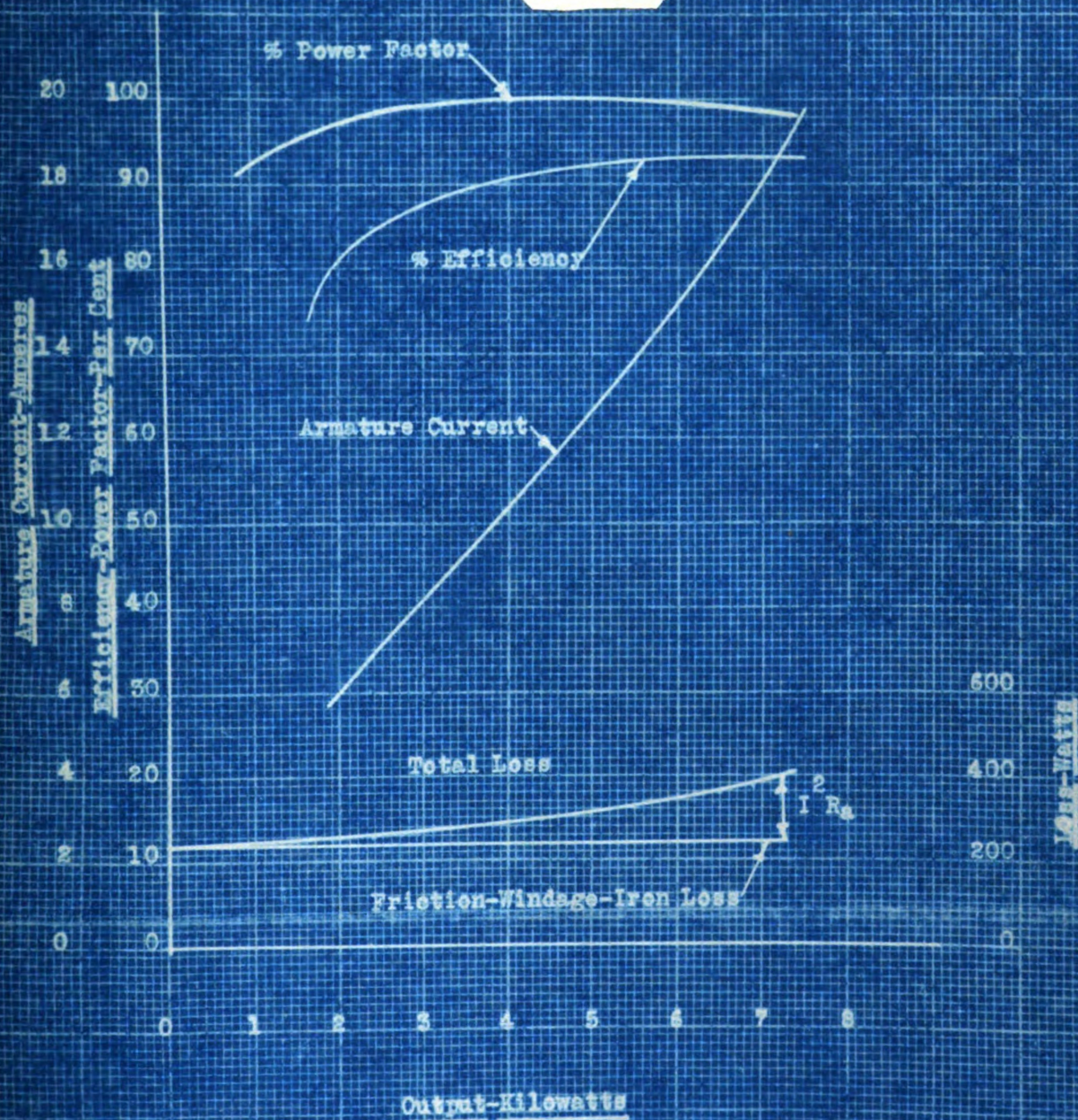




## Performance Curves

for S-7

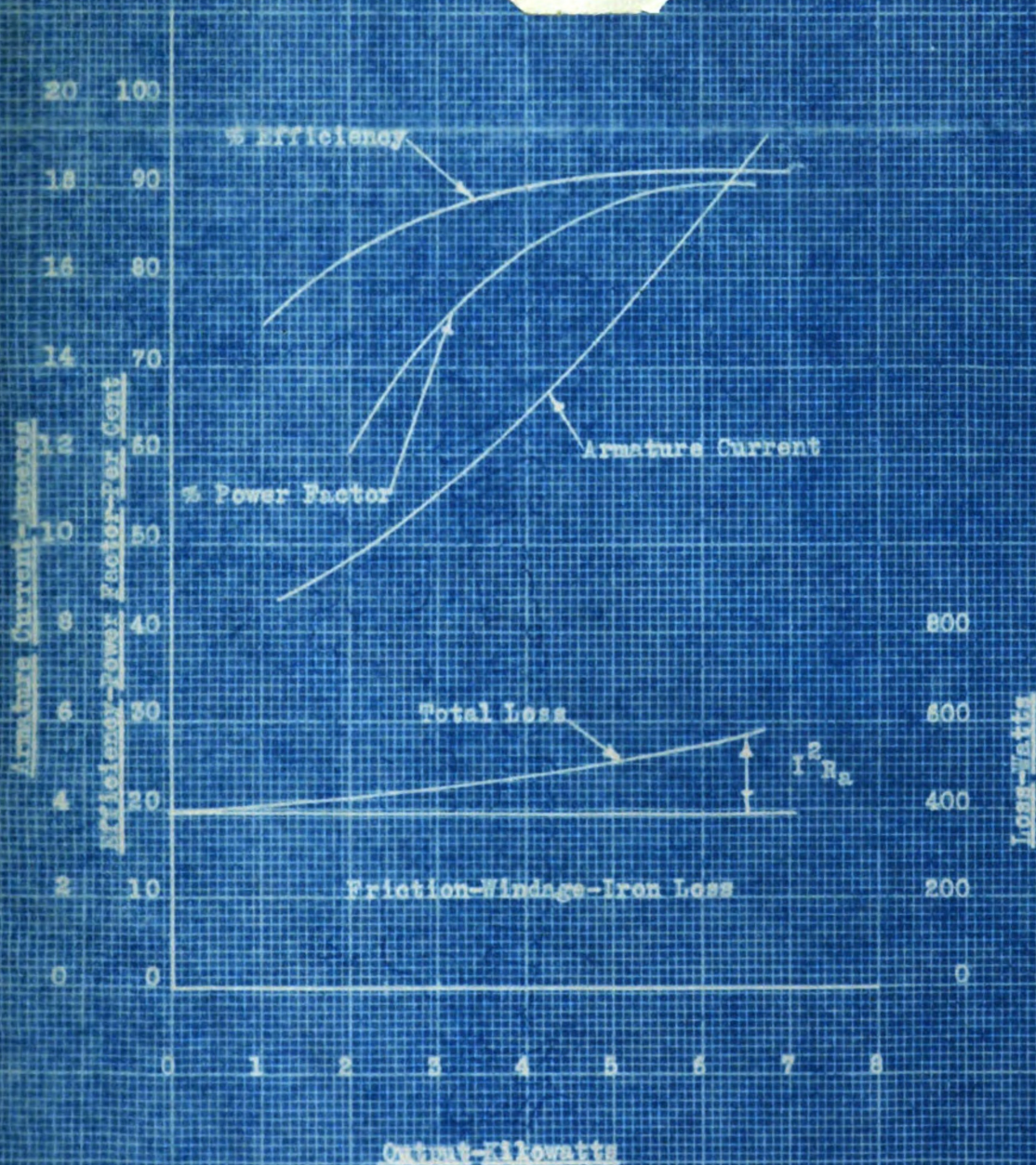
Excitation = 100%

Diagram  
No. 32.



Performance Curves  
for G-2  
Excitation = 120%

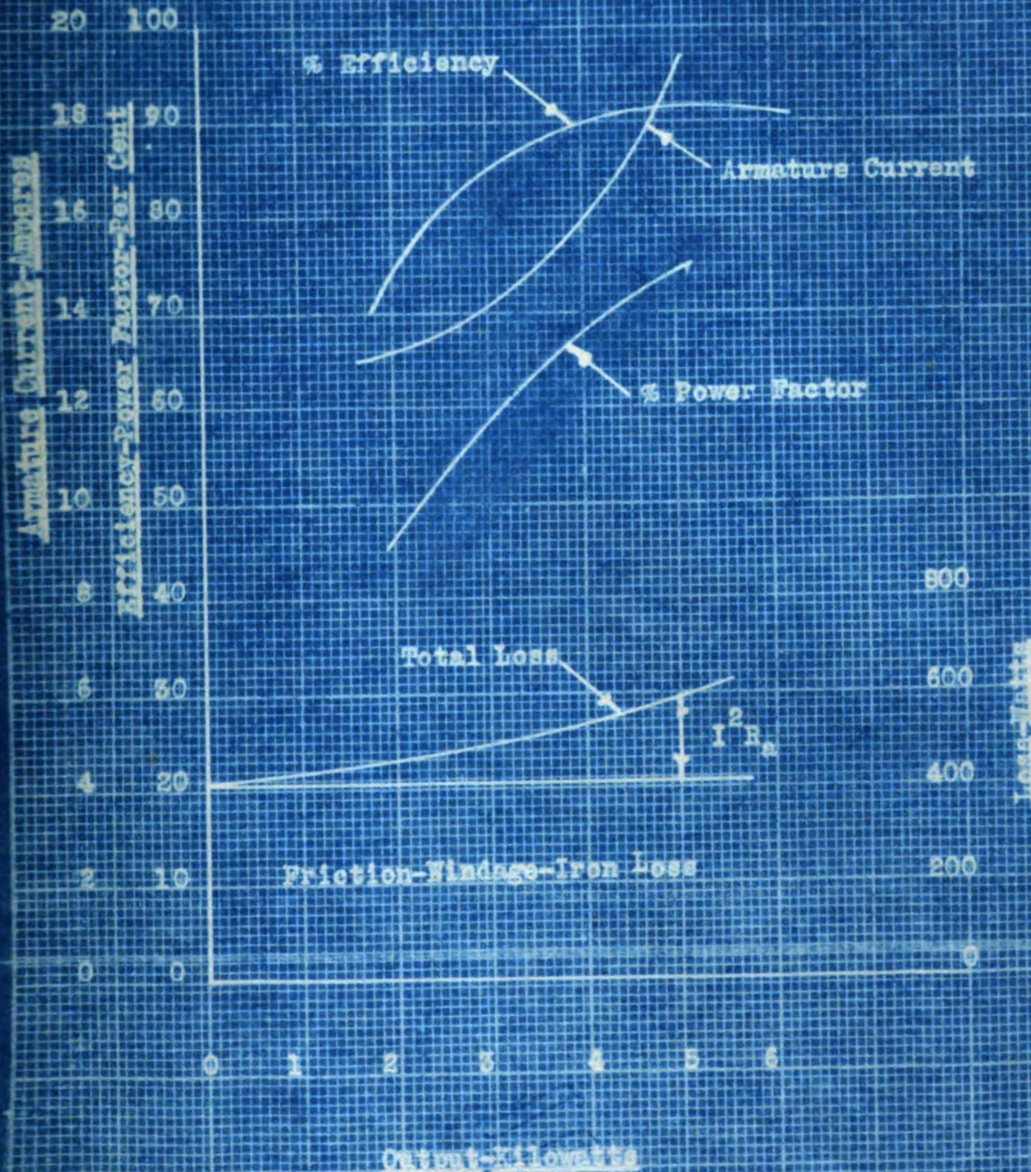
Diagram  
 No.33.





Performance Curves

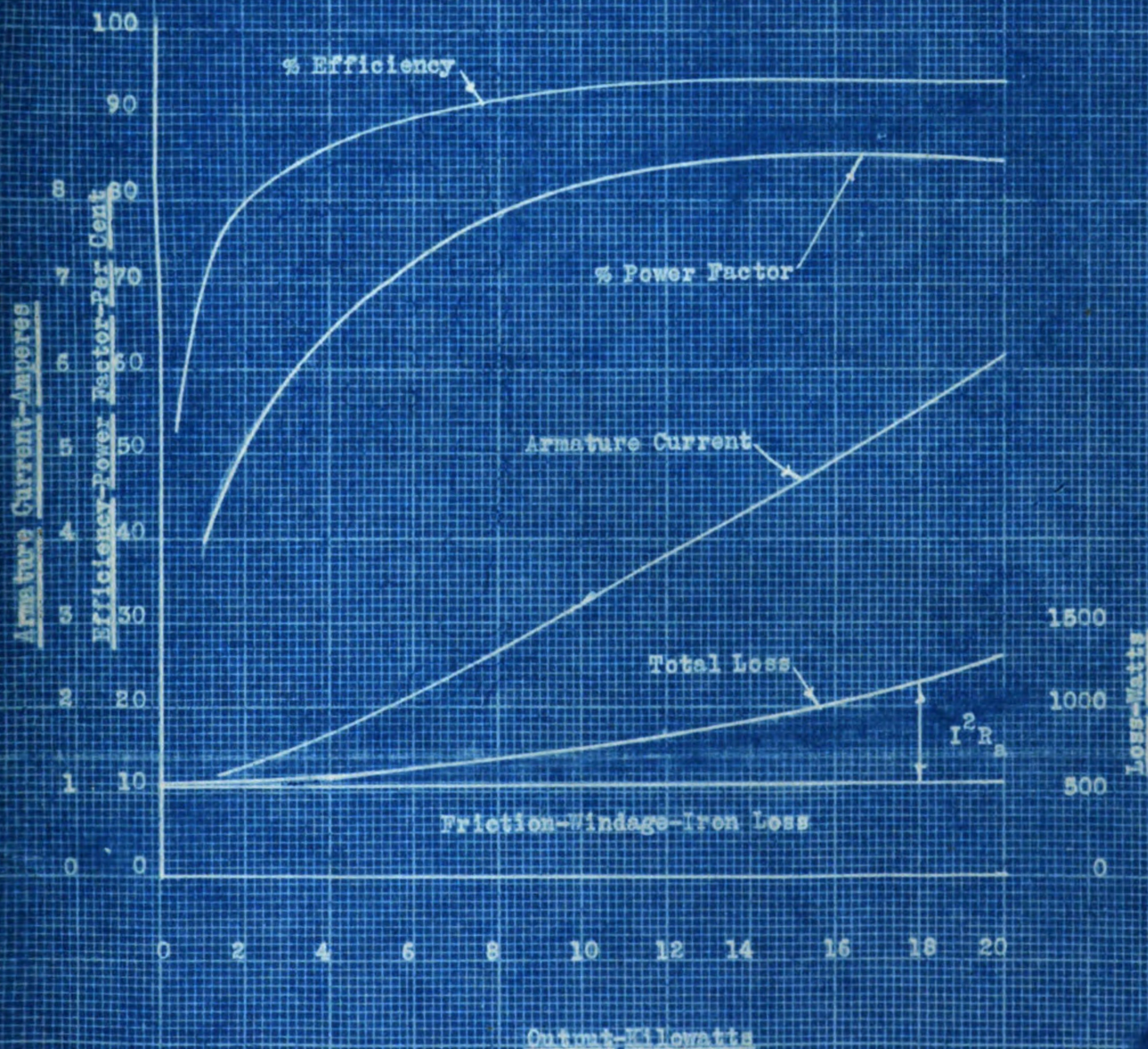
for 9-7

Excitation = 140%Diagram  
No. 34.



Performance Curves  
for M-7  
Excitation = 78%

Diagram  
 No.35.





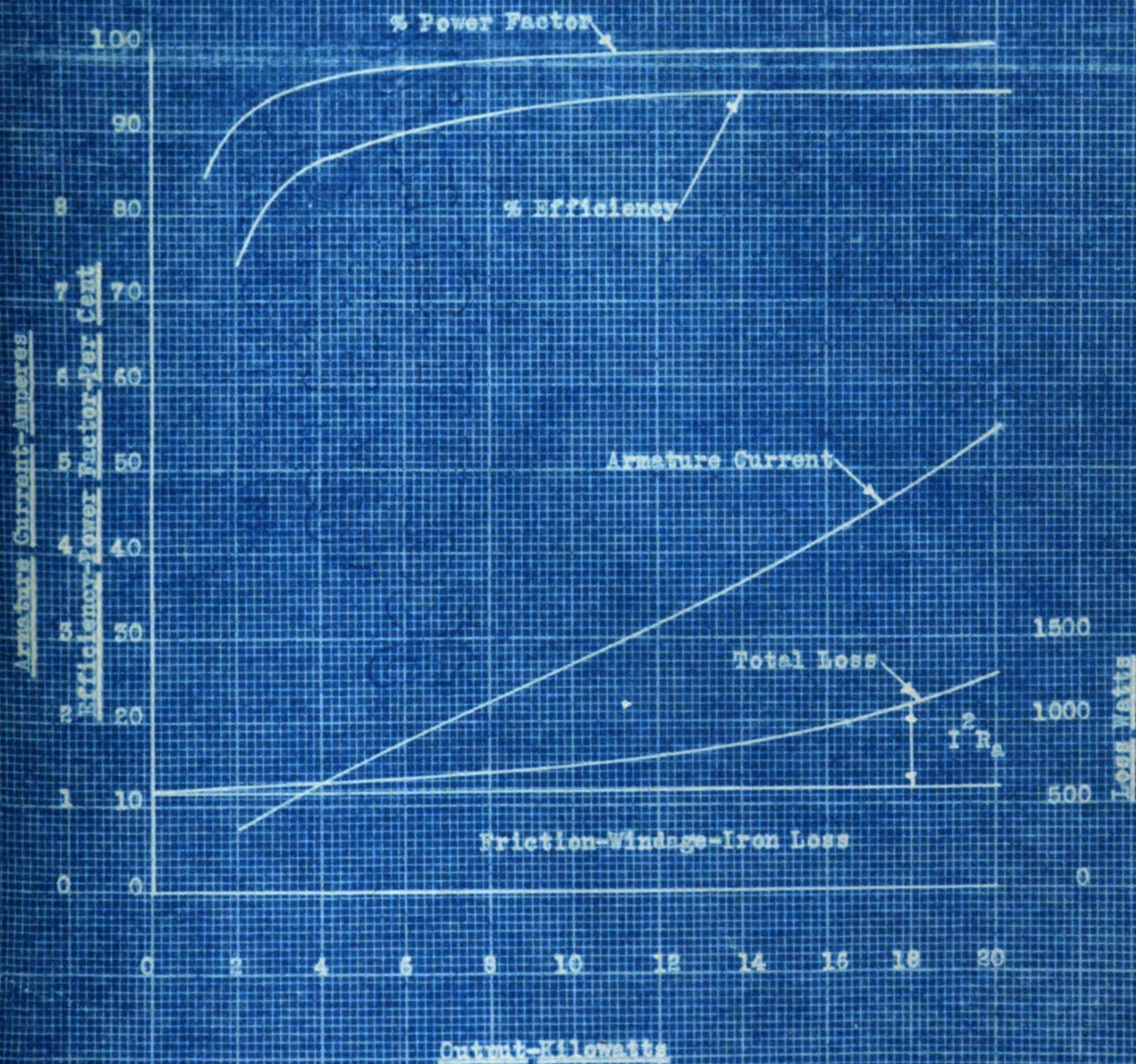
Performance Curves

for M-Z

Excitation = 100%

Diagram

No.36.





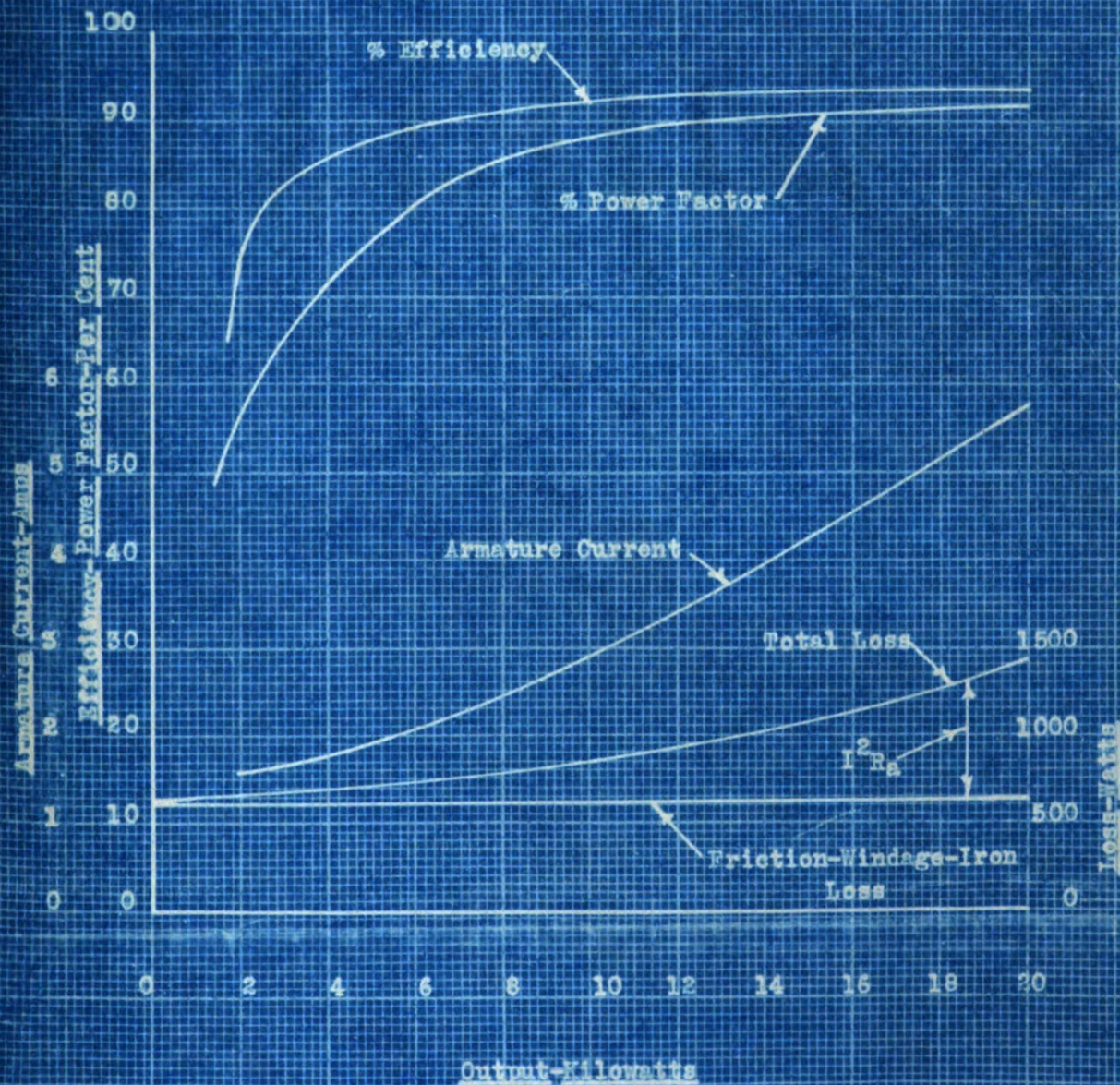
Performance Curves

for K-1

Excitation = 112%

Diagram

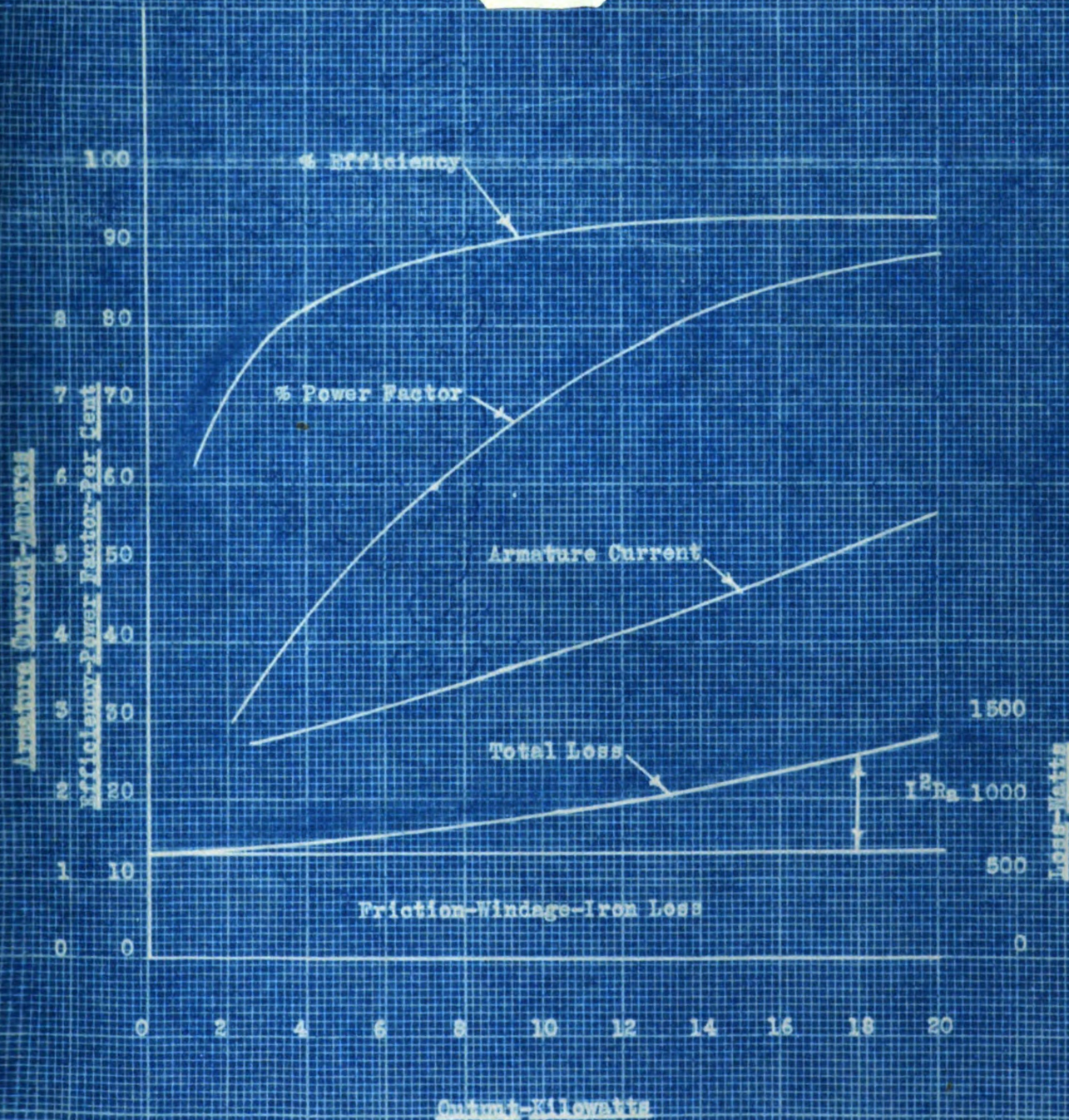
No.37.





Performance Curves  
for M-7  
Excitation = 141 %

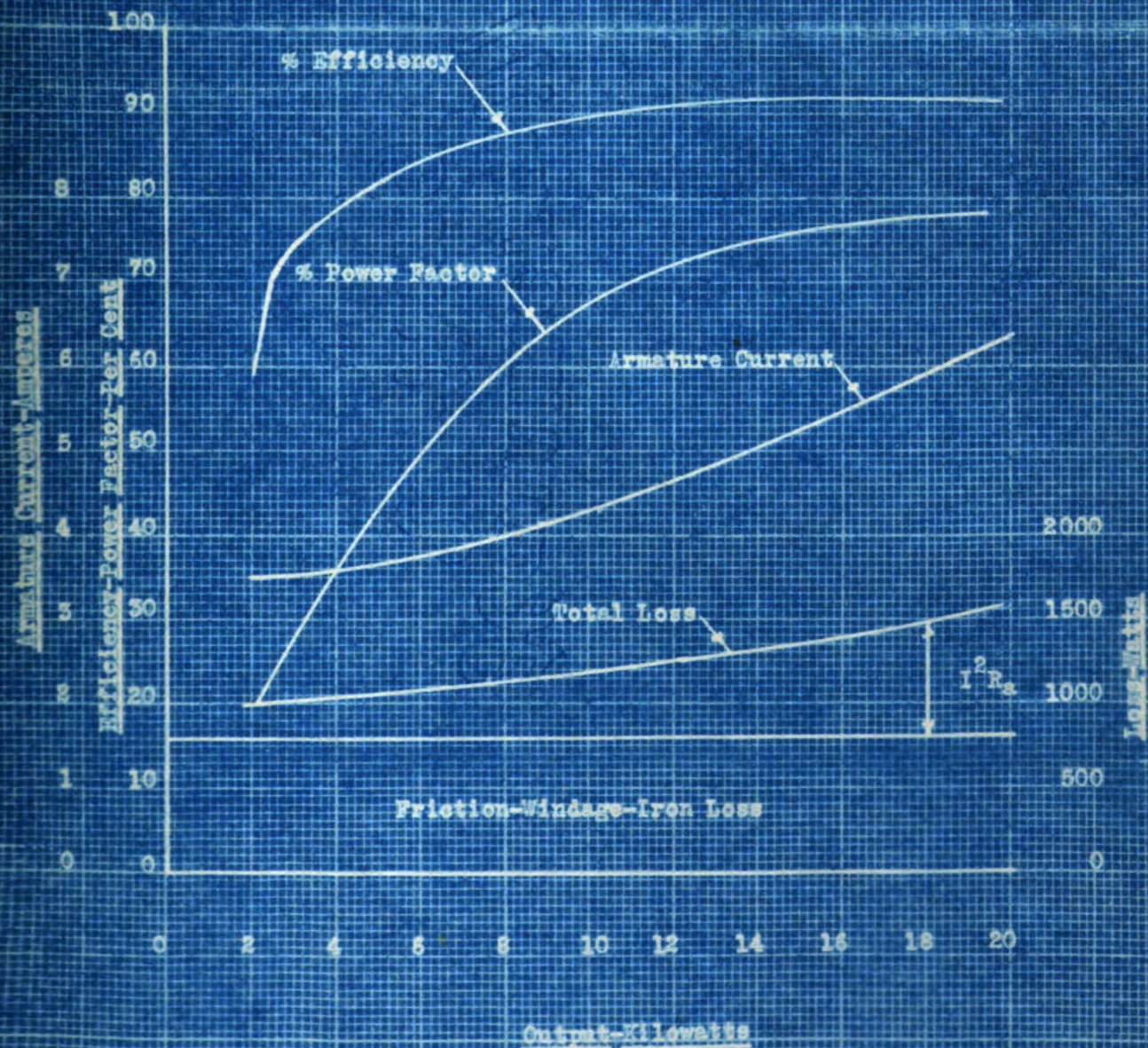
Diagram  
No. 38.





Performance Curves  
for M-7  
Excitation = 1575

Diagram  
 No.39.





CHAPTER NO. 6.PARALLEL OPERATION.**RESULTS OF TESTS:**

When two alternators have been adjusted to series opposition of phases as described in an earlier chapter, their voltages are in the proper relation to cause them to operate in parallel, delivering current to an external circuit attached between them to the bus bars.

In the initial consideration, G-7 and G-8 were placed in parallel without load but with equal terminal voltage. The phase of G-7 was shifted which effects the same result as a tendency to change the speed of the prime mover. All values of current and power were noted for various phase shifted under these conditions. Diagram No. 45 is a plot of power and current values for each machine against phase shift in electrical degrees for G-7. Since the same current flowed thru each machine the current curves are identical. Also the power supplied by one machine is practically equal to that supplied by the other ( with exception of  $I^2 R$  loss in bus bars between them). Both current and power increase and at an increasing rate with increase in phase angle. A given condition may be better understood from a vector diagram. Diagram No. 46 shows all currents and voltages at no load with a phase shift of  $60^\circ$ . It can be seen that a phase shift of  $60^\circ$  results practically in a shift of the phase of induced voltages of  $60^\circ$ . As already suggested, the lagging machine G-7 supplies power which the other machine receives. Diagram No. 47 is a plot of power factor for each machine at no load against phase shift. It can be seen that the power factor of each machine remains about unity— this follows from the fact that the induced voltages are





equal and the current lags about  $90^\circ$  behind  $E_g$ , thus bringing it in phase with the bus voltage.

A resistance load of constant magnitude was then applied to the bus and the phase angle was again shifted. Diagram No. 48 shows current and power values for each machine against phase shift under these conditions. It can be seen that as the phase angle is shifted the currents from each machine increase though in an opposite directional sense. The lagging machine G-7 supplies more power with each shift of phase until, in addition to supplying the load power, it is driving G-8 as a motor. Diagram No. 47 also indicates power factor plotted against phase shift for these conditions. As phase shift increases the power factor of each machine decreases though only a small amount as shown. The vector diagram for a phase shift of  $30^\circ$  is shown in diagram No. 49. At this point G-7 is supplying all of the power to the load and G-8 is merely floating on the line with induced voltage therefore, equal to its terminal voltage.

In the last part of the parallel operation consideration, bus voltage was maintained constant but excitation of G-7 was increased while that of G-8 was decreased. This caused an increase of induced voltage 7 and a decrease of induced voltage 8. Thus G-7 supplied a lagging current and G-8 a leading current. The vector diagram is No. 50 for a current value of 11.15 amperes for the current of G-7. Diagram No. 51 is a plot of power factor of each machine against its respective field excitation. Since the machines are ~~at~~ identical unity power factor for each occurs for each at <sup>similar</sup> simultaneous excitations. As already explained, above this value P.F. decreases and below it P.F. likewise decreases though not by the same amount due to a difference in armature reaction.

It is of interest to note that in each instance with two synchronous generators operating in parallel on a common load, the vector sum of the currents supplied by these machines is equal to the load current while the vector difference equals the circulating current.

#### EFFECT OF FORM OF VOLTAGE CURVE ON PARALLEL OPERATION :

The able designer, C.E.L. Brown, early operated his own alternators, with smooth iron armature cores, in parallel with Gans alternators which have highly reactive, pole type armatures. The former gave a voltage curve which approximated a sinusoid while the latter's curve was quite irregular and peaked. Dr. Steinmetz also early operated machines with smooth iron armature cores in parallel with others having toothed cores. These experiments showed that machines with different voltage curves could be run together satisfactorily, as is now very frequently done, but they require considerably increased change of current as compared with the synchronizing current of machines with voltage curves which are exactly alike. For, since the unlike curves cannot coincide even when the machines are exactly in step, a current of a more or less irregular wave form will be exchanged between the machines and this is superimposed upon the true synchronizing current. This superimposed current may have a very different frequency from that of the machines, as it is not necessarily without a power component, because  $I^2R$  losses always result from the flow of this current.



G-7:G-8 230 Volt Synchronous Alternators  
Operating in Parallel.  
At No Load

This Plot Indicates The Power and Current Values  
for Various phase Relations of the Induced Voltages 7 and 8

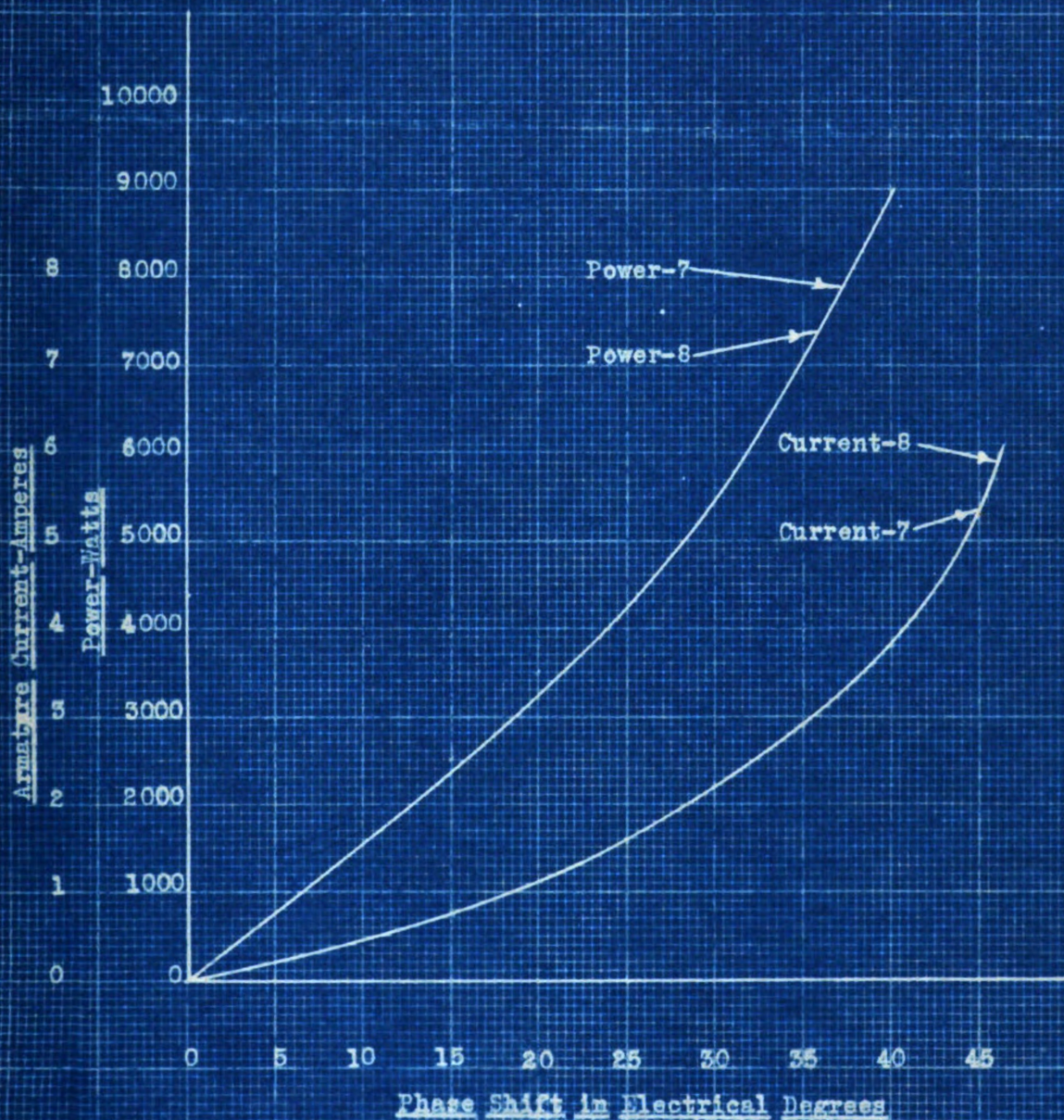
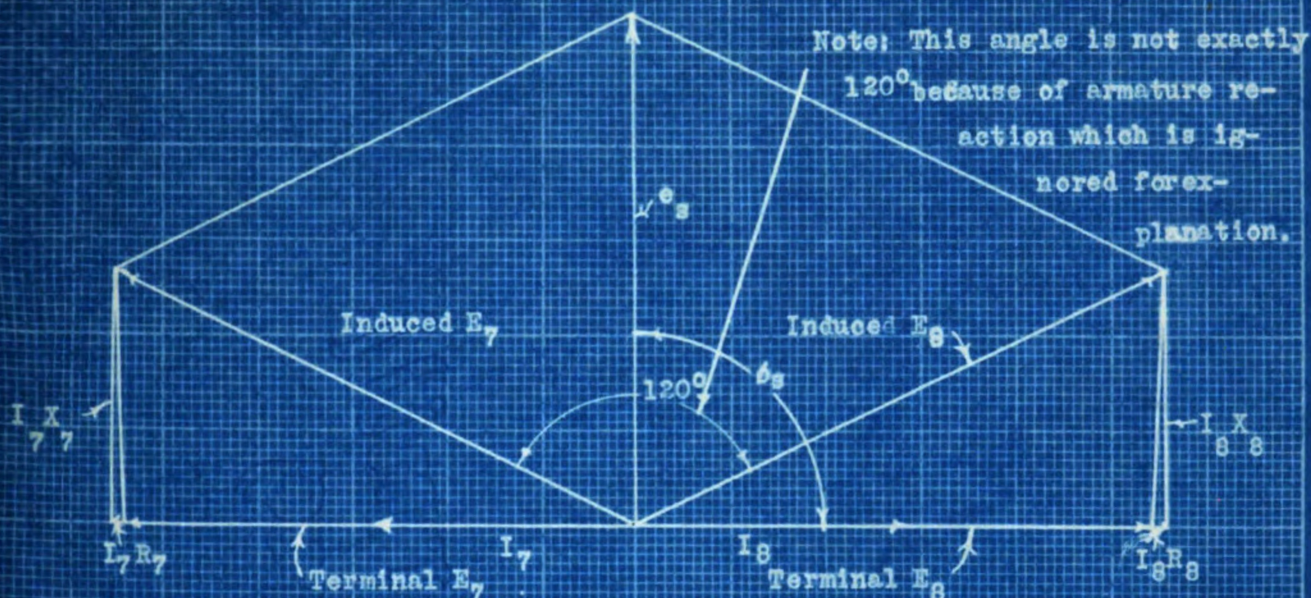


Diagram  
No.45.





Vector Diagram Showing  
all voltages and currents  
with G-7; G-8 Operating in Parallel  
without load  
With Phase shift of 60° or 30° (elec.)

$I_7$  equals  $I_8$  equals 13.85 amperes

$E_7$  equals  $E_8$  equals 229 volts

P.F.  $_7$  equals P.F.  $_8$  equals 100%

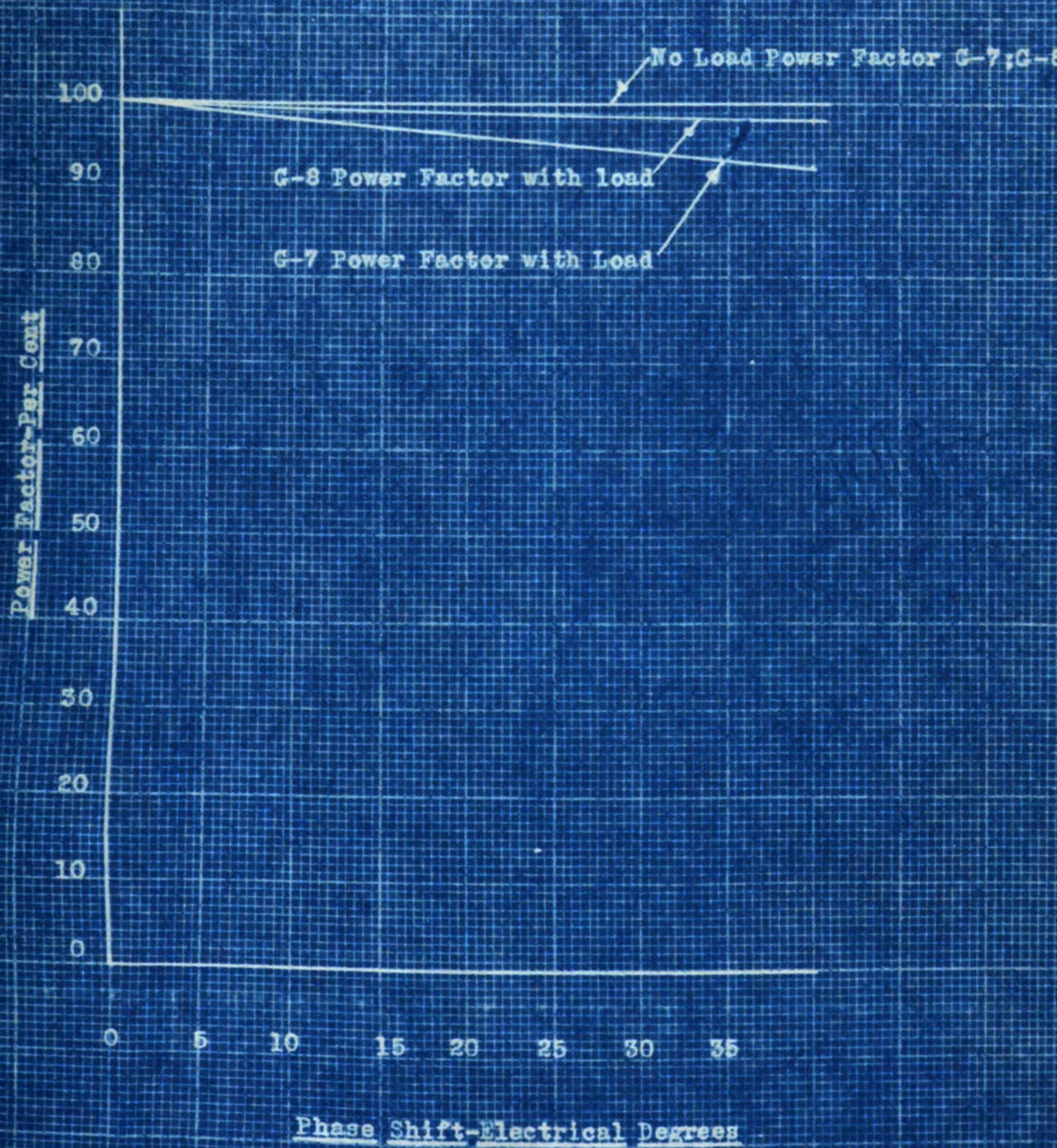
$I_7 R_7$  equals  $I_8 R_8$  equals 3.93 volts

$I_7 X_7$  equals  $I_8 X_8$  equals 67.2 volts.

Note: The above diagram, is constructed from phase values.

Diagram  
No.46.



G-7;G-8 230 Volts Synchronous Generators.Operating in ParallelPlot of Power Factor vs. Phase Shift without load and  
With Fixed Load

Diagram

No.47.



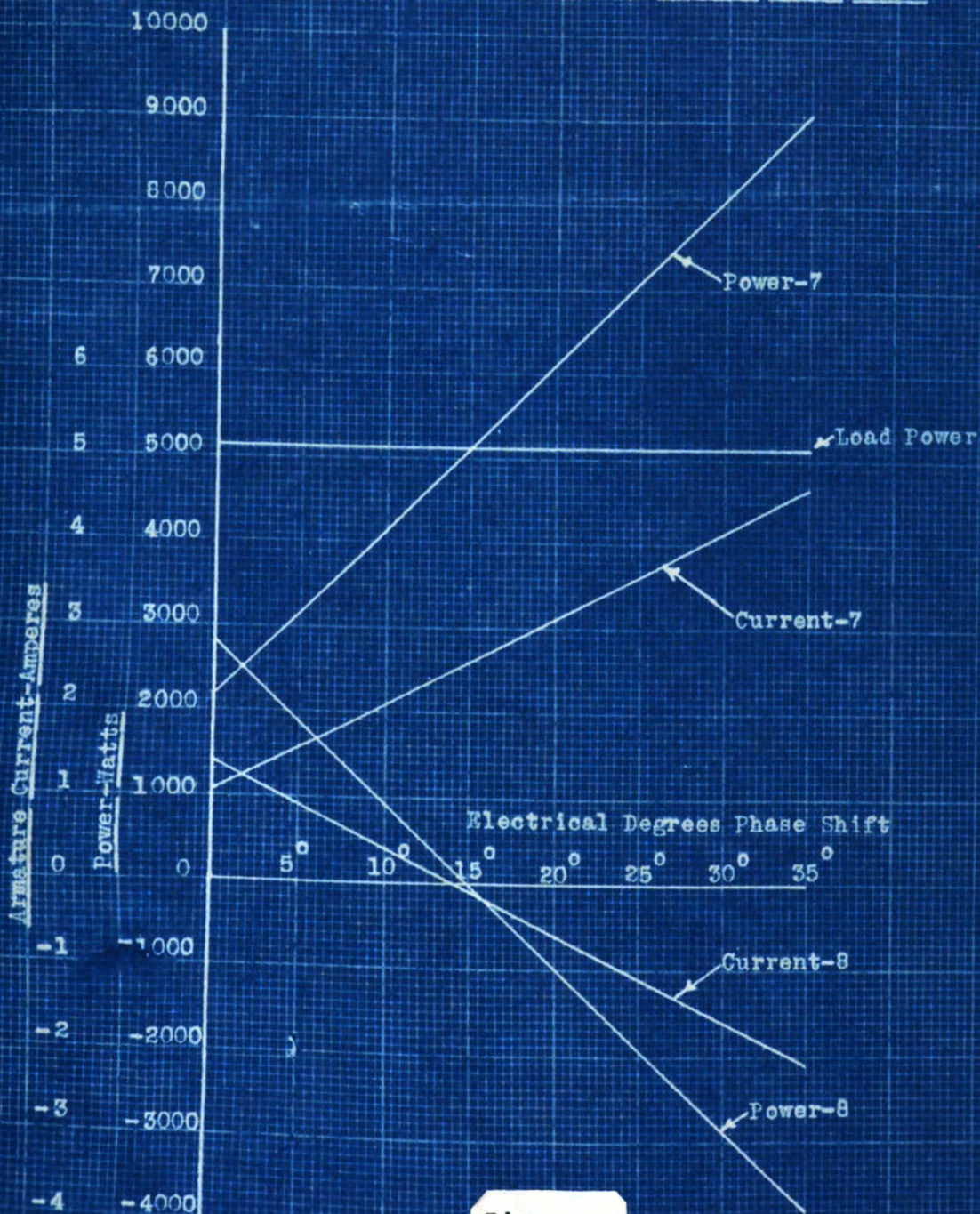
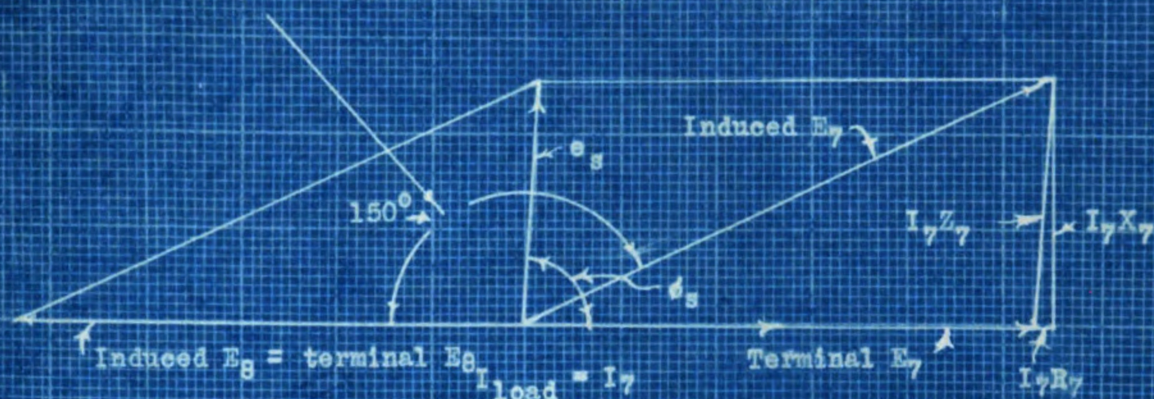
G-7; G-8 230 Volt Synchronous AlternatorsOperating in ParallelWith Constant LoadPlot of Current and Power Values against Phase Shift

Diagram  
No.48.



Note: Due to armature reaction, which is ignored for the purposes of explanation, this angle would not be exactly  $150^\circ$ .



Vector Diagram Showing  
all voltages and current res.  
with G-7; G-8 Operating in Parallel  
with resistance load  
and Phase Shift of  $15^\circ$  (E. Degr.)

---

$I_7$  equals 13.15 amperes

$E_7$  equals 230 volts

P.F.  $_7$  equals approx 1.00

$I_8$  equals 0

---

$I_7 R_7$  equals 3.83 volts

$I_7 X_7$  equals 65.4 volts

---

Note: The above diagram, is constructed from phase values.

Diagram  
 No. 49.



Note: The induced voltages are not respectively exactly  $180^\circ$  out of phase as they are indicated. This is due to ignoring armature reaction.



Diagram  
No. 50.

Vector Diagram Showing  
all Voltage and Currents.  
with G-7: G-8 Operating in Parallel  
with resistance load  
Excitation-7 Up: Excitation-8 Down

---

$I_7$  equals 11.15 amps

$I_8$  equals 9.15 amps

P.F. <sub>7</sub> equals .70

P.F. <sub>8</sub> equals .517

$I_7 R_7$  equals 3.17 v.  $I_8 R_8$  equals 2.6v.

$I_7 X_7$  equals 54.2 v.  $I_8 X_8$  equals 44.3 v.

---

Note: The above diagram is constructed using phase values.



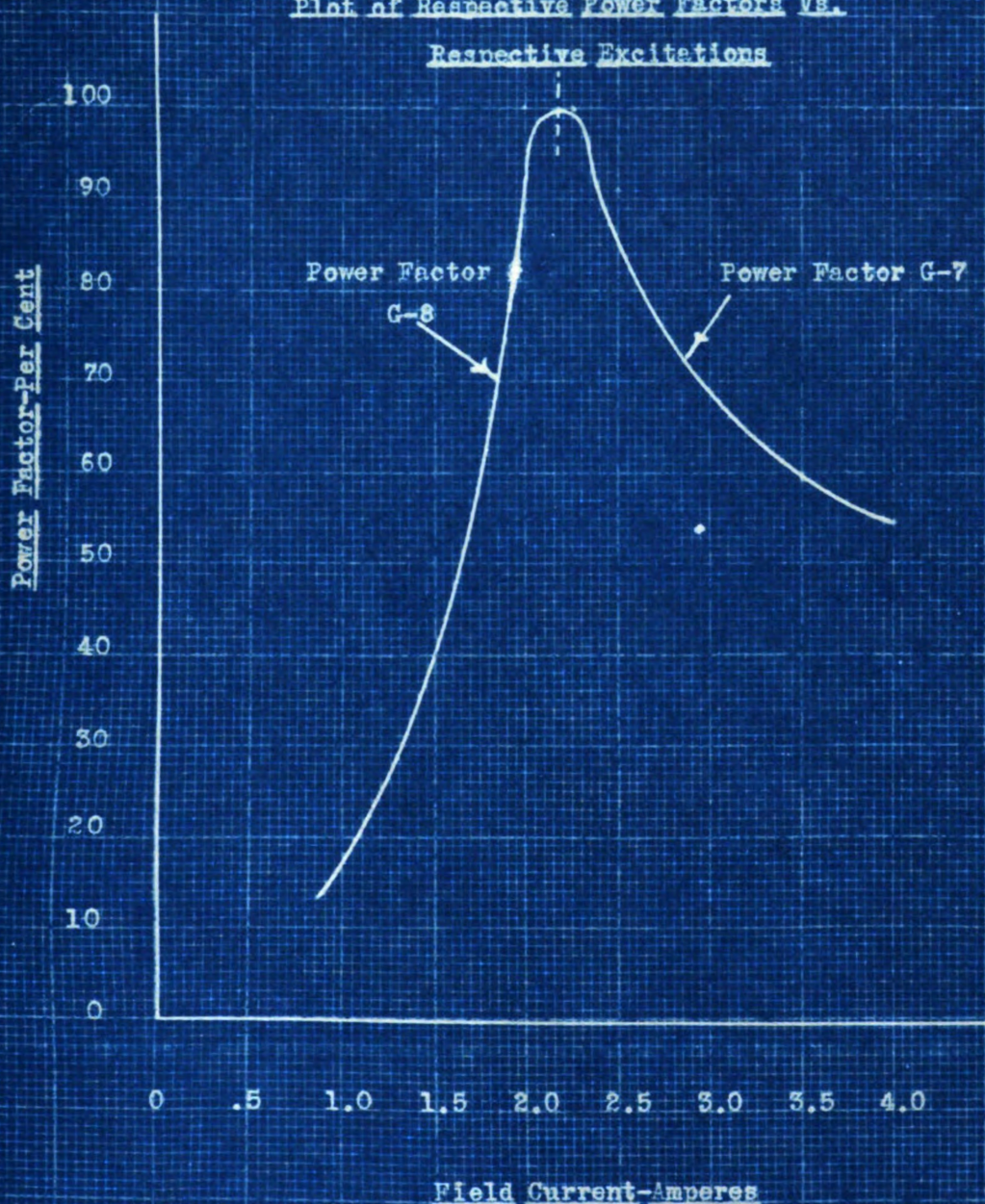
G-7; G-8 230 Volt Synchronous GeneratorsOperating in ParallelBus Voltage is held Constant - Excitation of G-7 increasedExcitation G-8 DecreasedPlot of Respective Power Factors Vs.Respective Excitations

Diagram  
No. 51.



CHAPTER NO. 7.REGULATIONDETERMINATIONS FOR G-7 and G-8 BY VARIOUS METHODS:

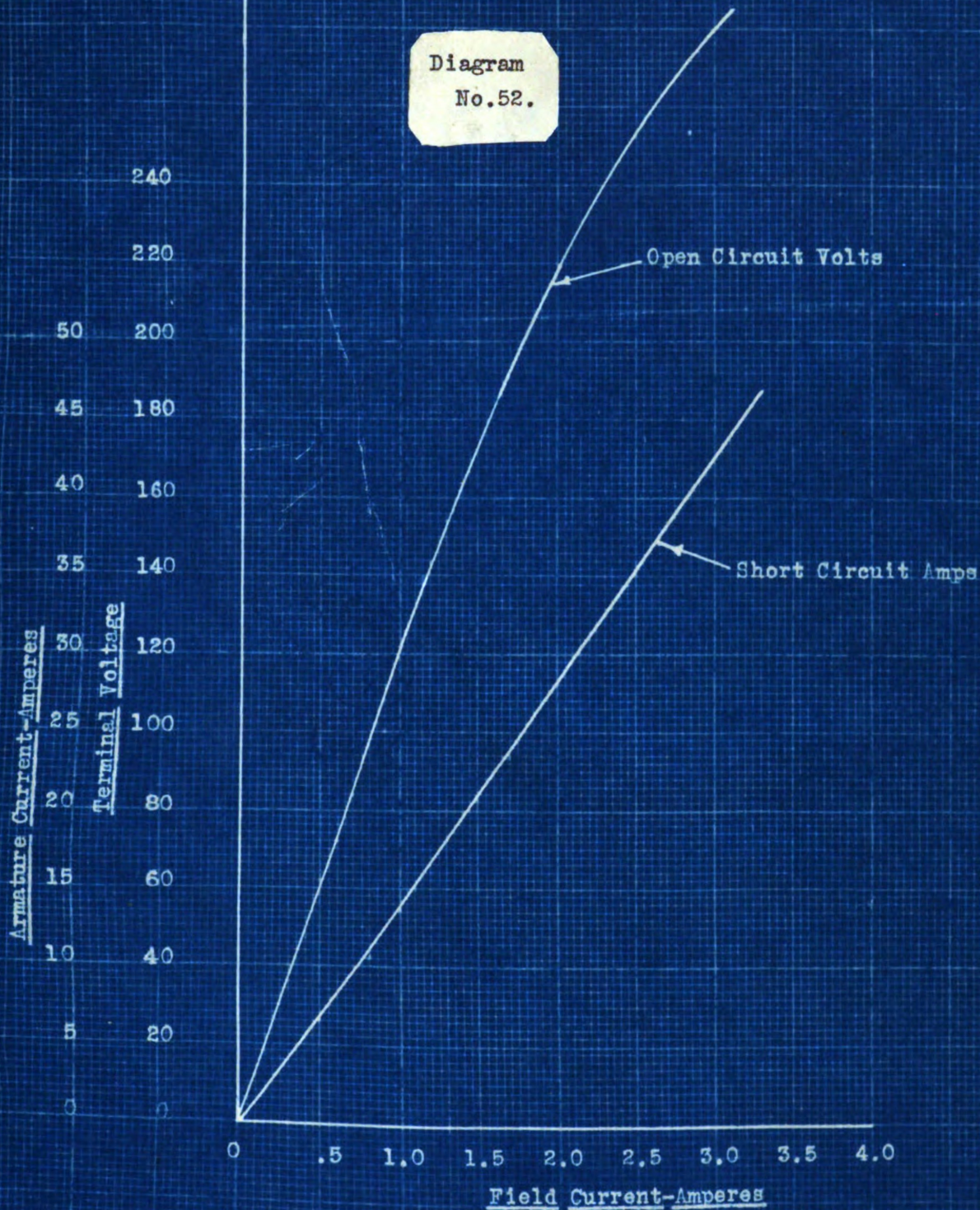
Open circuit and short circuit curves were drawn for G-7 and for G-8. These are included in diagrams No. 52 and 53. The curves for the two machines are so nearly identical that the regulation computations are carried thru for only one machine.

Regulation was also determined by actual test for unity power factor and for .7 lead and .7 lag.

The following table contains the results of the different methods of determining regulation together with the actual values obtained experimentally.

| REGULATION DATA         |         |          |              |
|-------------------------|---------|----------|--------------|
| Method of determination | % P. F. | Machine  | % Regulation |
| E. M. F.                | 100     | G-7; G-8 | 24.10        |
| M. M. F.                | 100     | ditto    | 10.90        |
| A. I. E. E.             | 100     | ditto    | 12.50        |
| Actual test G-7         | 100     | G-7      | 12.60        |
| Actual test             | 100     | G-8      | 12.80        |
| E. M. F.                | 70 lag  | G-7; G-8 | 48.80        |
| M. M. F.                | 70 lag  | ditto    | 41.70        |
| A. I. E. E.             | 70 Lag  | ditto    | 23.50        |
| Actual test             | 70 lag  | G-7      | 25.10        |
| Actual test             | 70 lag  | G-8      | 24.90        |
| E. M. F.                | 70 lead | G-7; G-8 | -25.95       |
| M. M. F.                | 70 lead | ditto    | -26.00       |
| A. I. E. E.             | 70 lead | ditto    | -21.70       |
| Actual test             | 70 lead | G-7      | -23.20       |
| Actual test             | 70 lead | G-8      | -23.70       |

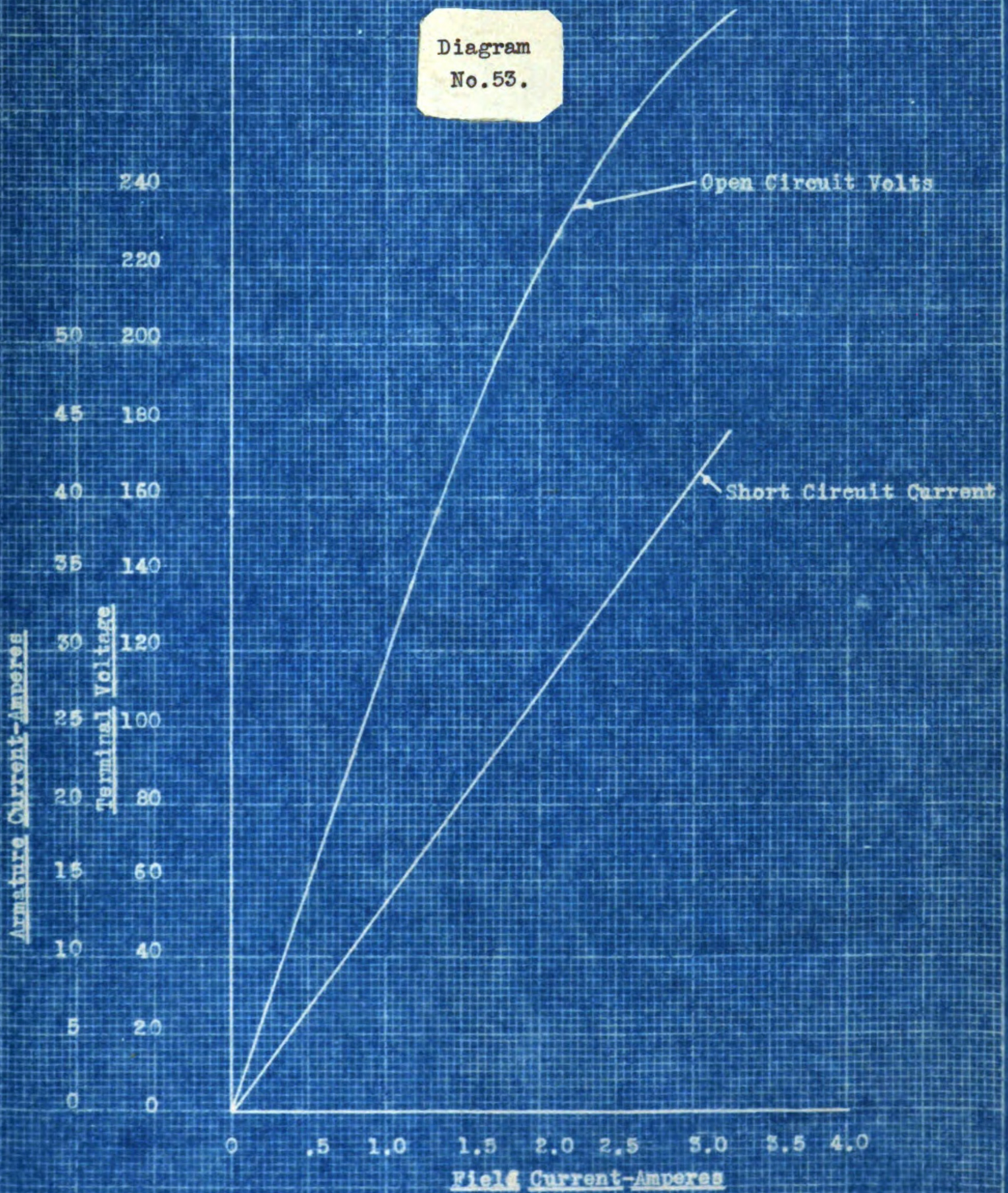




Open Circuit and Short Circuit Curves for G-8  
Based on Terminal Values



Diagram  
No. 53.



Open Circuit and Short Circuit Curves for G-7  
Based on Terminal Values



## REGULATION BY E.M.F. METHOD:

Rated current equal 18.8 amperes. From the short circuit curve this current corresponds to a field excitation at short circuit on the armature, of 1.35 amperes. The open circuit terminal voltage corresponding to this value of field current equals 158 volts. The reactance drop at full load current is thus shown to be 158 volts.  $IZ_s$  equals therefore,  $158/18.8 \sqrt{3}$  equals 4.85 ohms, the synchronous impedance per phase.

% Regulation equals  $100(\text{No load voltage} - \text{full load voltage}) / \text{full load voltage}$ . Let full load voltage equals  $E_L$  and no load voltage equal  $E_o$  with synchronous reactance and resistance per phase equal to  $x_s$  and  $r_s$  respectively. Consider diagram No. 54.

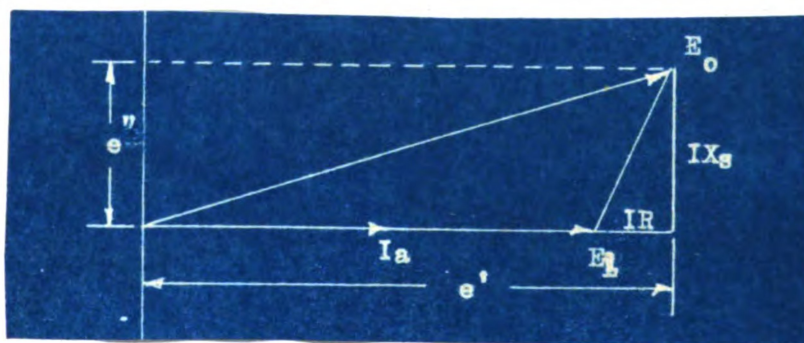


Diagram No. 54.

$\dot{E}_o$  equals  $\dot{E}_L$  plus  $\dot{I} (R + j x_s)$  When the power factor is unity  
 $\dot{E}_o$  equals  $(133.04 \text{ plus } j0) \text{ plus } 18.8 (.284 \text{ plus } j 4.85) \text{ equals}$   
 $(138.34 + j71.1)$ .  $E_o$  equals 165 volts. Thus % regulation equals  
 $100 (165 - 133) / 133 \text{ equals } 24.0 \%$

When power factor equals .7 lag  $\dot{E}_o$  equals  $(133 \times .7 \text{ plus } j .7 \times 133)$   
 $\text{plus } 18.8 (.284 \text{ plus } j 4.85) \text{ equals } 98.34 \text{ plus } j 184.1 \text{ equals an}$   
 $\text{effective value of voltage of } 208 \text{ volts. Thus \% regulation equals}$   
 $(208 - 133) 100 / 133 \text{ equals } 48.8 \%$



When power factor equals .7 lead  $E_o$  equals 133 (.7 - j.7)  
 plus 18.8 (.284 plus j 4.85 ) equals (93.1 - j93.1 ) plus (5.35 plus 91.2)  
 equals 98.45 - j1.9 .  $E_o$  equals 98.5 volts . % regulation equals  
 100 (98.5 -133/133 equals -25.95 % .

Diagrams No. 55 and 56 indicate the application of the e.m.f. and m.m.f. methods for power factors of  $\phi$  degrees lagging and leading respectively.

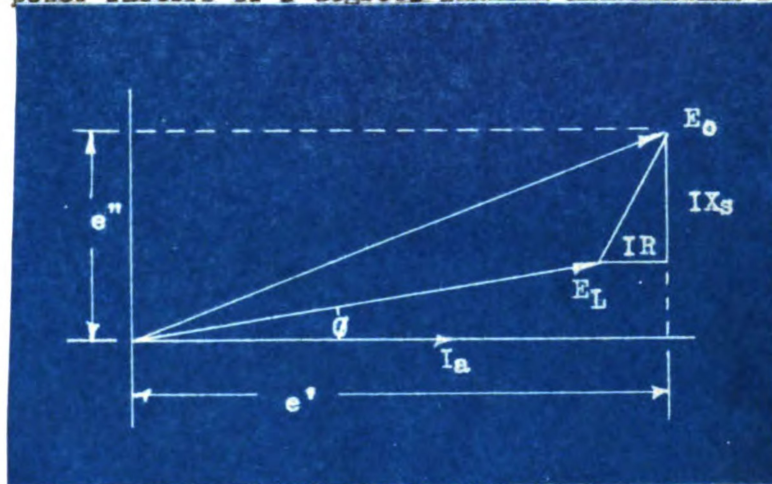


Diagram No. 55.

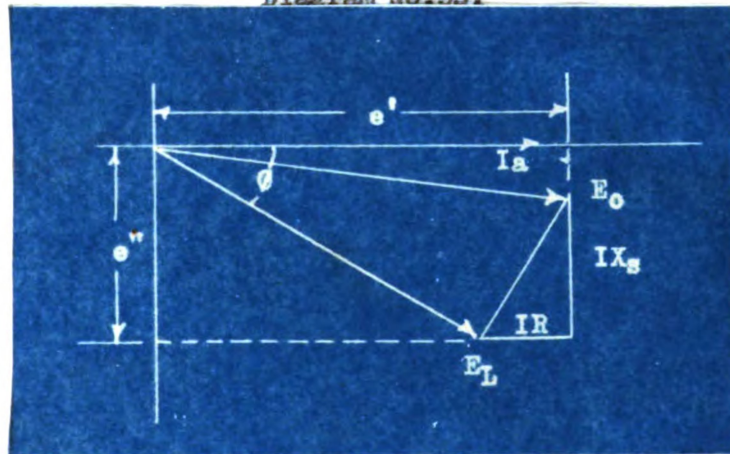


Diagram No. 56.

#### REGULATION BY M.M.F. METHOD:

The magnetomotive force method used was as follows.  $E_o$  was obtained in the same way as for the e.m.f. method and was then resolved into two components  $e_b$  and  $e''$  as shown in diagrams No. 54-56. The field currents corresponding to the voltages  $e_b$  and  $e''$  were obtained from the open circuit curve and were added vectorially



to obtain a value  $I_p$ . The voltage corresponding to a field current  $I_p$  was determined from the open circuit curve and was used as the no load voltage  $E_o$  in the determination of regulation.

For unity power factor.  $e'$  equals 116 and  $e''$  equals 116  
Then from the open circuit curve  $I_p'$  equals 1.8 amperes while  
 $I_p''$  equals 1.8 amperes.  $I_p$  equals 2.54 amperes.  $E_o$  corresponding  
to a field current of 2.54 amperes equals 147.5 volts. % regulation  
equals  $100(147.5-133)/133$  equals 10.9 %.

When power factor equals .7 lag.  $e'$  equals 98.34 while  $e''$   
equals 184.1.  $I_p'$  equals 1.5 amperes while  $I_p''$  equals 4.2 amperes.  
 $I_p$  equals 4.46 amperes.  $E_o$  corresponding to a field current of  
4.46 amperes equals 188.5 volts. Therefore % regulation equals  
 $100(188.5-133)/133$  equals 41.7%.

When the power factor equals .7 lead.  $e'$  equals 98.45  
while  $e''$  equals -1.9.  $I_p'$  equals 1.5  $I_p''$  equals practically zero  $I_p$   
Therefore equals 1.5 amperes which corresponds to a voltage of 98.45.  
Hence % regulation equals  $100(98.45-133)/133$  equals 26%.

#### REGULATION BY A.I.E.E. METHOD:

The zero power factor curve was constructed from the open  
circuit curve by subtracting from it at all points the full load  $I Z_s$   
drop. For any given field excitation and zero power factor the  
voltage that would be induced on open circuit referring to diagram  
No. 58 is c-a and the apparent internal drop under load is ba.  
The % regulation is thus  $100ba/ca$ . The terminal voltage for other  
power factors is found by drawing e.m.f. diagrams similar to diagram  
No. 58. The line b-f is drawn at the power factor angle  $\phi$  from the



the X axis. The IZ drop is drawn from b as shown, and then a-c as taken from the curve is drawn intersecting f-b at e. e-b is then the terminal voltage at the power factor equal to  $\cos \phi$ . c-b is then laid off on the curve of diagram No. 57 thus locating the point d. By repeating this process for several field excitations, the full load saturation curve may be obtained for any desired power factor. The regulation from this curve for a given power factor is  $\frac{100 d'a}{ea}$ . in which d' is the point of intersection between the normal voltage line and the saturation curve.

---

For unity power factor. % regulation equals  $16 \times 100 / 130$  equals 12.3

For power factor of .7 lag % regulation equals  $54 \times 100 / 230$  equals 23.3

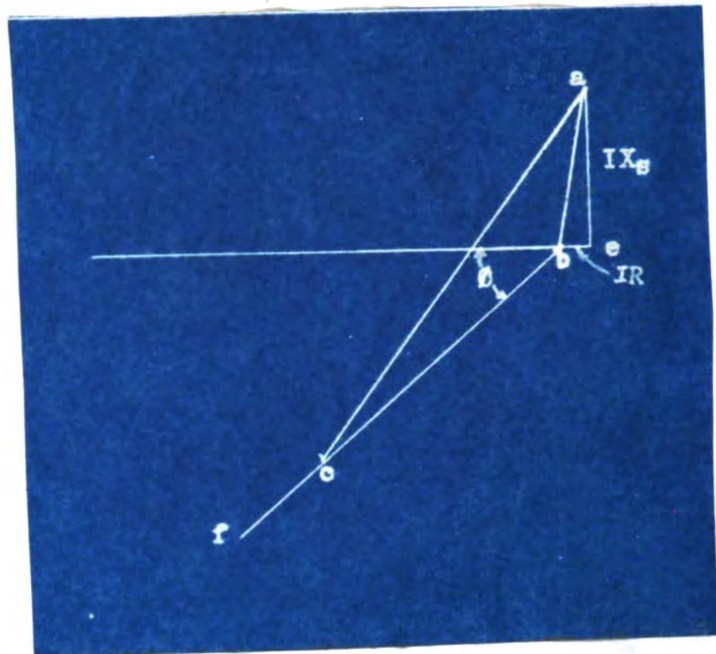
For power factor of .7 lead % regulation equals  $-50 \times 100 / 230$  or -21.7

---

#### DISCUSSION OF RESULTS:

The conclusion to be drawn from the above calculation, at <sup>last</sup> as far as the machines considered are concerned is clear cut and definite. The A.I.E.E method in each instance gives excellent results which check very well with those actually obtained in the laboratory. Both the m.m.f. method and the e.m.f. method give values in each case which do not check against the actual. The above calculations, do not bear out the <sup>statement</sup> generally supposed fact that the mean of the m.m.f. method and the e.m.f. methods gives about the correct values. While the results obtained in this connection may not be general, it can hardly be said that these conclusions are general. However, it would certainly be much safer in view of these results to advocate the A.I.E.E. method in preference to either of the other two as far as accuracy is concerned.

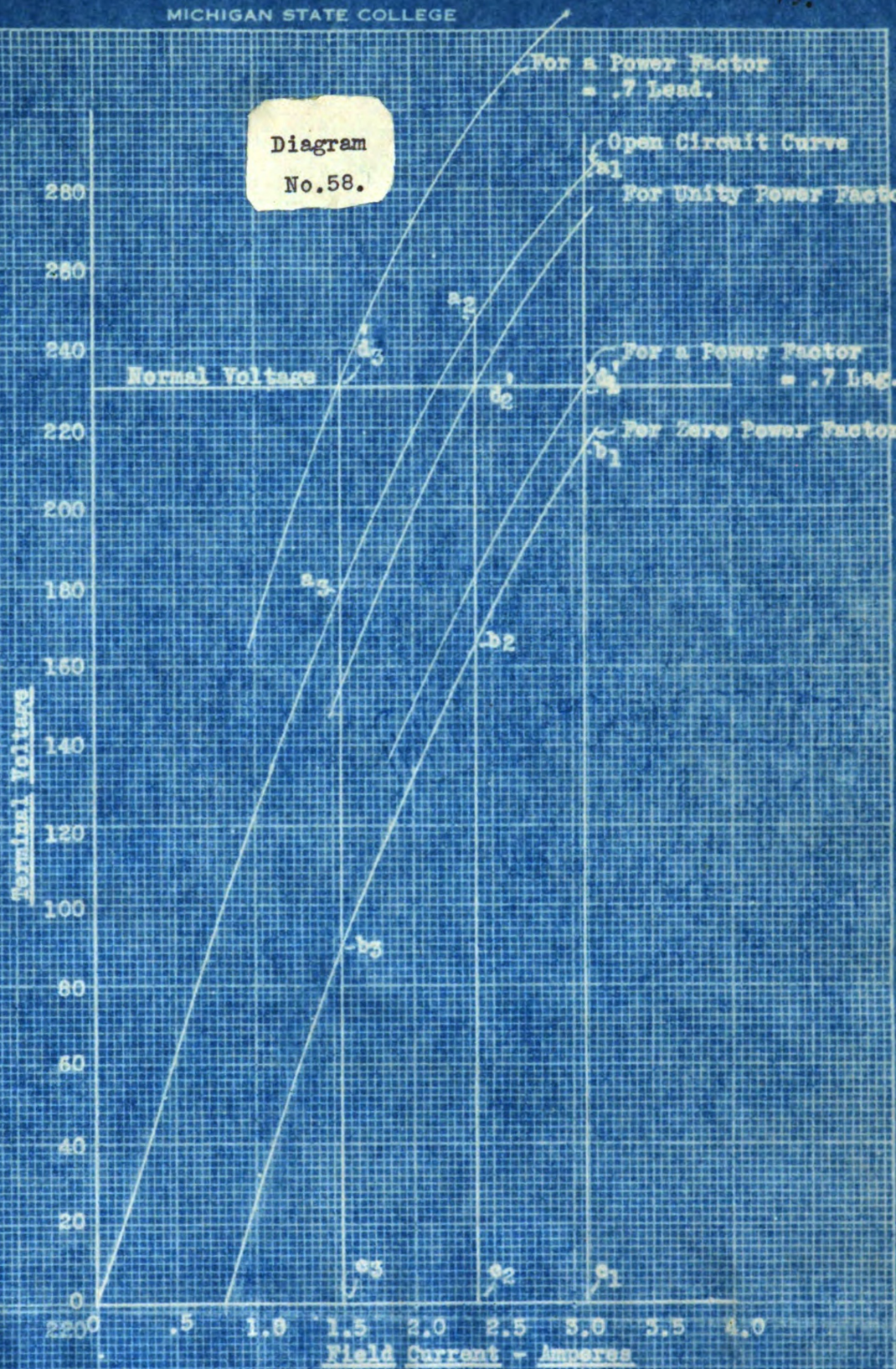




**Diagram No. 57- A.I.E.E. Method of Determining Regulation.**



Diagram  
No. 58.



Saturation Curves for G-7 and G-8

Used for the Determination of

Regulation by the A.I.E.E.

Method.



CHAPTER NO. 8.WAVE FORMS**COMMERCIAL WAVE FORMS:**

In small plants operating at comparatively low potentials the current and voltage waves are not of great importance. As this was the most common condition in the earlier development of the electrical industry, little attention was then given to wave forms. However, the vast extensions of electrical systems of distribution and the necessity for operating long distance transmission lines at high potentials demand very careful attention to all factors that may produce wave distortion.

There are two fundamental requisites of the wave form in constant potential systems:

- (1) In parallel operation, the waves should be equal at all instants. to prevent cross currents.
- (2) The differentials and integrals of the curve should have the same shape as the generated voltage wave.

For alternating currents generated by rotating machinery both requirements are met by simple sine waves.

The principle unavoidable factor in producing distortion in wave forms is the variable permeability of iron. Many other causes are due to faulty design or construction.

The generated voltage wave of a properly designed alternator should approach very closely the standard sinusoidal form. Of course in many cases, the inherent characteristics of the load lead to a distorted current wave which would be normal under a normal load.



Hence care must be exercised in large interconnected systems to avoid such conditions which would lead to distortion in parts of the network.

In the light of the above general observations it seems advisable to consider ~~at least~~ briefly the wave forms of the synchronous generators No.7 and 8.

Diagram No. 59 shows the wave form of the current supplied by G-8 under a heavy condensive load. Diagram No.60 indicates the same condition for G-7 though a slightly different shunt was used to actuate the oscillograph element. It may be readily seen that these waves are practically sinusoidal.

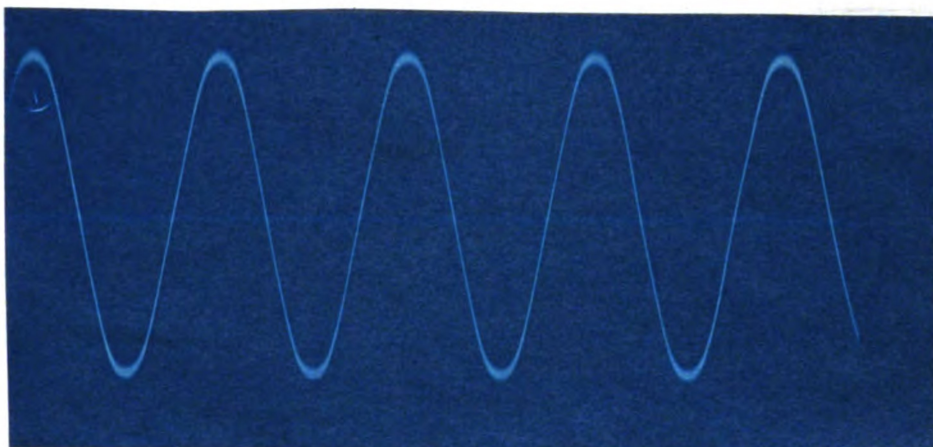


Diagram No. 59-Wave Form of G-8

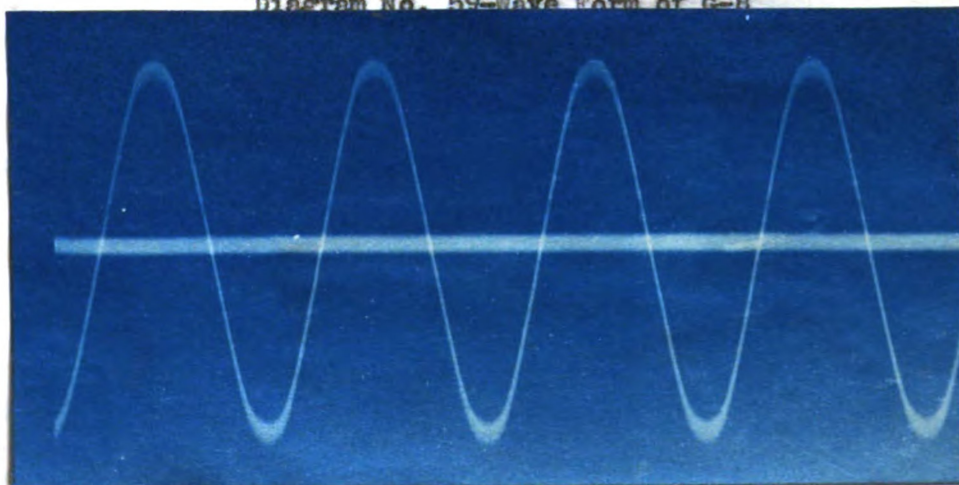


Diagram No.60.- Wave Form of G-7

Diagram No 61 indicates equal voltages of G-7 and G-8 in phase opposition. This corresponds to a zero phase rotation setting



of the G-7 rotor. It may be seen that the machines are properly aligned on the shaft for their voltages are correspondingly just  $180^\circ$  out of phase at all times. Likewise when the two voltages were connected in phase they appeared identical. This investigation was carried thru for each phase though only one pair of phases is considered in the diagram.

Diagram No. 62 shows the currents of each phase of G-7 with a balanced resistance load such as to give rated current.

Diagram No. 63 indicates starting conditions of armature voltage, current, and field current. It may be seen that for starting, reduced armature voltage is applied and a high armature current of irregular form flows. An alternating field current also flows due to the fact that the lines of force of the rotating field cut the field coils first at a high rate thereby inducing a high voltage across the terminals of the field which causes an alternating current to flow. The resistance is provided across the field for starting to prevent damage to insulation due to the high voltage induced. When the machine has reached synchronous speed, it may be seen that the field current is zero because the field structure is traveling at the same rate as the field, hence no lines of force cut the field windings. At this point, the d.c. switch is closed exciting the field. As the machine pulls into step there is a transitory rush of current as shown by the irregularity of the armature current wave. The full armature voltage was then applied and after a temporary instantaneous surge of field current and armature current, all values settled down to those of normal operation.



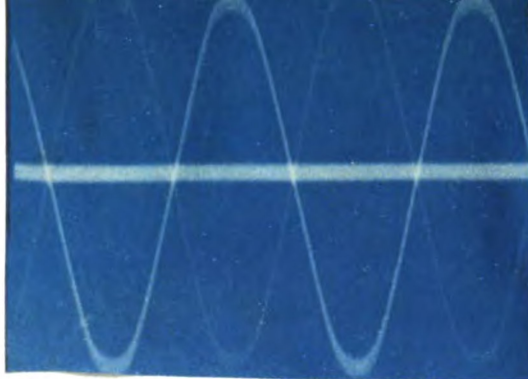


Diagram No. 61 G-7 and G-8 in phase opposition.

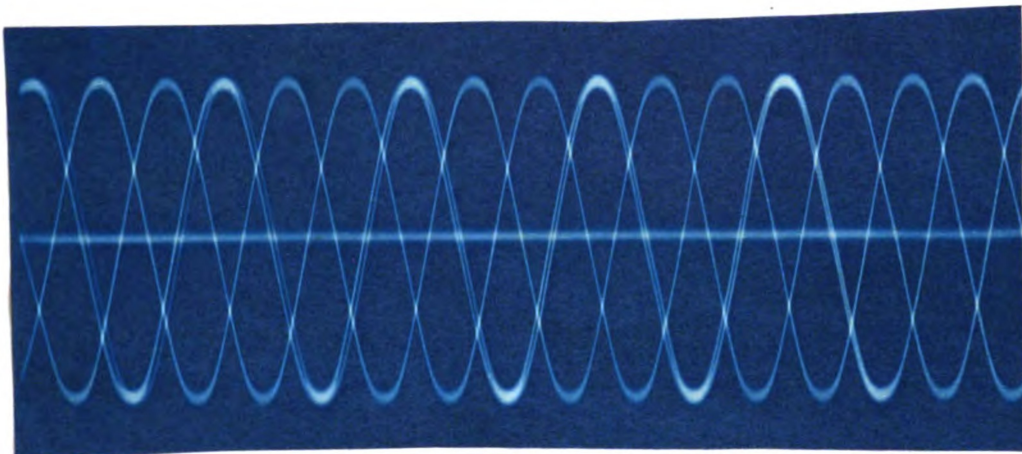


Diagram No. 62. Three phase currents of G-7.



$E_d$

$I_f$

$I_a$

— Reduced Armature Voltage-Field Shorted thru Resistance —

— d.c. field on Full Armature Volts —

Oscillograms showing starting armature current-field

current and armature terminal volts .

for 2200 Volt Motor

M-7

Diagram  
No. 63



Data for the Determination of Iron-Friction-Windage Losses for

G-7; G-8; M-7

Speed held constant at 1800 r.p.m.

Field Current of d.c. machine constant at .26 amps

| No Load                                                       | Power Input d.c. machine<br>watts | I <sub>a</sub><br>d.c. | I <sub>f</sub><br>alternator |
|---------------------------------------------------------------|-----------------------------------|------------------------|------------------------------|
| No Load                                                       | 145                               | 1.00                   | 0.0                          |
| Friction-Windage of                                           |                                   |                        |                              |
| G-7; G-8; M-7                                                 | 1045                              | 7.08                   | 0.0                          |
| Friction-Windage for<br>all machines Iron loss<br>for G-8     |                                   |                        |                              |
|                                                               | 1297                              | 8.78                   | 6.0                          |
| Ditto as above but iron<br>loss for different ex-<br>citation |                                   |                        |                              |
|                                                               | 1157                              | 7.80                   | 2.0                          |
| Ditto as above                                                |                                   |                        |                              |
|                                                               | 1208                              | 8.20                   | 4.0                          |
| Friction-Windage for<br>all machines and Iron<br>loss for G-7 |                                   |                        |                              |
|                                                               | 1510                              | 7.75                   | 6.0                          |
| Ditto as above for<br>different excitation                    |                                   |                        |                              |
|                                                               | 1214                              | 8.20                   | 4.0                          |
| Ditto as above                                                |                                   |                        |                              |
|                                                               | 1150                              | 8.75                   | 2.0                          |
| Friction-Windage for<br>all machines and Iron<br>loss for M-7 |                                   |                        |                              |
|                                                               | 2100                              | 13.70                  | 10.0                         |
| Ditto as above for<br>different excitation.                   |                                   |                        |                              |
|                                                               | 1714                              | 11.50                  | 6.0                          |
| Ditto as above                                                |                                   |                        |                              |
|                                                               | 1413                              | 8.50                   | 3.1                          |
| Friction-Windage of<br>G-8 alone                              |                                   |                        |                              |
|                                                               | 400                               | 2.60                   | 0.0                          |

Resistance Data for D.C. Machine

|   |      |      |      |
|---|------|------|------|
| I | 2.02 | 2.60 | 3.00 |
| E | 3.95 | 5.10 | 5.82 |
| R | 1.95 | 1.96 | 1.94 |

Mean Armature Resistance equals 1.95 ohms



Iron Losses of G-7; G-8; M-7.

---

Friction-Windage of all Machines plus No Load Losses of d.c.

---

Machine equal 947.5 Watts

---

Generator No.8.

| Field Current<br>of alternator | Total watts input to d.c.<br>machine | Cu. Loss in<br>d.c. machine | Watts Iron<br>loss G-8 |
|--------------------------------|--------------------------------------|-----------------------------|------------------------|
| 6.0                            | 1297                                 | 150                         | 200                    |
| 4.0                            | 1208                                 | 151                         | 150                    |
| 2.0                            | 1157                                 | 119                         | 91                     |

---

Generator No.7.

|     |      |     |     |
|-----|------|-----|-----|
| 6.0 | 1310 | 150 | 210 |
| 4.0 | 1214 | 151 | 154 |
| 2.0 | 1150 | 117 | 95  |

---

Motor No.7.

|      |      |     |     |
|------|------|-----|-----|
| 10.0 | 2100 | 330 | 825 |
| 6.0  | 1714 | 275 | 510 |
| 3.1  | 1413 | 141 | 325 |

---

Friction-Windage Losses

---

|                                          |           |
|------------------------------------------|-----------|
| Friction-Windage Loss of Generator No.7. | 285 watts |
| Friction-Windage Loss of Generator No.8. | 244 watts |
| Friction-Windage Loss of Motor No.7.     | 275 watts |

---

**Note:**

It is of interest to note in the above tabulation of friction-windage losses, the machine G-7 has a somewhat larger loss than the machine G-8 while their construction is to all appearances identical. This is due, however, to the fact that the stator of G-7 is actually suspended from the shaft, thus causing a greater friction loss.



Open Circuit Data for G-7 : G-8

| $I_f$ | $\overset{G-7}{E_{x-y}}$ | $E_{s-y}$ | $E_{x-s}$ | $I_f$ | $\overset{G-8}{E_{x-y}}$ | $E_{s-y}$ | $E_{x-s}$ |
|-------|--------------------------|-----------|-----------|-------|--------------------------|-----------|-----------|
|       |                          |           |           |       |                          |           |           |
| .40   | 48.5                     | 50.0      | 49.5      | .30   | 35.0                     | 36.0      | 36.0      |
| .50   | 61.0                     | 62.0      | 61.5      | .40   | 47.5                     | 50.0      | 47.5      |
| .60   | 73.0                     | 74.0      | 73.5      | .50   | 61.0                     | 62.2      | 61.5      |
| .70   | 85.0                     | 86.5      | 85.5      | .60   | 71.8                     | 73.0      | 72.2      |
| .80   | 98.0                     | 99.0      | 98.5      | .70   | 83.5                     | 84.5      | 84.0      |
| .90   | 109.5                    | 110.5     | 110.0     | .80   | 97.2                     | 98.0      | 97.5      |
| 1.00  | 123.0                    | 123.5     | 123.0     | .90   | 109.5                    | 110.5     | 110.0     |
| 1.10  | 132.0                    | 133.0     | 132.5     | 1.00  | 121.5                    | 122.5     | 121.8     |
| 1.30  | 156.0                    | 155.0     | 156.0     | 1.10  | 132.0                    | 132.5     | 132.0     |
| 1.40  | 166.0                    | 165.0     | 166.0     | 1.20  | 143.5                    | 144.2     | 143.8     |
| 1.50  | 177.0                    | 176.0     | 177.0     | 1.30  | 156.0                    | 155.0     | 156.0     |
| 1.60  | 186.0                    | 185.0     | 186.0     | 1.40  | 164.5                    | 164.0     | 164.0     |
| 1.70  | 197.0                    | 196.0     | 197.0     | 1.50  | 175.0                    | 174.0     | 175.0     |
| 1.90  | 206.0                    | 205.0     | 206.0     | 1.60  | 185.0                    | 184.0     | 185.0     |
| 2.00  | 220.0                    | 219.0     | 220.0     | 1.70  | 195.0                    | 194.0     | 195.0     |
| 2.22  | 234.0                    | 233.0     | 235.0     | 1.80  | 204.0                    | 203.0     | 204.0     |
| 2.50  | 252.0                    | 252.0     | 252.0     | 2.00  | 220.0                    | 219.0     | 220.0     |
| 2.70  | 263.0                    | 262.0     | 263.0     | 2.20  | 234.0                    | 233.0     | 234.0     |
| 2.90  | 273.0                    | 272.0     | 273.0     | 2.40  | 243.0                    | 243.0     | 243.0     |
| 3.20  | 286.0                    | 285.0     | 285.0     | 2.60  | 258.0                    | 257.0     | 258.0     |
|       |                          |           |           | 3.00  | 278.0                    | 276.0     | 277.0     |

Short Circuit Data For G-7; G-8

| $I_f$ | $I_x$ | $I_y$ | $I_s$ | $I_f$ | $I_x$ | $I_y$ | $I_s$ |
|-------|-------|-------|-------|-------|-------|-------|-------|
| .28   | 4.0   | 4.0   | 4.0   | .27   | 4.0   | 4.0   | 4.0   |
| .40   | 5.2   | 5.2   | 5.2   | .40   | 5.2   | 5.2   | 5.2   |
| .55   | 7.3   | 7.2   | 7.3   | .50   | 6.7   | 6.5   | 6.6   |
| .60   | 7.9   | 7.8   | 7.8   | .60   | 8.0   | 7.8   | 7.8   |
| .70   | 9.4   | 9.3   | 9.4   | .70   | 9.3   | 9.2   | 9.3   |
| .80   | 10.7  | 10.7  | 10.7  | .80   | 10.7  | 10.6  | 10.6  |
| .90   | 12.2  | 12.2  | 12.2  | .90   | 12.3  | 12.2  | 12.2  |
| 1.10  | 15.2  | 15.3  | 15.3  | 1.00  | 13.7  | 13.7  | 13.7  |
| 1.20  | 16.30 | 16.3  | 16.2  | 1.10  | 15.0  | 15.0  | 15.0  |
| 1.30  | 17.7  | 17.8  | 17.7  | 1.20  | 16.4  | 16.3  | 16.3  |
| 1.40  | 19.2  | 19.2  | 19.1  | 1.30  | 17.7  | 17.7  | 17.7  |
| 1.50  | 20.4  | 20.5  | 20.3  | 1.40  | 19.1  | 19.2  | 19.1  |
| 1.60  | 21.9  | 22.0  | 21.8  | 1.50  | 20.6  | 20.7  | 20.6  |
| 1.70  | 23.4  | 23.4  | 23.2  | 1.60  | 22.0  | 22.0  | 21.8  |
|       |       |       |       | 1.70  | 23.4  | 23.4  | 23.3  |



Performance Curve Data for G-8 .

Field Excitation equals

1.5 Amps or 60%

| K.W. Input | Cu. Loss<br>watts | Input-Losses<br>K.W. | Efficiency-% | I<br>amperes | P.F.-% |
|------------|-------------------|----------------------|--------------|--------------|--------|
| 6.85       | 170               | 6.15                 | 92.6         | 20.0         | 80.0   |
| 5.43       | 110               | 5.00                 | 92.2         | 16.4         | 79.6   |
| 4.10       | 73                | 3.70                 | 90.4         | 13.2         | 74.7   |
| 3.52       | 64                | 3.13                 | 89.5         | 12.1         | 70.0   |
| 3.00       | 48                | 2.63                 | 84.4         | 10.4         | 69.5   |

In the above calculations, Constant Friction-Windage Loss - 326 watts  
E Constant at 244 volts & Iron

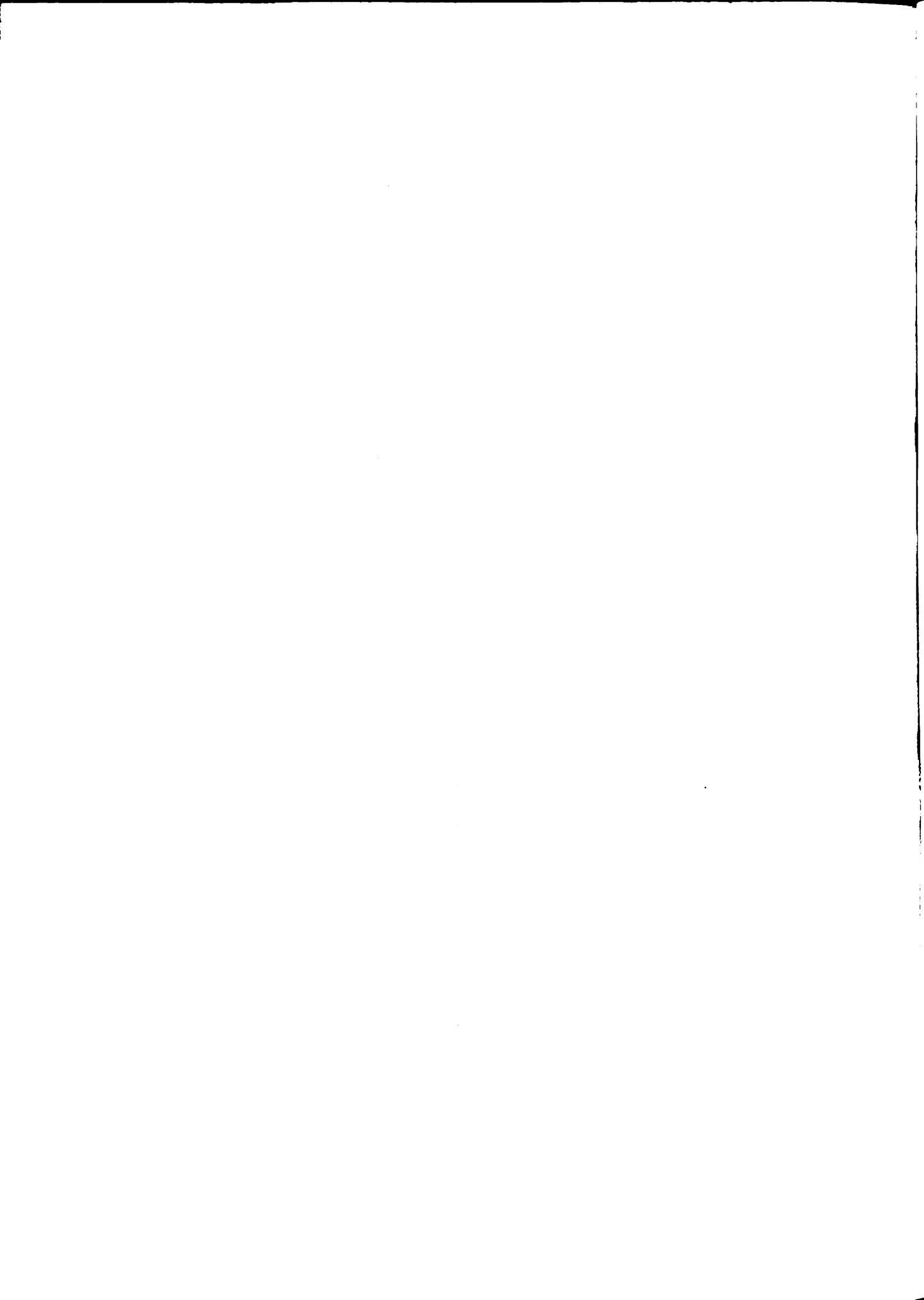
Performance Curve Data for G-7

Field Excitation equals

2.5 Amps or 100%

|      |     |      |      |      |       |
|------|-----|------|------|------|-------|
| 7.90 | 153 | 7.36 | 93.2 | 19.0 | 98.5  |
| 7.50 | 135 | 6.98 | 95.0 | 17.8 | 99.3  |
| 7.04 | 119 | 6.43 | 92.4 | 16.7 | 99.8  |
| 5.95 | 80  | 5.49 | 92.3 | 13.8 | 100.0 |
| 5.44 | 69  | 4.99 | 91.7 | 12.7 | 100.0 |
| 4.92 | 55  | 4.46 | 90.8 | 11.3 | 100.0 |
| 4.63 | 44  | 3.99 | 90.0 | 10.2 | 100.0 |
| 3.94 | 36  | 3.52 | 89.4 | 9.3  | 99.9  |
| 3.29 | 28  | 2.88 | 87.5 | 8.1  | 99.4  |
| 2.77 | 20  | 2.36 | 85.3 | 6.8  | 98.5  |

In the above calculations, Constant Friction-Windage Loss - 387 watt  
E constant at 244 volts & Iron





Performance Curve Data for G-8.

Field Excitation equals

3 Amps or 120%

| K.W. Input | Cu. Loss<br>watts | Input-Losses<br>K.W. | Efficiency-% | I<br>amperes | P.F.-% |
|------------|-------------------|----------------------|--------------|--------------|--------|
| 7.20       | 153               | 6.70                 | 93.0         | 19.0         | 91.4   |
| 6.45       | 125               | 5.97                 | 92.6         | 17.1         | 90.9   |
| 5.22       | 91                | 4.79                 | 92.1         | 14.5         | 86.5   |
| 4.15       | 64                | 3.73                 | 90.0         | 12.2         | 82.0   |
| 3.45       | 54                | 3.05                 | 88.4         | 11.3         | 73.6   |
| 2.78       | 44                | 2.38                 | 85.6         | 10.0         | 66.8   |

In the above calculations, Constant Friction-Windage loss - 352 watts  
E constant at 240 volts & Iron

Field Excitation equals

3.5 Amps or 140%

|      |     |      |      |      |      |
|------|-----|------|------|------|------|
| 5.50 | 137 | 5.00 | 91.0 | 18.0 | 73.6 |
| 4.82 | 121 | 4.34 | 89.8 | 16.9 | 69.5 |
| 4.48 | 104 | 4.02 | 89.5 | 15.7 | 68.5 |
| 4.00 | 89  | 3.55 | 88.7 | 14.8 | 65.2 |
| 3.00 | 64  | 2.56 | 85.4 | 14.0 | 51.7 |

In the above calculations, Constant Friction-Windage Loss - 360 watts  
E constant at 240 volts & Iron

Field Excitation equals

2.5 Amps or 100%

|      |     |      |      |      |       |
|------|-----|------|------|------|-------|
| 7.85 | 153 | 7.36 | 93.9 | 19.0 | 99.5  |
| 7.26 | 134 | 6.79 | 93.4 | 17.5 | 100.0 |
| 5.86 | 82  | 5.44 | 92.6 | 14.1 | 100.0 |
| 4.75 | 54  | 4.36 | 92.0 | 11.2 | 100.0 |
| 3.78 | 36  | 3.41 | 90.2 | 9.3  | 98.5  |
| 2.62 | 20  | 2.27 | 86.7 | 6.7  | 96.4  |

In the above calculations, constant Friction-Windage Loss - 333 watts  
E constant at 244 volts & Iron

Performance Curve Data for G-7

Field Excitation equals .

1.5 Amps or 50%

| K.W. Input | Cu. Loss<br>watts | Input-Losses<br>K.W. | Efficiency-% | I<br>amperes | P.F.-% |
|------------|-------------------|----------------------|--------------|--------------|--------|
| 6.65       | 170               | 6.10                 | 91.7         | 20.0         | 80.0   |
| 6.00       | 154               | 5.49                 | 91.5         | 17.8         | 81.5   |
| 5.45       | 112               | 4.96                 | 91.2         | 16.2         | 81.5   |
| 4.20       | 71                | 3.75                 | 89.4         | 13.0         | 77.5   |
| 3.53       | 62                | 3.09                 | 85.5         | 12.1         | 70.5   |
| 2.90       | 47                | 2.48                 | 85.5         | 10.5         | 66.5   |

In the above calculations, Constant Friction-Windage Loss - 375 watts  
E constant at 244 volts      & Iron

Field Excitation equals

3.0 Amps or 120%

|      |     |      |      |      |      |
|------|-----|------|------|------|------|
| 7.15 | 151 | 6.62 | 92.5 | 18.8 | 91.7 |
| 6.47 | 126 | 6.00 | 92.7 | 17.2 | 90.5 |
| 5.91 | 109 | 5.43 | 92.0 | 15.9 | 89.5 |
| 5.23 | 92  | 4.76 | 91.2 | 14.7 | 85.5 |
| 4.73 | 77  | 4.27 | 90.4 | 13.4 | 85.0 |
| 4.15 | 64  | 3.71 | 89.4 | 12.5 | 81.4 |
| 3.42 | 53  | 3.00 | 87.2 | 11.2 | 73.7 |
| 2.80 | 44  | 2.38 | 85.0 | 10.2 | 66.2 |

In the above calculations, Constant Friction-Windage loss- 395 watts  
E constant at 244 volts      & Iron

Field Excitation equals

3.5 Amps or 140%

|      |     |      |      |      |      |
|------|-----|------|------|------|------|
| 5.30 | 133 | 4.75 | 17.8 | 80.7 | 73.7 |
| 4.73 | 120 | 4.30 | 16.8 | 91.0 | 67.8 |

Cont'd on next page.



Performance Curve Data for G-7

Field Excitation equals

3.5 Amps or 140%

| K.W. Input | Cu Loss<br>watts | Input-Losses<br>K.W. | Efficiency-% | I<br>amperes | P.F.-% |
|------------|------------------|----------------------|--------------|--------------|--------|
| 5.30       | 135              | 4.75                 | 89.7         | 17.8         | 73.7   |
| 4.75       | 120              | 4.30                 | 91.0         | 16.8         | 67.8   |
| 4.50       | 105              | 3.99                 | 88.8         | 15.8         | 64.5   |
| 4.10       | 94               | 3.58                 | 87.5         | 14.8         | 62.5   |
| 3.02       | 81               | 2.53                 | 83.8         | 13.8         | 53.2   |

---

In the above calculation, Constant Friction-Windage Losses - 415 watts  
E constant at 244 volts & Iron

---

Performance Curve Data for H-7

Field Excitation equals

2.5 Amps or 78%

|       |     |       |       |      |      |
|-------|-----|-------|-------|------|------|
| 2.65  | 51  | 2.15  | 81.2  | 1.22 | 52.4 |
| 4.10  | 55  | 3.47  | 84.5  | 1.61 | 61.4 |
| 5.74  | 85  | 5.09  | 88.7  | 2.00 | 69.3 |
| 7.55  | 116 | 6.66  | 90.6  | 2.34 | 75.8 |
| 8.90  | 154 | 8.17  | 91.8  | 2.70 | 79.4 |
| 10.57 | 204 | 9.79  | 92.5  | 3.11 | 81.9 |
| 12.88 | 303 | 12.00 | 93.2  | 3.80 | 81.7 |
| 15.60 | 430 | 14.60 | 93.5  | 4.50 | 84.7 |
| 17.33 | 530 | 16.22 | 93.70 | 5.00 | 84.7 |
| 19.64 | 661 | 18.41 | 93.9  | 5.60 | 84.7 |

---

In the above calculation, Constant Friction-Windage Losses - 575 w.  
E Constant at 2400 volts & Iron

---

& Iron

Performance Curve Data for M-7

Field Excitation equals

3.2 Amperes or 100%

| K.W. Input | Cu. Loss<br>watts | Input-Losses<br>K.W. | Efficiency-% | I<br>amperes | P.F.-% |
|------------|-------------------|----------------------|--------------|--------------|--------|
| 22.30      | 650               | 21.05                | 94.5         | 5.5          | 100.0  |
| 17.40      | 390               | 16.50                | 94.3         | 4.3          | 100.0  |
| 13.40      | 222               | 12.57                | 93.8         | 3.4          | 99.4   |
| 8.75       | 102               | 8.05                 | 92.0         | 2.2          | 98.2   |
| 4.90       | 28                | 4.27                 | 87.5         | 1.3          | 96.7   |

In the above calculation, Constant Friction-Windage & Losses- 605 watts  
E Constant at 2350 volts Iron

Field Excitation equals

3.6 Amperes or 112%

|       |     |       |      |      |      |
|-------|-----|-------|------|------|------|
| 18.97 | 551 | 17.80 | 93.9 | 5.1  | 91.9 |
| 17.15 | 425 | 16.10 | 93.9 | 4.5  | 91.8 |
| 15.18 | 340 | 14.22 | 93.8 | 4.0  | 91.5 |
| 13.50 | 276 | 12.60 | 93.5 | 3.60 | 90.5 |
| 12.62 | 233 | 11.76 | 93.2 | 3.32 | 91.7 |
| 10.61 | 178 | 9.81  | 92.4 | 2.91 | 88.1 |
| 7.72  | 104 | 6.99  | 90.5 | 2.22 | 84.0 |
| 5.85  | 78  | 5.15  | 88.1 | 1.92 | 75.5 |
| 4.20  | 50  | 3.53  | 84.1 | 1.54 | 65.7 |
| 2.65  | 27  | 2.00  | 75.6 | 1.12 | 57.0 |

In the above calculations, Constant Friction-Windage Loss - 625 watts  
E is constant at 2420 & Iron



Performance Curve Data for M-7

Field Excitation equals

4.5 AMPS or 140%

| K.W. Input | Cu. Loss<br>watts | Input-Losses<br>K.W. | Efficiency-% | I    | P.F.-% |
|------------|-------------------|----------------------|--------------|------|--------|
| 3.50       | 170               | 2.65                 | 75.8         | 2.74 | 30.4   |
| 4.98       | 180               | 4.13                 | 82.8         | 2.80 | 42.4   |
| 6.75       | 225               | 5.85                 | 86.6         | 3.20 | 50.4   |
| 8.15       | 254               | 7.22                 | 88.6         | 3.36 | 57.6   |
| 9.52       | 278               | 8.57                 | 90.0         | 3.54 | 64.2   |
| 11.00      | 332               | 10.09                | 91.6         | 3.74 | 70.0   |
| 13.36      | 373               | 12.41                | 93.2         | 4.20 | 75.6   |
| 15.32      | 428               | 14.22                | 93.4         | 4.50 | 82.0   |
| 17.69      | 510               | 16.51                | 93.6         | 4.90 | 86.0   |
| 19.99      | 594               | 18.72                | 93.9         | 5.30 | 89.7   |

In the above calculation, Constant Friction-Windage  
E Constant at 2430 & Iron Loss

675 watts

Field Excitation equals

5.0 AMPS or 155%

|       |     |       |      |      |      |
|-------|-----|-------|------|------|------|
| 4.04  | 263 | 2.97  | 73.5 | 3.54 | 27.2 |
| 5.65  | 284 | 4.56  | 80.8 | 3.67 | 36.6 |
| 7.34  | 296 | 6.24  | 85.1 | 3.75 | 46.5 |
| 8.80  | 330 | 7.67  | 87.3 | 3.96 | 53.0 |
| 10.10 | 360 | 8.94  | 88.5 | 4.13 | 58.4 |
| 11.40 | 390 | 10.27 | 90.0 | 4.30 | 63.3 |
| 15.68 | 551 | 14.32 | 91.5 | 5.10 | 73.2 |
| 19.12 | 711 | 17.60 | 92.0 | 5.80 | 78.6 |

In the above calculations, Constant Friction-Windage  
E Constant at 2440 & Iron Loss

- 805 watts

**"I" Curves**

**for G-2**

| $I_f$          | $I_a$ |          | $I_f$           | $I_a$         |
|----------------|-------|----------|-----------------|---------------|
| <u>No Load</u> |       |          | <u>20% Load</u> |               |
| .25            | 20.80 |          | .25             | 23.40         |
| .50            | 18.00 |          | .50             | 20.60         |
| .75            | 15.20 |          | .75             | 18.00         |
| 1.00           | 12.60 |          | 1.00            | 15.30         |
| 1.25           | 10.00 |          | 1.25            | 12.50         |
| 1.50           | 7.20  |          | 1.50            | 9.80          |
| 1.75           | 4.50  |          | 1.75            | 7.50          |
| 2.00           | 2.30  |          | 2.00            | 4.60          |
| 2.25           | 1.20  | P.F. = 1 | 2.25            | 3.70 P.F. = 1 |
| 2.50           | 2.10  |          | 2.50            | 4.40          |
| 2.75           | 4.70  |          | 2.75            | 7.30          |
| 3.00           | 7.70  |          | 3.00            | 9.80          |
| 3.25           | 10.70 |          | 3.25            | 12.30         |
| 3.50           | 13.30 |          | 3.50            | 14.70         |
| 3.75           | 15.60 |          | 3.75            | 16.80         |
| 4.00           | 17.60 |          | 4.00            | 18.00         |

---



**"V" Curves**

**for G-8**

| $I_f$           | $I_a$         | $I_f$           | $I_a$     |
|-----------------|---------------|-----------------|-----------|
| <u>40% Load</u> |               | <u>60% Load</u> |           |
| .50             | 23.70         | .75             | 24.00     |
| .75             | 21.00         | 1.00            | 21.30     |
| 1.00            | 18.40         | 1.25            | 18.50     |
| 1.25            | 15.60         | 1.50            | 17.70     |
| 1.50            | 13.00         | 1.75            | 13.20     |
| 1.75            | 10.30         | 2.00            | 11.00     |
| 2.00            | 8.40          | 2.25            | 9.80 P.F. |
| 2.27            | 7.30 P.F. = 1 | 2.50            | 10.40     |
| 2.50            | 8.00          | 2.75            | 12.20     |
| 2.75            | 10.00         | 3.00            | 14.00     |
| 3.00            | 12.30         | 3.25            | 16.00     |
| 3.25            | 14.40         | 3.50            | 17.60     |
| 3.50            | 16.30         | 3.75            | 19.00     |
| 3.75            | 18.00         | 4.00            | 20.60     |
| 4.00            | 19.60         |                 |           |

---

# "I" Curves

for G-8

| $I_r$    | $I_a$          | $I_r$     | $I_a$          |
|----------|----------------|-----------|----------------|
| 80% Load |                | 100% Load |                |
| 1.00     | 24.00          | 1.25      | 24.10          |
| 1.25     | 21.60          | 1.50      | 22.00          |
| 1.50     | 19.00          | 1.75      | 20.50          |
| 1.75     | 16.80          | 2.00      | 19.30          |
| 2.00     | 15.30          | 2.25      | 18.40          |
| 2.25     | 14.40          | 2.55      | 18.00 P.F. = 1 |
| 2.42     | 14.30 P.F. = 1 | 2.75      | 18.20          |
| 2.50     | 14.60          | 3.00      | 19.00          |
| 2.75     | 15.60          | 3.25      | 19.60          |
| 3.00     | 16.70          | 3.50      | 20.40          |
| 3.25     | 17.90          | 3.75      | 21.30          |
| 3.50     | 19.00          | 4.00      | 22.10          |
| 3.75     | 20.10          |           |                |
| 4.00     | 21.10          |           |                |



**"Y" Curves**

**for G-7**

| $I_f$          | $I_a$ |          | $I_f$           | $I_a$         |
|----------------|-------|----------|-----------------|---------------|
| <u>No Load</u> |       |          | <u>20% Load</u> |               |
| .25            | 20.40 |          | .25             | 23.00         |
| .50            | 18.00 |          | .50             | 20.30         |
| .75            | 15.10 |          | .75             | 17.80         |
| 1.00           | 12.30 |          | 1.00            | 15.00         |
| 1.25           | 9.80  |          | 1.25            | 12.10         |
| 1.50           | 7.00  |          | 1.50            | 9.60          |
| 1.75           | 4.40  |          | 1.75            | 7.00          |
| 2.00           | 2.50  |          | 2.00            | 4.60          |
| 2.20           | 2.00  | P.F. = 1 | 2.25            | 3.60 P.F. = 1 |
| 2.50           | 2.70  |          | 2.50            | 4.40          |
| 2.75           | 4.80  |          | 2.75            | 7.40          |
| 3.00           | 8.00  |          | 3.00            | 10.00         |
| 3.25           | 10.90 |          | 3.25            | 12.80         |
| 3.50           | 13.30 |          | 3.50            | 14.90         |
| 3.75           | 15.30 |          | 3.75            | 16.60         |
| 4.00           | 16.90 |          | 4.00            | 18.30         |

---

# **"Y" Curve**

**for M-7**

| $I_f$          | $I_a$ | $I_f$           | $I_a$ |          |
|----------------|-------|-----------------|-------|----------|
| <u>No Load</u> |       | <u>20% Load</u> |       |          |
| .25            | 5.65  | .50             | 6.20  |          |
| .50            | 5.15  | .75             | 5.65  |          |
| .75            | 4.65  | 1.00            | 5.15  |          |
| 1.00           | 4.15  | 1.25            | 4.60  |          |
| 1.25           | 3.60  | 1.50            | 4.10  |          |
| 1.50           | 3.05  | 1.75            | 3.50  |          |
| 1.75           | 2.55  | 2.00            | 3.00  |          |
| 2.00           | 2.00  | 2.50            | 2.00  |          |
| 2.25           | 1.50  | 2.75            | 1.40  |          |
| 2.50           | 1.00  | 3.00            | 1.10  | P.F. = 1 |
| 3.00           | .40   | 3.25            | 1.35  |          |
| 3.25           | .65   | 3.50            | 1.95  |          |
| 3.50           | 1.25  | 3.75            | 2.50  |          |
| 3.75           | 1.90  | 4.00            | 3.00  |          |
| 4.00           | 2.50  | 4.25            | 3.50  |          |
| 4.25           | 3.00  | 4.50            | 3.95  |          |
| 4.50           | 3.50  | 4.75            | 4.25  |          |
| 4.75           | 3.85  | 5.00            | 4.65  |          |
| 5.00           | 4.20  |                 |       |          |

Unity Power Factor



**"Y" Curves**

**for N-7**

| $I_f$           | $I_a$         | $I_f$           | $I_a$ |
|-----------------|---------------|-----------------|-------|
| <u>40% Load</u> |               | <u>60% Load</u> |       |
| 1.00            | 6.20          | 1.50            | 6.20  |
| 1.25            | 5.60          | 1.75            | 5.60  |
| 1.50            | 5.15          | 2.00            | 5.10  |
| 1.75            | 4.65          | 2.25            | 4.50  |
| 2.00            | 4.10          | 2.50            | 4.10  |
| 2.25            | 3.50          | 2.75            | 3.50  |
| 2.50            | 3.00          | 3.00            | 3.30  |
| 2.75            | 2.50          | 3.25            | 3.50  |
| 3.00            | 2.25 P.F. = 1 | 3.50            | 3.70  |
| 3.25            | 2.35          | 3.75            | 4.00  |
| 3.50            | 2.75          | 4.00            | 4.30  |
| 3.75            | 3.20          | 4.25            | 4.60  |
| 4.00            | 3.60          | 4.50            | 4.80  |
| 4.25            | 4.00          | 4.75            | 5.00  |
| 4.50            | 4.30          | 5.00            | 5.20  |
| 4.75            | 5.65          |                 |       |
| 5.00            | 5.90          |                 |       |

---

**V Curves**  
**for M-7**

| $I_f$           | $I_a$         | $I_f$            | $I_a$         |
|-----------------|---------------|------------------|---------------|
| <u>80% Load</u> |               | <u>100% Load</u> |               |
| 1.25            | 6.70          | 2.25             | 6.95          |
| 1.50            | 6.25          | 2.50             | 6.20          |
| 1.75            | 5.70          | 2.75             | 5.85          |
| 2.00            | 5.15          | 3.00             | 5.60          |
| 2.25            | 4.65          | 3.25             | 5.50 P.F. = 1 |
| 2.50            | 4.15          | 3.50             | 5.55          |
| 2.75            | 3.50          | 3.75             | 5.57          |
| 3.00            | 3.30          | 4.00             | 5.61          |
| 3.05            | 4.35 P.F. = 1 | 4.25             | 5.65          |
| 3.25            | 4.40          | 4.50             | 5.71          |
| 3.50            | 4.60          | 4.75             | 5.75          |
| 3.75            | 4.75          | 5.00             | 5.80          |
| 4.00            | 4.90          |                  |               |
| 4.25            | 5.05          |                  |               |
| 4.50            | 5.25          |                  |               |
| 4.75            | 5.40          |                  |               |
| 5.00            | 5.55          |                  |               |



Cold Armature Resistance for G-8

| <u>Trial</u> | <u>Terminals</u> | <u>E</u> | <u>I</u> | <u>R</u> |
|--------------|------------------|----------|----------|----------|
| 1            | X-Y              | 7.80     | 13.55    | .575     |
| 2            | X-Y              | 5.30     | 9.20     | .576     |
| 3            | X-Y              | 2.76     | 4.77     | .577     |
| <hr/>        |                  |          |          |          |
| 1            | X-Z              | 7.80     | 13.70    | .570     |
| 2            | X-Z              | 5.00     | 8.65     | .578     |
| 3            | X-Z              | 2.80     | 4.86     | .578     |
| <hr/>        |                  |          |          |          |
| 1            | Y-Z              | 7.70     | 13.50    | .571     |
| 2            | Y-Z              | 4.90     | 8.64     | .568     |
| 3            | Y-Z              | 2.80     | 4.88     | .573     |

Calculated Resistance Values

| <u>Terminals</u> | <u>Avg. Res. Terminal</u> | <u>Avg. Res. Phase</u> |
|------------------|---------------------------|------------------------|
| X-Y              | .5761                     | .2881                  |
| X-Z              | .5753                     | .2876                  |
| Y-Z              | .5707                     | .2853                  |

**Note:**

Each of the trials indicated in the above tabulation of resistance data, is in turn the mean of three additional trials.

Cold Armature Resistance for G-7

| <u>Trial</u> | <u>Terminals</u> | <u>E</u> | <u>I</u> | <u>R</u> |
|--------------|------------------|----------|----------|----------|
| 1            | X-Y              | 7.80     | 13.70    | .570     |
| 2            | X-Y              | 5.30     | 9.20     | .576     |
| 3            | X-Y              | 2.80     | 4.86     | .575     |
| <hr/>        |                  |          |          |          |
| 1            | X-Z              | 7.70     | 13.40    | .574     |
| 2            | X-Z              | 5.00     | 8.65     | .578     |
| 3            | X-Z              | 2.76     | 4.77     | .577     |
| <hr/>        |                  |          |          |          |
| 1            | Y-Z              | 7.80     | 13.56    | .575     |
| 2            | Y-Z              | 4.90     | 8.62     | .270     |
| 3            | Y-Z              | 2.80     | 4.82     | .581     |
| <hr/>        |                  |          |          |          |

Calculated Resistance Data

| <u>Terminals</u> | <u>Ay. Res. Terminal</u> | <u>Ay. Res. Phase</u> |
|------------------|--------------------------|-----------------------|
| X-Y              | .5750                    | .2875                 |
| X-Z              | .5760                    | .2880                 |
| Y-Z              | .5750                    | .2875                 |
| <hr/>            |                          |                       |

**Note:**

Each of the trials indicated in the above tabulation of resistance data, is in turn the mean of three additional trials.

---



**Cold Armature Resistance for H-7**

| <u>Trials</u> | <u>Terminals</u> | <u>E</u> | <u>I</u> | <u>R</u> |
|---------------|------------------|----------|----------|----------|
| 1             | X-Y              | 46.0     | 3.26     | 14.10    |
| 2             | X-Y              | 50.0     | 3.55     | 14.10    |
| 3             | X-Y              | 61.0     | 4.28     | 14.20    |
| <hr/>         |                  |          |          |          |
| 1             | X-Z              | 45.6     | 3.23     | 14.12    |
| 2             | X-Z              | 50.7     | 3.60     | 14.10    |
| 3             | X-Z              | 60.8     | 4.30     | 14.15    |
| <hr/>         |                  |          |          |          |
| 1             | Y-Z              | 46.7     | 3.50     | 14.10    |
| 2             | Y-Z              | 51.0     | 3.62     | 14.12    |
| 3             | Y-Z              | 60.8     | 4.32     | 14.10    |

**Calculated Resistance Values**

| <u>Terminals</u> | <u>Avg. Res. Terminal</u> | <u>Avg. Res. Phase</u> |
|------------------|---------------------------|------------------------|
| X-Y              | 14.13                     | 7.06                   |
| X-Z              | 14.12                     | 7.06                   |
| Y-Z              | 14.10                     | 7.05                   |

**Note:**

Each of the trials indicated in the above tabulation of resistance data, is in turn the mean of three additional trials.

# Parallel Operation Data

for G-7:G-8

| G-7 Part 1. |         | 11111111 |             |                                   |    |
|-------------|---------|----------|-------------|-----------------------------------|----|
| $I_x$       | $I_s$   | $I_f$    | total Watts | Phase Shift<br>electrical degrees |    |
| Volts       | amperes | amperes  | amperes     |                                   |    |
| 229         | 0.00    | 0.00     | 2.10        | 0                                 | 0  |
| 230         | 0.00    | 0.00     | 2.10        | 650                               | 5  |
| 228         | .70     | .80      | 2.10        | 1550                              | 10 |
| 229         | 1.30    | 1.50     | 2.15        | 2550                              | 15 |
| 230         | 1.80    | 1.80     | 2.20        | 3580                              | 20 |
| 231         | 2.23    | 2.23     | 2.26        | 4460                              | 25 |
| 232         | 2.78    | 2.75     | 2.26        | 5550                              | 30 |
| 232         | 3.95    | 3.90     | 2.55        | 7850                              | 35 |
| 232         | 4.55    | 4.50     | 2.70        | 9000                              | 40 |

## G-8 Part 1.

|     |      |      |      |       |    |
|-----|------|------|------|-------|----|
| 230 | 0.00 | 0.00 | 2.16 | 0     | 0  |
| 230 | 0.00 | 0.00 | 2.16 | -610  | 5  |
| 230 | .50  | .50  | 2.16 | -1550 | 10 |
| 230 | 1.23 | 1.23 | 2.20 | -2490 | 15 |
| 230 | 1.75 | 1.78 | 2.18 | -3520 | 20 |
| 230 | 2.18 | 2.22 | 2.32 | -4370 | 25 |
| 230 | 2.75 | 2.75 | 2.37 | -5445 | 30 |
| 230 | 3.86 | 3.91 | 2.63 | -7700 | 35 |
| 230 | 4.47 | 4.49 | 2.76 | -8845 | 40 |

### **Note:**

In the above tabulation, when power values are indicated as negative, this is interpreted to mean that the power is flowing from the machine with such a sign.



Parallel Operation

Power Factor Data

G-7 Part 1.

| Phase Shift<br>electrical degrees | Total Watts | $\sqrt{3} E I$ | Power Factor<br>Per Cent x100 |
|-----------------------------------|-------------|----------------|-------------------------------|
| 10                                | 1550        | 1550           | 1.000                         |
| 15                                | 2550        | 2775           | .946                          |
| 20                                | 3580        | 3585           | .997                          |
| 25                                | 4450        | 4460           | .997                          |
| 30                                | 5550        | 5550           | 1.000                         |
| 35                                | 7850        | 7870           | .998                          |
| 40                                | 9000        | 9050           | .997                          |

G-8 Part 1.

|    |      |      |       |
|----|------|------|-------|
| 10 | 1550 | 1590 | .998  |
| 15 | 2490 | 2490 | 1.000 |
| 20 | 3520 | 3580 | .998  |
| 25 | 4370 | 4380 | .999  |
| 30 | 5445 | 5500 | .988  |
| 35 | 6410 | 6620 | .970  |
| 40 | 7700 | 7900 | .975  |

G-7 Part 2a.

|    |      |      |      |
|----|------|------|------|
| 0  | 2180 | 2240 | .973 |
| 5  | 3275 | 3280 | .999 |
| 10 | 4200 | 4270 | .985 |
| 15 | 5150 | 5225 | .987 |
| 20 | 6200 | 6240 | .978 |
| 25 | 7150 | 7280 | .982 |
| 30 | 8150 | 8340 | .978 |

# Parallel Operation Data

## G-7 Part 2a

| <u>E</u><br><u>Volts</u> | <u>I</u><br><u>amperes</u> | <u>I</u><br><u>amperes</u> | <u>I</u><br><u>amperes</u> | <u>Watts</u> | <u>Phase Shift</u><br><u>electrical degrees</u> |
|--------------------------|----------------------------|----------------------------|----------------------------|--------------|-------------------------------------------------|
| 229                      | 1.15                       | 1.10                       | 2.20                       | 2180         | 0                                               |
| 229                      | 1.65                       | 1.65                       | 2.20                       | 3275         | 5                                               |
| 229                      | 2.16                       | 2.11                       | 2.20                       | 4200         | 10                                              |
| 229                      | 2.65                       | 2.61                       | 2.25                       | 5150         | 15                                              |
| 230                      | 3.15                       | 3.13                       | 2.30                       | 6200         | 20                                              |
| 230                      | 3.67                       | 3.65                       | 2.40                       | 7150         | 25                                              |
| 230                      | 4.20                       | 4.16                       | 2.50                       | 8150         | 30                                              |
| 230                      | 4.74                       | 4.70                       | 2.51                       | 9205         | 35                                              |

## G-8 Part 2a.

|     |      |      |      |       |    |
|-----|------|------|------|-------|----|
| 230 | 1.44 | 1.44 | 2.26 | 2860  | 0  |
| 230 | .75  | .75  | 2.26 | 1775  | 5  |
| 230 | .15  | .15  | 2.27 | 820   | 10 |
| 230 | .00  | .00  | 2.30 | -90   | 15 |
| 230 | .40  | .40  | 2.38 | -960  | 20 |
| 230 | 1.15 | 1.13 | 2.42 | -1920 | 25 |
| 230 | 1.65 | 1.65 | 2.51 | -2925 | 30 |
| 230 | 2.20 | 2.20 | 2.60 | -3950 | 35 |

### **Note:**

In the above data, when power values are preceded by a negative sign, it is interpreted to mean that power is in such instances flowing from the machine under consideration.



Load Data

Part 2a.

Parallel Operation

| <u>E</u><br><u>volts</u> | <u>I</u><br><u>amps</u> | <u>I</u><br><u>amps</u> | <u>Watts</u> | <u>Phase Shift</u><br><u>electrical degrees</u> |
|--------------------------|-------------------------|-------------------------|--------------|-------------------------------------------------|
| 228                      | 1.26                    | 1.26                    | 5160         | 0                                               |
| 228                      | 1.25                    | 1.26                    | 5140         | 5                                               |
| 227                      | 1.25                    | 1.25                    | 5108         | 10                                              |
| 227                      | 1.25                    | 1.25                    | 5108         | 15                                              |
| 229                      | 1.27                    | 1.26                    | 5160         | 20                                              |
| 228                      | 1.26                    | 1.25                    | 5110         | 30                                              |
| 227                      | 1.25                    | 1.25                    | 2060         | 35                                              |

Part 2b.

|     |       |       |      |
|-----|-------|-------|------|
| 227 | 1.26  | 1.25  | 5080 |
| 226 | 1.252 | 1.240 | 5040 |
| 226 | 1.25  | 1.24  | 5040 |
| 226 | 1.23  | 1.24  | 5040 |
| 226 | 1.25  | 1.241 | 5060 |
| 227 | 1.25  | 1.24  | 5060 |
| 227 | 1.25  | 1.24  | 5060 |
| 226 | 1.25  | 1.24  | 5040 |

Note:

In the above tabulation, no great care has been exercised to record exact current and voltage values, though the power values indicated are as accurate as could be obtained. This accounts for the fact that though the load was pure resistance in each case, the product of volts and amperes in some instances, does not check accurately with the value indicated for power. The actual power values shown are used as the ultimate values.

Parallel Operation

Power Factor Data

G-8 Part 2a.

| Phase Shift<br>electrical degrees | Total Watts | $\sqrt{3} E I$ | Power Factor |
|-----------------------------------|-------------|----------------|--------------|
| 0                                 | 2860        | 2860           | 1.000        |
| 5                                 | 1775        | 1780           | .999         |
| 10                                | 820         | 880            | .996         |
| 15                                | error       | error          | error        |
| 20                                | 960         | 960            | 1.000        |
| 25                                | 1920        | 2150           | .900         |
| 30                                | 2925        | 3280           | .890         |
| 35                                | 3950        | 4360           | .918         |

G-7 Part 2b.

|      |      |      |
|------|------|------|
| 2500 | 2770 | .920 |
| 2600 | 3210 | .812 |
| 2850 | 3590 | .793 |
| 3100 | 4450 | .700 |
| 3350 | 5230 | .640 |
| 3525 | 5880 | .598 |
| 3870 | 6840 | .566 |
| 4000 | 7440 | .538 |

G-8 Part 2b.

|      |      |      |
|------|------|------|
| 2530 | 2770 | .914 |
| 2340 | 2890 | .810 |
| 2155 | 3160 | .682 |
| 1890 | 2890 | .517 |
| 1710 | 4220 | .405 |
| 1490 | 4820 | .309 |
| 1250 | 5630 | .222 |



Parallel Operation Data

G-7 Part 2b.

| <b>E</b>     | <b>I<sub>1</sub></b> | <b>I<sub>3</sub></b> | <b>Watts</b> | <b>I<sub>2</sub></b> |
|--------------|----------------------|----------------------|--------------|----------------------|
| <b>Volts</b> | <b>amperes</b>       | <b>amperes</b>       |              | <b>amperes</b>       |
| 229          | 1.40                 | 1.40                 | 2500         | 2.50                 |
| 228          | 1.62                 | 1.60                 | 2600         | 2.60                 |
| 228          | 1.90                 | 1.75                 | 2850         | 2.70                 |
| 228          | 2.26                 | 2.20                 | 3100         | 2.95                 |
| 228          | 2.66                 | 2.61                 | 3350         | 2.15                 |
| 228          | 2.98                 | 2.95                 | 3525         | 3.50                 |
| 228          | 3.45                 | 3.39                 | 3870         | 3.50                 |
| 228          | 3.77                 | 3.70                 | 4000         | 3.70                 |

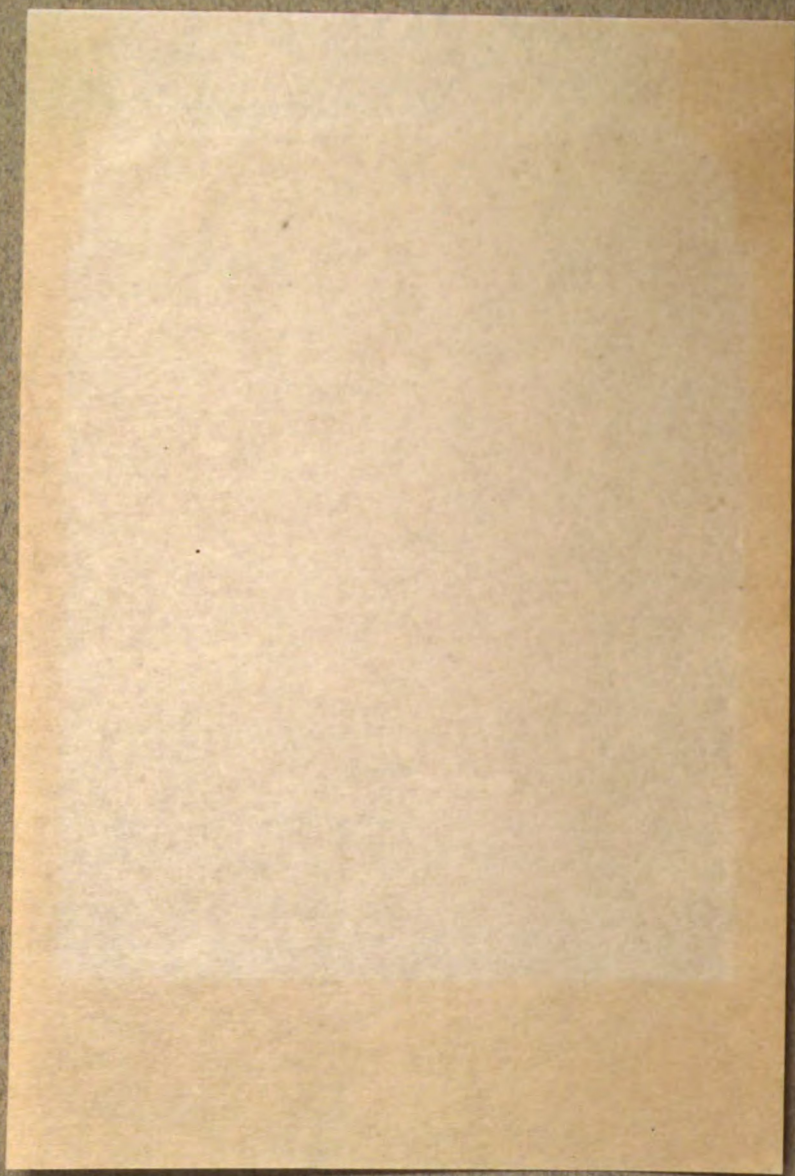
G-8 Part 2b.

|     |      |      |      |      |
|-----|------|------|------|------|
| 230 | 1.40 | 1.40 | 2530 | 2.00 |
| 229 | 1.45 | 1.46 | 2340 | 1.87 |
| 230 | 1.58 | 1.60 | 2155 | 1.72 |
| 230 | 1.81 | 1.85 | 1890 | 1.52 |
| 229 | 2.12 | 2.18 | 1710 | 1.36 |
| 230 | 2.40 | 2.45 | 1490 | 1.20 |
| 230 | 2.80 | 2.83 | 1230 | 1.02 |
| 229 | 3.10 | 3.13 | 1045 | .88  |

## INDEX

|                                                  | Pages          |
|--------------------------------------------------|----------------|
| Alternators, construction and theory of. -----   | 1-8.           |
| Armature Reaction.-----                          | 18-19.         |
| Burke M-G Set, description and pictures of.----- | 20-25.         |
| No-Load losses.-----                             | 26-28, 42.     |
| Oscillograms.-----                               | 35, 37, 80-84. |
| Open-circuit tests.-----                         | 28, 72, 73.    |
| Parallel operation.-----                         | 35, 61-79.     |
| Performance curves.-----                         | 57-60.         |
| Regulation.-----                                 | 71-79, 53, 55. |
| Rotating magnetic fields.-----                   | 4-7.           |
| Synchronous machines.-----                       | 9-19.          |
| Synchronous motors.-----                         | 7-8.           |
| starting methods.-----                           | 14-15.         |
| hunting.-----                                    | 15-16.         |
| damping.-----                                    | 16-17.         |
| Synchronous condensers.-----                     | 17-18.         |
| Synchronising current.-----                      | 10-11.         |
| Synchronising, methods of.-----                  | 11-13.         |
| Short circuit tests.-----                        | 28, 72, 73.    |
| Test data.-----                                  | 84-113.        |
| "V" Curves.-----                                 | 28, 33, 44-46. |
| Wave forms.-----                                 | 80-84.         |











MICHIGAN STATE UNIVERSITY LIBRARIES



3 1293 03177 9907