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A TEST AND ANALYSIS OF THE
SYNCHRONOUS MOTOR GENERATOR SET NO. M. 4
IN THE ALTERNATING CURRENT LABORATORY
OF THE MICHIGAN STATE COLLEGE
THESIS FOR DEGREE OF B. S.

W. D. HOWELL H. C. ROBERTS

1926

THESIS

Electric meters, Synchronous
Electric meters - Testing

A TEST AND ANALYSIS
OF THE
SYNCHRONOUS MOTOR GENERATOR SET No. M 4
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ALTERNATING CURRENT LABORATORY
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MICHIGAN STATE COLLEGE

A THESIS
SUBMITTED TO THE FACULTY
OF THE
MICHIGAN STATE COLLEGE
BY

W. D. HOWELL

H. C. ROBERTS

CANDIDATES FOR DEGREE OF
BACHELOR OF SCIENCE

JUNE, 1926

THESIS

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1. The first part of the document is a letter from the President of the United States to the Congress, dated January 3, 1862. It is a very important document, as it contains the President's annual message to Congress. The letter is written in a formal, dignified style, and it is one of the most important documents in the history of the United States. It is a document that has been read and studied by many generations of Americans, and it is a document that has shaped the course of our nation's history. The letter is a masterpiece of American literature, and it is a document that has inspired many Americans to strive for a better future for our nation.

2. The second part of the document is a letter from the Secretary of the War Department to the Secretary of the Navy, dated January 10, 1862. It is a very important document, as it contains the Secretary's report on the state of the war. The letter is written in a formal, dignified style, and it is one of the most important documents in the history of the United States. It is a document that has been read and studied by many generations of Americans, and it is a document that has shaped the course of our nation's history. The letter is a masterpiece of American literature, and it is a document that has inspired many Americans to strive for a better future for our nation.

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LIST OF SYMBOLS

- E = Impressed voltage.
 E' = Counter-voltage generated by motor.
 E'' = Resultant voltage.
 e = Power component of the impressed voltage.
 e' = Wattless component of the impressed voltage.
 e'' = Power component of the counter-voltage.
 e''' = Wattless component of the counter-voltage.
 I = Armature current.
 i = Power component of the armature current.
 i' = Wattless component of the armature current.
 P = Mechanical power output of motor.
 r = Effective resistance of armature.
 x = Synchronous reactance of motor.
 z = Synchronous impedance of the motor.
 ϕ = Angle between armature current and impressed voltage.
 θ = Angle between armature current and resultant voltage.
 β = Angle between impressed voltage and counter-voltage (reversed).

PREFACE

There has been a desire to have a separate source of Direct Current Power Supply in the Electrical Laboratories at Michigan State College which would be independent of the College Power Plant D.C. Supply. This was accomplished recently by the installation of the Westinghouse Synchronous Motor-Generator Set.

This test was the first to be made on the M-G Set after installation in the Alternating Current Laboratory, and was performed with the view of obtaining its operating characteristics. The test as performed included not only the operating characteristics of the set, but also data to determine theoretical characteristics of the Synchronous Motor.

Throughout this test we have received excellent co-operation from the members of the Electrical Engineering Faculty and from Mr. F. Mitchell and Mr. Thompson of the Michigan State College Power Plant; for this we wish to express our sincere thanks.

INTRODUCTION

The purpose of this test has been to obtain data for both practical and theoretical performance, and to supply experimental material which would be valuable to the department and to classes in Electrical Engineering.

Through out this experiment, care has been exercised to obtain accurate results as far as practicable. The measurements, in all cases, were taken by the use of suitable meters and transformers. The meters were calibrated after each test. Transformers were introduced in the high tension line in order to measure the power input by the instruments available and also to offer greater protection to those working around the instruments and machines. In this test the transformers were not calibrated because the calibration curves of these transformers showed but a slight variation in phase angle - less than five seconds.

All instrument transformer cases and secondaries, motor frames, control switches, and water barrel rheostats were grounded. This was done to give protection to those reading instruments or working with the apparatus. The water barrel rheostats used were made of metal and after experiencing several "pokes" it was decided to ground the barrels to the water main.

1. The first part of the paper is devoted to a general discussion of the problem of the origin of the universe. It is shown that the problem is not only a philosophical one, but also a scientific one. The author discusses the various theories of the origin of the universe, and shows that the most plausible one is the theory of the origin of the universe from a state of equilibrium.

2. The second part of the paper is devoted to a discussion of the problem of the origin of life. It is shown that the problem is not only a philosophical one, but also a scientific one. The author discusses the various theories of the origin of life, and shows that the most plausible one is the theory of the origin of life from a state of equilibrium.

3. The third part of the paper is devoted to a discussion of the problem of the origin of the human race. It is shown that the problem is not only a philosophical one, but also a scientific one. The author discusses the various theories of the origin of the human race, and shows that the most plausible one is the theory of the origin of the human race from a state of equilibrium.

When the meters were installed on the panels the field discharge resistance was lacking. An improvised resistance, consisting of a 220 volt 60 watt bulb, was used but which exploded when the motor was started and an arc-over occurred in the compensator. After this experience it was decided to insert a resistance box with a rating of 1000 watts at 220 volts. This was found to work satisfactorily.

The power factor meter furnished would not operate to measure the power factor in the three phase system because it was a single phase meter and thus it does not measure the phase current and voltage. It was necessary to reverse the leads on the ammeters of the direct current generators, because, although the voltmeters would read in the same direction, the ammeters would read correctly when power was supplied to the machines but read backwards when power was supplied by the machines. It was also necessary to take apart and readjust the circuit breaker on the 125 volt machine before it would function properly.

The synchronous motor bearing on the end toward the 250 volt generator was found to run hot throughout the test without apparent cause. The synchronous motor was started by means of a compensator. This was used in all cases when starting the motor instead of trying to synchronize the machine with the supply line.

When starting, the motor drew a very heavy current in comparison with its name plate rating which amounted to about five and one-half times rated current at full load.

When running some of the tests certain peculiar phenomena occurred. This was especially noticeable during the retardation runs and at certain times in the night which occurred generally in the form of static discharges or apparent grounds.

CHAPTER I

THEORY OF THE SYNCHRONOUS MOTOR

CHAPTER 1.

THEORY OF THE SYNCHRONOUS MOTOR

PRINCIPLE

The term "synchronous" means in unison, that is, in step. A synchronous motor then, may be defined as one which rotates in unison or in step with the phase of the alternating current which operates it.

A coil of wire if carrying current and placed in a magnetic field will tend to turn about an axis perpendicular to the field. This principle may be applied in the form of a motor to produce useful work. If such a coil is placed in a magnetic field as shown in Fig. 1

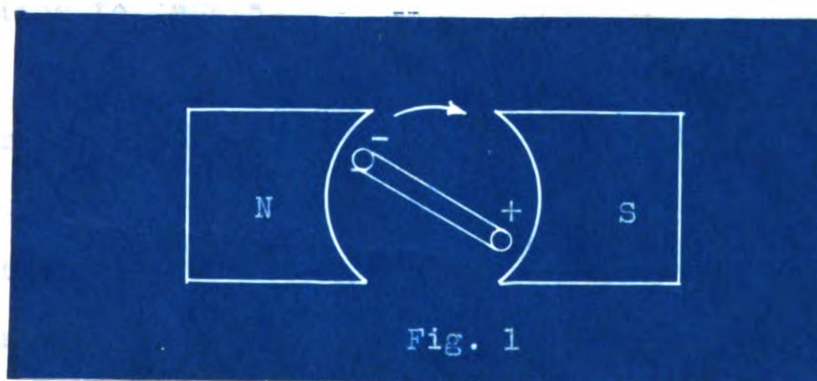


Fig. 1

Diagram of an elementary motor.

and current allowed to flow through it, it can be seen by the left hand motor rule that the coil tends to turn in a clockwise direction. When the coil has reached the position as shown in Fig. 2, the coil would tend to turn counter-clockwise by use of the same motor rule.

• Introduction

• The Role of the Teacher

1. Introduction

1.1. The Role of the Teacher

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1.13. The Role of the Teacher

1.14. The Role of the Teacher

If the current in the coil was reversed just

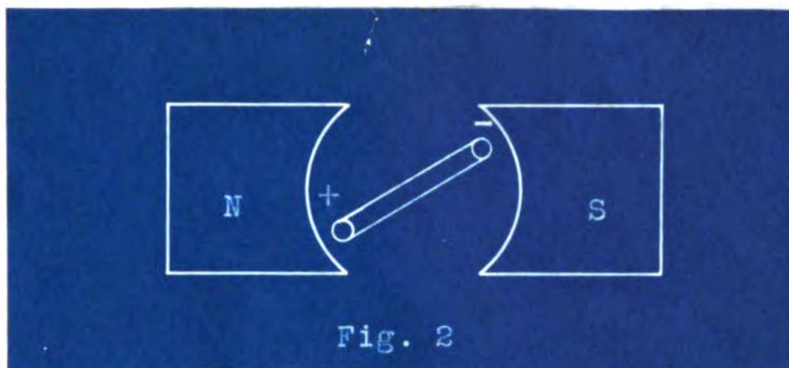


Diagram of an elementary motor

as the coil passes through its vertical or neutral position, the turning moment of the coil would always be in the same direction and thus the coil would continue to rotate.

This may be done by supplying the coil with alternating current and if the rotation of the coil keeps in synchronism with the current, the motor thus constructed will be a synchronous motor. Since action and reaction are always equal and opposite, it makes no difference whether the field or the armature revolves. On large machines it is generally found that the alternating current circuit is the stator and the field the rotor of the motor. Direct current is used for the field excitation.

A synchronous motor is in principle simply a reversed alternator. Instead of receiving mechanical energy and changing it to electrical energy, it receives electrical energy at synchronous speed and delivers mechanical energy. Synchronous motors are constructed as single and polyphase machines. This discussion will

treat only the poly-phase motor.

The condition necessary for synchronous motor operation is that the motor be speeded up until it rotates in synchronism, that is, in step with the alternator that supplies the power to run the motor. This means that the motor must run at the same frequency as the alternator but not necessary at the same speed. The speed of the motor is governed by the number of poles of the motor and the frequency of the power supply.

The principles upon which such motors operate may be explained by considering the action of an alternator and a synchronous motor connected in a circuit. Suppose that the motor is at rest when it is connected to the circuit with the alternator. The alternating current will flow through the armature of the motor and produce a reaction upon the field which would tend to rotate the rotor first in one direction then in the other. Because of the rapid reversal in direction of the torque thus set up, the time is not sufficient to allow the torque produced to overcome the inertia of the rotor, before a torque is produced in the opposite direction due to the reversal of the current. Hence the rotor remains stationary or, strictly speaking, vibrates. Thus, if the motor is first brought up to synchronism with the supply power and then connected in the circuit, the motor will continue to operate because the field flux and the armature flux are

Anda sebagai mahasiswa dapat melakukan

kegiatan sebagai berikut dalam rangka meningkatkan

kegiatan belajar mengajar di dalam kelas.

- Berikan penjelasan yang jelas, singkat dan padat, serta
terarah, sehingga dapat meningkatkan kemampuan berfikir
siswa dalam memahami materi yang disampaikan. Untuk itu
diperlukan waktu yang cukup untuk menyampaikan materi
yang akan disampaikan. Untuk itu, sebaiknya materi yang
akan disampaikan harus dipersiapkan terlebih dahulu.

• Kegiatan lain yang dapat dilakukan oleh mahasiswa untuk
meningkatkan kemampuan berfikir adalah dengan melakukan

kegiatan lain yang dapat meningkatkan kemampuan berfikir.

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meningkatkan kemampuan berfikir adalah dengan melakukan

always in the same relative position which produces a torque pulling the rotor around in the same direction.

The motor under test was started as an induction motor by means of an auxiliary squirrel cage winding on the rotor. Reduced voltage was applied to the stator through a compensator and when the machine had reached approximately synchronous speed, the field switch was closed on the direct current circuit which brought the machine into synchronism after which full voltage was applied to the stator. When the field switch is closed, the magnetic flux already set up in the fields by the armature reaction may be in the wrong direction in which case the rotor must fall back the distance of the polar pitch before the regular field flux can produce forward operating torque. Synchronous machines as compared to asynchronous machines run at a constant speed regardless of the load until such a load has been reached that the over-load capacity of the machine has been exceeded at which time the motor falls out of step and stops.

A synchronous motor has the important advantage that its power factor is adjustable and it can be made to take a leading or lagging current by varying the field excitation; its leading current can be used to offset the lagging current taken by induction motors thus improving the power factor .

Synchronous motors are sometimes installed solely for this purpose.

SYNCHRONOUS IMPEDANCE

Synchronous impedance may be defined as the ratio of the voltage that would be developed at a certain excitation, if the machine were run as a generator at synchronous speed without current in the armature, to the current that would flow through the armature at the same excitation when it is short-circuited. The synchronous impedance of the armature is composed of two components, i.e. effective resistance and synchronous reactance. Synchronous reactance includes reactance due to induction and the effect of armature reaction in strengthening or weakening the field. These two effects are so similar that they are generally considered as one.

In The vector diagrams that are to follow the motor generated voltages are those that would be generated if the armature reactions were absent. To compensate for this assumption the synchronous impedance of the armature, which includes the effect of reactions, has been used instead of the ordinary impedance which consists only of true ohmic resistance and inductive reactance. The synchronous impedance has been considered constant with the variation of excitation, but in reality the field reactions and

1. *Journal of the American Medical Association*, 1997; 278: 1022-1026.

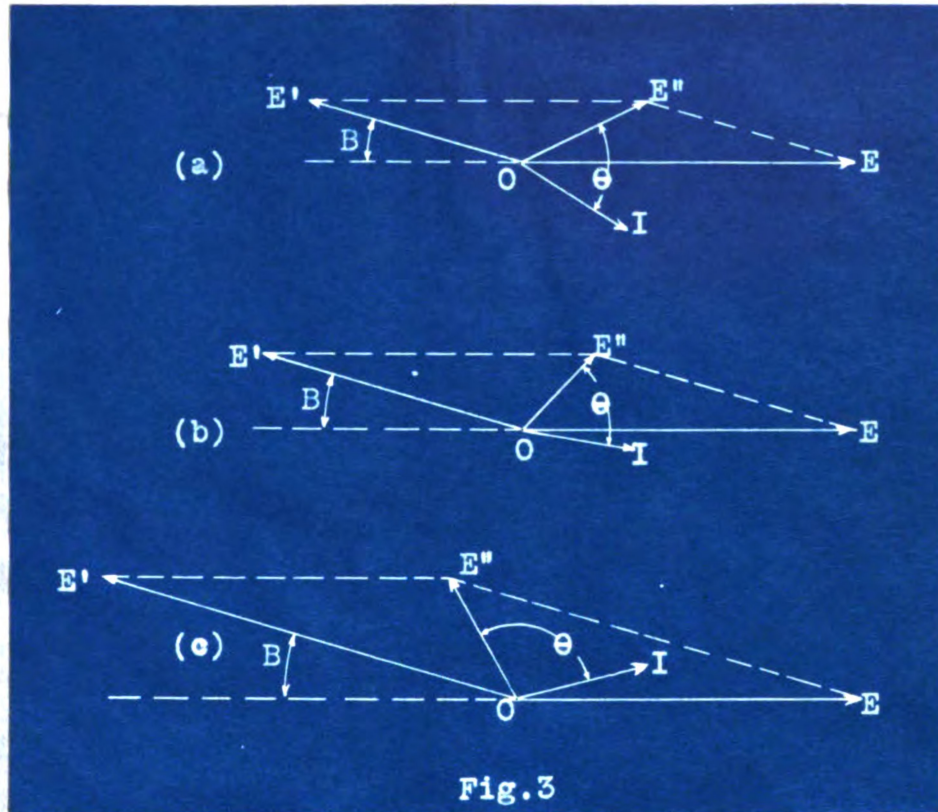
the true reactance of the armature vary with the space position of the armature coils in reference to the field magnets and time phase of the current as well as upon the reluctance of the leakage magnetic circuit, so there is some error in assuming the synchronous impedance to be constant. Thus it is evident that the synchronous impedance is less for very high values of excitation than for low values, since the magnetic circuits are more highly saturated and a given armature magneto-motive force has less effect upon the field flux than for low values of excitation.

VECTOR DIAGRAMS

The complete action of a synchronous motor can be explained analytically by means of vector diagrams. Let E represent the impressed voltage, E' the counter voltage generated by the motor, and E'' the resultant voltage that causes current to flow through the machine. Then E'' equals $E + E'$ and the armature current $I = E''/z$, where z is the synchronous impedance. The current I lags behind E'' by an angle ϕ whose tangent is x/r where x is the synchronous reactance and r is the effective resistance of the armature circuit.

In Fig. 3(a), suppose the motor is thrown on the line at a time when E' and E are exactly opposite in phase. E'' is then a minimum since,

then it is the arithmetical difference between E and E' ; the current I that flows is zero or so



(a) under-excited (b) under-excited (c) over-excited
 Fig. 3 Electromotive force diagram for a synchronous motor; three typical cases.

small and generally will not produce enough power to maintain rotation of the motor. The rotor tends to slow down, but as the rotor drops back in its running position E' drops back in phase, thus increasing E'' , I , and the power. A balance is reached at some point as d , when the power developed is just sufficient to meet the demand. The diagrams in Fig. 3 show three typical

the first of these is the fact that the system is not a simple one, and the second is the fact that the system is not a simple one.

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cases where I lags behind, falls between, and precedes E and E' prolonged.

The value of E' depends upon the excitation of the motor. If the excitation of the motor is changed the resultant voltage and the synchronous current, I , change in phase position and in magnitudes, but the motor still runs in synchronism.

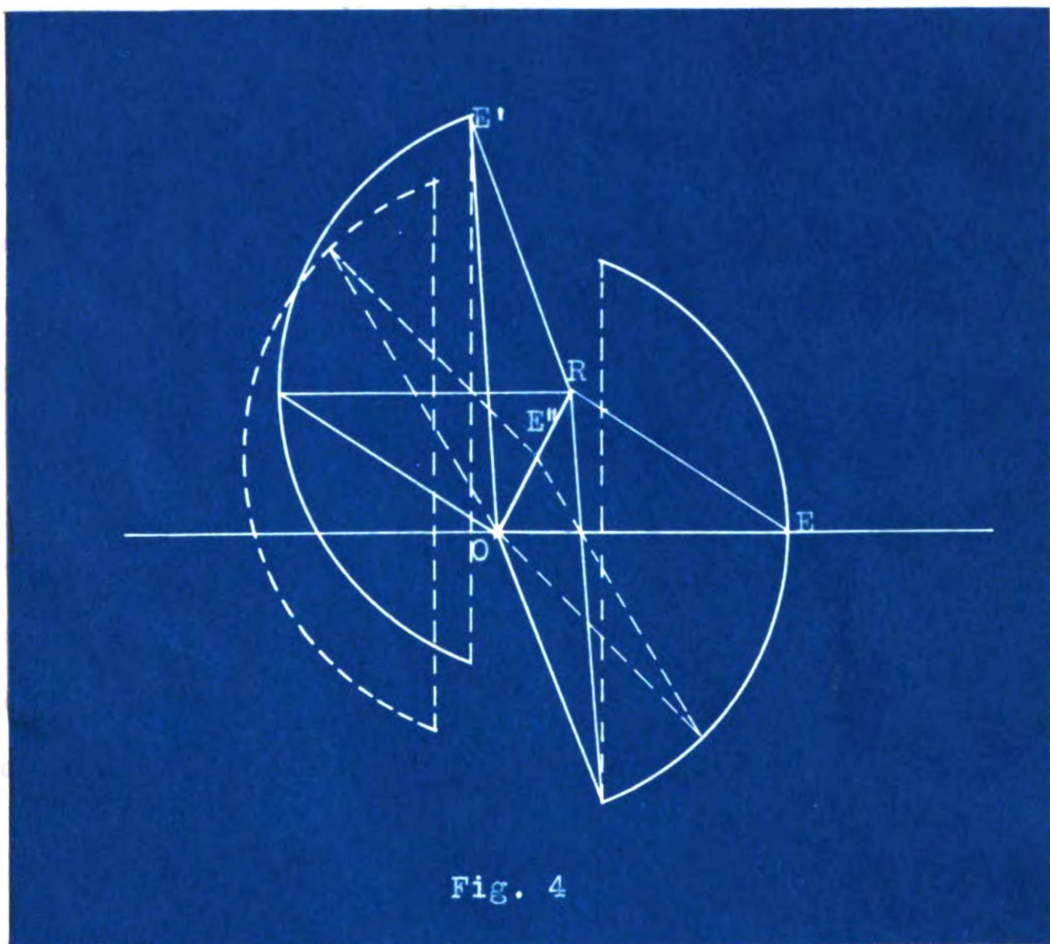


Fig. 4

Fig. 4 The locus of the counter-voltage of a Synchronous motor.

The above Fig. 4 shows the locus of the

counter-voltage in the synchronous motor when the current and the impressed voltage and current remain constant. The current vector is made the reference vector. For changes in load the impressed voltage and counter-voltage vary in phase position and for any given excitation of the motor, the locus of the counter-voltage is a circle as shown above, with its center at R . The current I , is constant and also the resultant voltage E^* , is constant if the synchronous impedance is assumed constant. The latter assumption is not exact because of the effect of saturation in the magnetic circuit with different excitations, as well as the effect of changes of power factor of the motor, but the assumption is sufficiently accurate for this explanation and test.

In order to have the resultant voltage E^* constant, the locus of the counter-voltage E' is a circle and must have its center at R and radius equal to E . This can be seen readily from the geometrical construction.

CURRENT LOCI

Since the loci of the counter-voltage E' is a circle, the resultant voltage E^* , is also a circle because it is the vectorial sum of a circle and a constant; likewise the loci of the current will be a circle since it is equal to the resultant voltage E^* ,

Fig. 6 is an expansion of Fig. 5 showing the current loci for a number of different excitations.

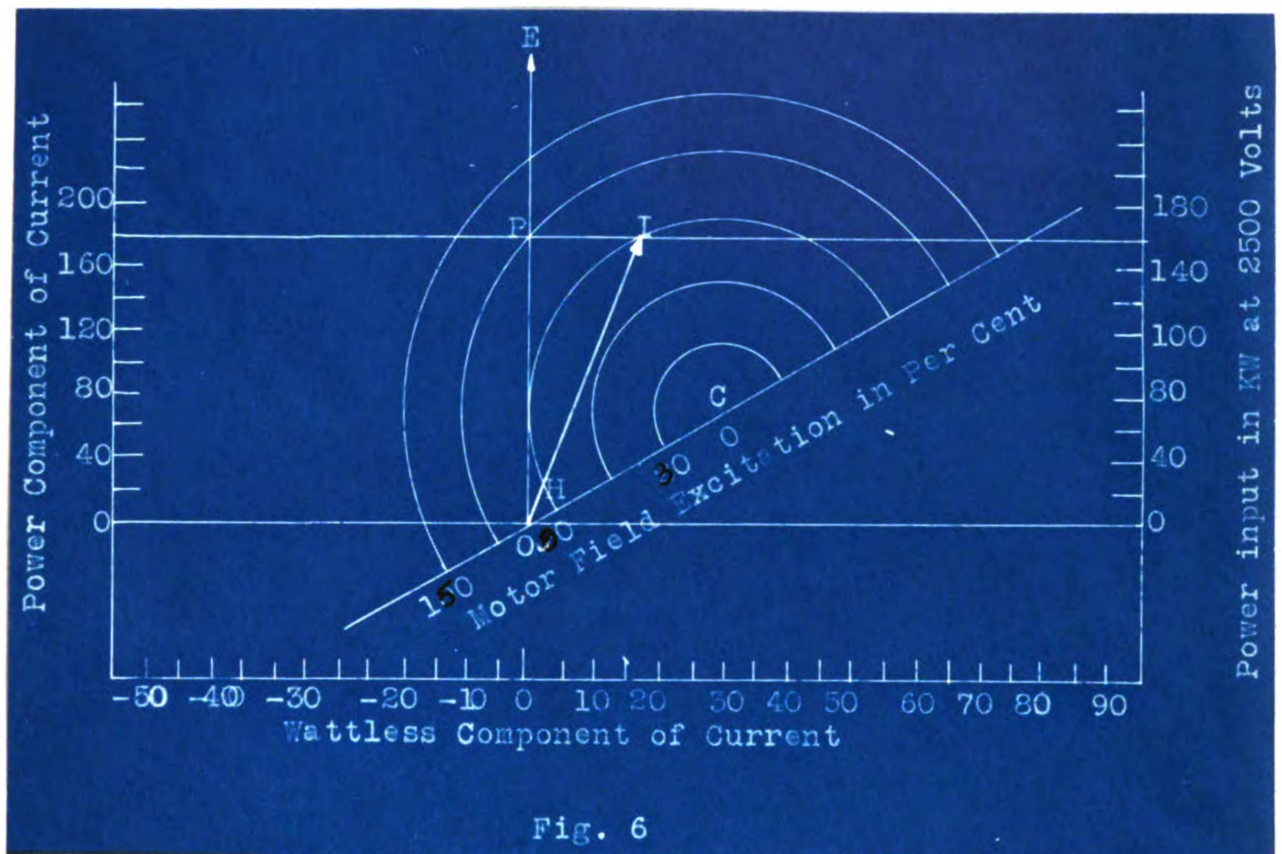


Fig. 6

Fig. 6 Current loci for various motor excitations.

OI is the input current to the motor; OP is the power component of the current; OP/OI is the power factor = $\cos \phi$. $OP \times OE = I \cos \phi E$ equals input watts; $I E \cos \phi - \text{Losses} = \text{Output watts}$. Efficiency = Output watts / Input watts. OC is the short-circuit current at full speed without

- **Stress** is a response to a stimulus (stressor) that is perceived as a threat or challenge.
- **Stressors** can be physical (e.g., injury, illness) or psychological (e.g., anxiety, depression).

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excitation; CH/OC = motor E.M.F./ supply E.M.F. = percent of excitation; OH is the minimum possible armature current.

CIRCULAR CURRENT LOAD LOCI

To determine the current that is required at a given power factor to supply a certain load P , a locus of current for constant power may be determined from the above current loci.

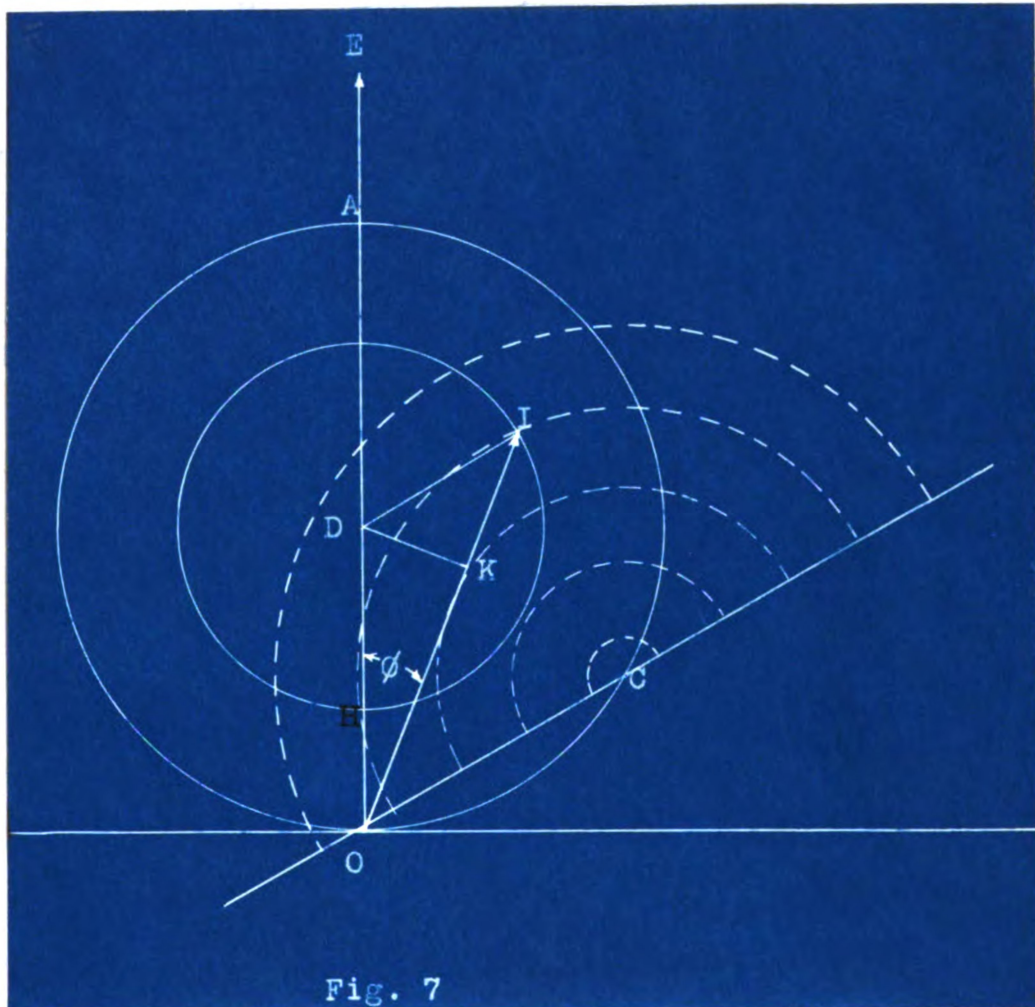


Fig. 7

Fig. 7 Diagram showing current loci in a synchronous motor for constant power output when the impressed voltage is constant.

Thus in Fig. 7 let OE be the direction of the impressed voltage (which is made the reference vector). Assume that the rotor is delivering a certain output P including core and friction losses, then the input is

$$(1) \quad E I \cos \phi = P + I^2 r$$

where E is the impressed voltage, I the current flowing, and ϕ the angle of lag between the current and impressed voltage. From this

$$(2) \quad I^2 - \frac{E I \cos \phi}{r} = -P/r$$

then completing the square

$$(3) \quad I^2 - E \cos \phi I/r + \frac{1}{4} \frac{E^2 \cos^2 \phi}{r^2} = \frac{1}{4} \frac{E^2 \cos^2 \phi}{r^2} - \frac{P}{r}$$

therefore

$$(4) \quad I = \frac{1}{2} \frac{E \cos \phi}{r} \pm \left(\frac{1}{4} \frac{E^2 \cos^2 \phi}{r^2} - \frac{P}{r} \right)^{\frac{1}{2}}$$

DETERMINATION OF THE RADIUS

From the above equation it is seen that there are two values of armature current for each value of $\cos \phi$ except one, and also that the currents are numerically equal but opposite in algebraic signs for equal positive and negative values of $\cos \phi$.

From the equation for I it can be seen that the current I is equal to E/r when P and ϕ are zero. The current is then in phase with the voltage, thus following Ohm's Law, making the loss entirely $I^2 r$.

...
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...
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$$\dots = \dots \quad (1)$$

...
...
...
...

$$\dots = \dots \quad (2)$$

...

$$\dots = \dots \quad (3)$$

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$$\dots = \dots \quad (4)$$

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This could only occur when the core losses and friction losses are supplied from external sources, and the rotor has taken such a position that the resultant voltage produces a current in phase with the impressed voltage. This occurs when the counter-voltage is at right-angles to the current. This current, E/r , is laid off as OA in Fig. 7.

Take any value of current I for a given power P and for any angle ϕ and assume I lags E by an angle ϕ as drawn. Then draw the perpendicular DK from a point D midway between O and A and connect the point D and I. The length $OD = \frac{1}{2}E/r$ equals $\frac{1}{2}OA$ and by construction

$$(5) \quad OK = \frac{1}{2} (E/r) \cos \phi$$

$$(6) \quad DK = \frac{1}{2} (E/r) \sin \phi = \frac{1}{2} \frac{E}{r} (1 - \cos^2 \phi)^{\frac{1}{2}}$$

$$\text{also } (7) \quad KI = OI - OK = I - \frac{1}{2} (E/r) \cos \phi$$

By construction

$$(8) \quad (DI)^2 = (DK)^2 + (KI)^2$$

Substituting the values DK and KI and using the value for current from equation (4), then

$$(9) \quad (DI)^2 = \left(\frac{1}{2} \frac{E}{r} \sqrt{1 - \cos^2 \phi} \right)^2 + \left[\frac{1}{2} (E \cos \phi)/r \right. \\ \left. \pm \left(\frac{1}{4} \frac{E^2 \cos^2 \phi}{r^2} - P/r \right)^{\frac{1}{2}} - \frac{1}{2} (E \cos \phi)/r \right]^2$$

which reduces to

$$(10) \quad (DI)^2 = \frac{1}{4} E^2/r^2 - P/r$$

or

$$(11) \quad DI = HD = \pm \left(\frac{1}{4} E^2/r^2 - P/r \right)^{\frac{1}{2}}$$

1. The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \int_0^x f(t) dt$. It is shown that $f(x)$ is a constant function, and its value is determined by the initial condition $f(0) = 1$. The proof is based on the fact that the derivative of $f(x)$ is equal to $f(x)$, which implies that $f(x)$ is an exponential function. Since $f(0) = 1$, it follows that $f(x) = e^x$.

2. In the second part, we consider the function $g(x)$ defined by the equation $g(x) = \int_0^x g(t) dt$. It is shown that $g(x)$ is a constant function, and its value is determined by the initial condition $g(0) = 1$. The proof is based on the fact that the derivative of $g(x)$ is equal to $g(x)$, which implies that $g(x)$ is an exponential function. Since $g(0) = 1$, it follows that $g(x) = e^x$.

3. The third part of the paper is devoted to the study of the properties of the function $h(x)$ defined by the equation $h(x) = \int_0^x h(t) dt$. It is shown that $h(x)$ is a constant function, and its value is determined by the initial condition $h(0) = 1$. The proof is based on the fact that the derivative of $h(x)$ is equal to $h(x)$, which implies that $h(x)$ is an exponential function. Since $h(0) = 1$, it follows that $h(x) = e^x$.

4. In the fourth part, we consider the function $k(x)$ defined by the equation $k(x) = \int_0^x k(t) dt$. It is shown that $k(x)$ is a constant function, and its value is determined by the initial condition $k(0) = 1$. The proof is based on the fact that the derivative of $k(x)$ is equal to $k(x)$, which implies that $k(x)$ is an exponential function. Since $k(0) = 1$, it follows that $k(x) = e^x$.

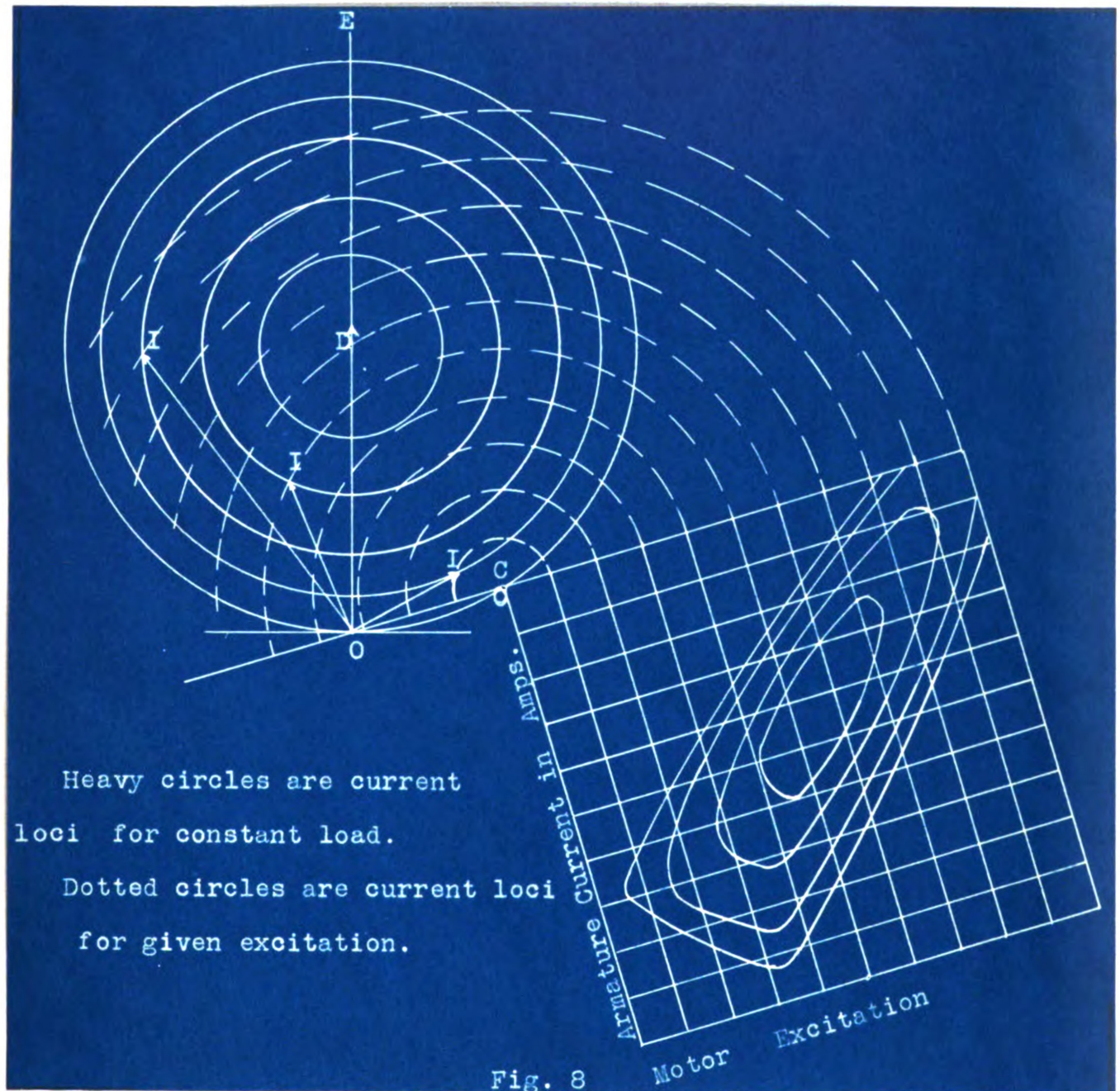
Hence so long as the power P is constant, the locus of the current I will be a circle whose radius is equal to DI with its center D at a distance equal to $\frac{1}{2} E/r$ from the origin O . For different values of power P the loci of the current are concentric circles with D as a center.

THE V AND O CURVES

The power factor of a synchronous motor is unity when the armature current is a minimum for a constant mechanical output. By varying the field excitation of the motor the power factor may be varied with corresponding change in the armature current. The V curves show the relation between field excitation and the armature current at a constant load and are usually plotted with field current as abscissa and armature current as ordinates, or sometimes plotted with excitation in counter-volts as abscissa instead of field amperes. This constitutes the experimental method of determining the phase characteristics.

The V curves can be determined graphically as shown in Fig. 8. Find the intersections of the current locus, for a definite load, with the different field excitation loci. Plot on the graph the distances from the origin O to the intersections as ordinates against the corresponding field excitations as abscissa thus obtaining the V curves shown which are known as

the complete V curves or O curves. The heavy part of the curve is called the V curve and may be determined experimentally.



ANALYTICAL DETERMINATION OF THE PHASE CHARACTERISTICS

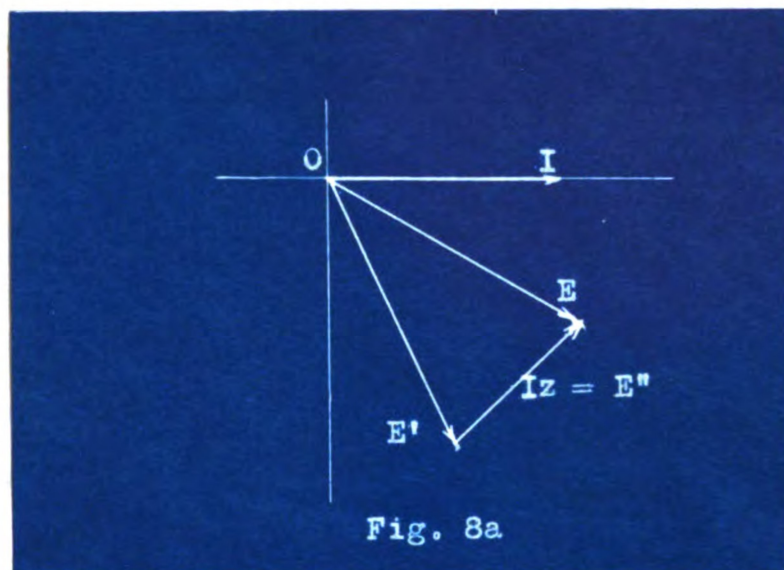


Fig. 8a Vector Diagram of voltages and current

Let E = impressed voltage on the motor.

E' = the voltage consumed by the counter-voltage of the motor.

Iz = drop or net loop voltage.

I = line current.

(12) $z = r + j x$ = the complete impedance of a phase loop.

(13) $I = i + j0$

(14) $E = e - j e'$

(15) $E' = e'' - j e'''$

Then (16) $E = E' + Iz = e'' + ir - j(e'' - ix)$

Therefore (17) $e = e'' + ir$ and $e' = e'' - ix$

The motor power is $P = e''i$ or $e'' = P/i$

1. The first part of the paper is devoted to the study of the

properties of the function $f(x)$ defined by the equation

$$f(x) = \int_0^x \frac{1}{1+t^2} dt$$

for $x \in \mathbb{R}$. It is shown that $f(x)$ is an odd function and

that $f(x)$ is bounded on $\mathbb{R}$. The second part of the paper

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for $x \in \mathbb{R}$. It is shown that $f(x)$ is an odd function and

that $f(x)$ is bounded on $\mathbb{R}$. The fifth part of the paper

is devoted to the study of the function $f(x)$ defined by the equation

$$f(x) = \int_0^x \frac{1}{1+t^2} dt$$

for $x \in \mathbb{R}$. It is shown that $f(x)$ is an odd function and

that $f(x)$ is bounded on $\mathbb{R}$. The sixth part of the paper

is devoted to the study of the function $f(x)$ defined by the equation

$$f(x) = \int_0^x \frac{1}{1+t^2} dt$$

for $x \in \mathbb{R}$. It is shown that $f(x)$ is an odd function and

that $f(x)$ is bounded on $\mathbb{R}$. The seventh part of the paper

is devoted to the study of the function $f(x)$ defined by the equation

$$f(x) = \int_0^x \frac{1}{1+t^2} dt$$

for $x \in \mathbb{R}$. It is shown that $f(x)$ is an odd function and

that $f(x)$ is bounded on $\mathbb{R}$. The eighth part of the paper

$$(18) \quad E = (e^2 + e'^2)^{\frac{1}{2}} \text{ and } E' = (e''^2 + e'''^2)^{\frac{1}{2}}$$

Eliminating e , e' , e'' , e''' , and solving for i in the power equation

$$(19) \quad E = (e^2 + e'^2)^{\frac{1}{2}} = \pm \left[(P/i)^2 + (e'' + ix)^2 \right]^{\frac{1}{2}}$$

$$\vdots$$

$$\vdots$$

$$\vdots$$

$$= \pm \left[i^2 x^2 - i^2 r^2 + E^2 - 2Pr + 2ix \sqrt{E^2 - 2Pr - i^2 r^2 - (P/i)^2} \right]^{\frac{1}{2}}$$

After squaring twice and transposing and collecting terms

$$(20) \quad i^4 - i^2 \left[\frac{2E'^2(x^2 - r^2) + (r^2 + x^2)(2E^2 - 4Pr)}{(x^2 + r^2)^2} \right] + \left[(E'^2 + 2Pr - E^2)^2 + 4P^2 x^2 \right] = 0$$

Which reduces to

$$(21) \quad i^4 - B i^2 + C = 0$$

Hence by solving the quadratic equation of the second degree:

$$i = \pm \left[\frac{B \pm \sqrt{B^2 - 4C}}{2} \right]^{\frac{1}{2}}$$

MAXIMUM OPERATING CONDITION

It can easily be seen from Fig. 9 that as the mechanical output increases the circle of the current locus decreases in size. Hence for maximum power output the circle of the current locus has contracted

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motor power, must be constant. From construction

$$(30) \quad e' = (E'^2 - e'^2)^{\frac{1}{2}}$$

Substituting in equation (29)

$$(31) \quad P = \frac{rE'^2 - e(re' + x\sqrt{E'^2 - e'^2})}{r^2 + x^2}$$

The differential of P with respect to e' will be zero since the motor power is constant.

Differentiating:

$$(32) \quad \frac{dP}{de'} = 2rE' \frac{dE'}{de'} - er - ex \left[\frac{E' \frac{dE'}{de'} - e'}{\sqrt{E'^2 - e'^2}} \right] = 0$$

Clearing fractions and solving for $\frac{dE'}{de'}$

$$(33) \quad \frac{dE'}{de'} = \frac{e \left[r - \frac{xe'}{(E'^2 - e'^2)^{\frac{1}{2}}} \right]}{2rE' - \frac{ex E'}{(E'^2 - e'^2)^{\frac{1}{2}}}} = 0$$

$$(34) \quad \text{Hence } e \left[r - \frac{xe'}{(E'^2 - e'^2)^{\frac{1}{2}}} \right] = 0$$

Transposing and squaring:

$$(35) \quad r^2 E'^2 - r^2 e'^2 = x^2 e'^2$$

Solving for e'

$$(36) \quad e' = (r E') / (r^2 + x^2) = r E' / z^2$$

Substituting the value of e' and z^2 in equation (31)

$$(37) \quad Pz^2 = rE'^2 - er^2 E' / z - ex(E'^2 - r^2 E'^2 / z^2)^{\frac{1}{2}} \\ = r E'^2 - e z E'$$

From which

$$(38) \quad E' = \frac{z}{2r} (e \pm \sqrt{4Pr + e^2})$$

But since $E = e + j0$

$$(39) \quad E' = \frac{Z}{2r} \left(E \pm \sqrt{4Pr + E^2} \right)$$

The maximum possible motor excitation comes when the motor power P equals zero, then the maximum excitation

$$(40) \quad E' = E_z/r$$

The minimum excitation is zero.

MAXIMUM MOTOR POWER WITH FIXED EXCITATION, IMPRESSED VOLTAGE, EQUIVALENT RESISTANCE, AND SYNCHRONOUS IMPEDANCE

The motor power must be negative and therefore, since the first term of equation (29) is constant, the second must be negative in order to have maximum motor power. $(re' + xe'')$ must be a maximum to have maximum motor power.

Then:

$$(41) \quad \frac{d}{de'}(re' + xe'') = r + x \frac{de''}{de'} = 0$$

$$(42) \quad E'^2 = e'^2 + e''^2 = \text{a constant.}$$

$$(43) \quad \frac{dE'}{de'} = 2e' + 2e'' \frac{de''}{de'} = 0$$

Combining equations (41) and (42) and (43)

$$(44) \quad \frac{d}{de'}(re' + xe'') = r - x \frac{e'}{e''} = 0$$

$$(45) \quad \text{Therefore} \quad r/x = e'/e''$$

1. $\frac{1}{x^2} = x^{-2}$ (differentiate)

$$= \frac{1}{-2} x^{-2-1} = -\frac{1}{2} x^{-3} = -\frac{1}{2} \frac{1}{x^3}$$

2. $\frac{1}{x^3} = x^{-3}$ (differentiate)

$$= \frac{1}{-3} x^{-3-1} = -\frac{1}{3} x^{-4} = -\frac{1}{3} \frac{1}{x^4}$$

3. $\frac{1}{x^4} = x^{-4}$ (differentiate)

$$= \frac{1}{-4} x^{-4-1} = -\frac{1}{4} x^{-5} = -\frac{1}{4} \frac{1}{x^5}$$

4. $\frac{1}{x^5} = x^{-5}$ (differentiate)

5.

6. $\frac{1}{x^6} = x^{-6}$ (differentiate)

$$= \frac{1}{-6} x^{-6-1} = -\frac{1}{6} x^{-7} = -\frac{1}{6} \frac{1}{x^7}$$

7.

8. $\frac{1}{x^7} = x^{-7}$ (differentiate)

$$= \frac{1}{-7} x^{-7-1} = -\frac{1}{7} x^{-8} = -\frac{1}{7} \frac{1}{x^8}$$

9. $\frac{1}{x^8} = x^{-8}$ (differentiate)

$$= \frac{1}{-8} x^{-8-1} = -\frac{1}{8} x^{-9} = -\frac{1}{8} \frac{1}{x^9}$$

10. $\frac{1}{x^9} = x^{-9}$ (differentiate)

$$= \frac{1}{-9} x^{-9-1} = -\frac{1}{9} x^{-10} = -\frac{1}{9} \frac{1}{x^{10}}$$

$$\frac{1}{x^{10}} = x^{-10} \quad \frac{1}{x^{11}} = x^{-11}$$

$$\frac{1}{x^{12}} = x^{-12} \quad \frac{1}{x^{13}} = x^{-13}$$

$$\frac{1}{x^{14}} = x^{-14} \quad \frac{1}{x^{15}} = x^{-15}$$

$$\frac{1}{x^{16}} = x^{-16} \quad \frac{1}{x^{17}} = x^{-17}$$

$$\frac{1}{x^{18}} = x^{-18} \quad \frac{1}{x^{19}} = x^{-19}$$

$$\frac{1}{x^{20}} = x^{-20}$$

That is, the maximum power(motor) will occur when E' lags behind E by an angle equal to $\tan^{-1} x/r$.
Substituting the value of e^* from equation (45):

$$(46) \quad \text{Maximum } P = \frac{rE'^2 - e(re' + x^2e'/r)}{z^2}$$

$$= rE'^2/z^2 - ee'/r$$

But $E = e + j0$, therefore

$$(47) \quad \text{Maximum } P = rE'^2/z^2 - E e'/r$$

$$\text{And } E'^2 = e'^2 + e^{*2}$$

And from equation (45) $e^* = e' x/r$

$$(48) \quad \text{Therefore } e'^2 = E'^2 - e'^2 x^2/r^2$$

$$\text{Or: } e' = E' r/z$$

Substituting this value of e' in equation (47)

$$(49) \quad \text{Maximum power} = E'^2 r/z^2 - EE'/z$$

From equation (49) it follows that a synchronous motor with the excitation voltage greater than the impressed voltage cannot operate unless it has reactance. If the reactance is zero equation (49) becomes

$$(50) \quad \text{Maximum } P = E'^2/r - EE'/r$$

For any value of E' greater than E , P will be positive and will represent generator action.

MAXIMUM POSSIBLE MOTOR EXCITATION WITH FIXED IMPRESSED VOLTAGE AND FIXED RESISTANCE AND REACTANCE

P must be negative in order to have the

machine run as a motor. The limiting value of E' will be that value which makes P zero.

$$(51) \quad \text{Maximum } P = E'^2 r / z^2 - E E' / z = 0$$

Therefore

$$(52) \quad \frac{E'^2 r}{z^2} = \frac{E E'}{z} \quad \text{or} \quad E' = E z / r$$

This equation shows that the maximum possible motor voltage is equal to the impressed voltage multiplied by the ratio of the synchronous impedance to the equivalent resistance.

MAXIMUM MOTOR ACTIVITY WITH FIXED IMPRESSED VOLTAGE AND FIXED REACTANCE AND RESISTANCE

Substituting $E = e + j0$ in equation (51) and differentiating with respect to E' :

$$(53) \quad \frac{dP}{dE'} = \frac{d}{dE'} (E'^2 r / z^2 - E' e / z) = 0$$

Therefore

$$(54) \quad 2 E' r / z^2 = e / z \quad \text{or}$$

$$(55) \quad E' = e z / 2r = E z / 2r$$

The maximum motor power, therefore, occurs when the motor voltage is one-half of its maximum possible value. Substituting the value of E' from equation (55) in equation (51), the maximum motor power then becomes :

$$(56) \quad \text{Maximum } P = - E^2 / 4r$$

Equation (56) gives the maximum motor power possible.

OPERATING CONDITIONS OF A SYNCHRONOUS MOTOR

For the following discussion refer to Fig.3.

If B remains constant and E' is increased by increasing the field, the current I will move up to a leading position. If the excitation of the motor (E') is held constant but let B increase by putting a load on the motor, then as B increases, E^* will also increase and follow a circle as a locus. The current I will also increase and depend upon B and shift to more lagging behind E . For a general case let E and E' be unequal; taking E as the reference vector let:

$$\begin{aligned}
 (57) \quad E^* &= E + E' \\
 &= E - E'(\cos B - j \sin B) \\
 &= E - E' \cos B + j E' \sin B \\
 &= e + j e'
 \end{aligned}$$

Let the impedance of the loop circuit be $z = r + jx$ which includes the resistance and reactance of the line and the machines.

$$\begin{aligned}
 (58) \quad I &= E^*/z = (E - E' \cos B + j E' \sin B)/(r + jx) \\
 &= \frac{1}{z^2} \left[Er - E'r \cos B + E' \sin B + \right. \\
 &\quad \left. j(-E + E'x \cos B + E'r \sin B) \right] \\
 &= i + j i'
 \end{aligned}$$

Let P = motor power, then

$$(59) \quad P = (E' \sin B)i - (E' \cos B) i'$$

From equation (57)

$$e = E - E' \cos B \quad \text{and} \quad e' = E' \sin B$$

Then

$$(60) \quad P = \frac{E'}{Z} (e'r \sin B - ex \sin B - er \cos B - e'x \cos B)$$

Substituting the values for $r = z \cos \theta$ and

$x = z \sin \theta$:

$$(61) \quad P = \frac{E'}{Z} (E' \cos \theta - E' \cos(\theta - B))$$

By differentiating P with respect to B , the maximum power is found for P when $B = \theta$.

Substituting $B = \theta$ in the equation (61)

$$(62) \quad P = \frac{E'}{Z} (E' \cos \theta - E)$$

HUNTING

Synchronous motors are subject to vibratory irregularities called hunting which are due to the fact that they depend upon a synchronizing current to hold them in step. The explanation of hunting can best be shown from a vector diagram as in Fig. 11.

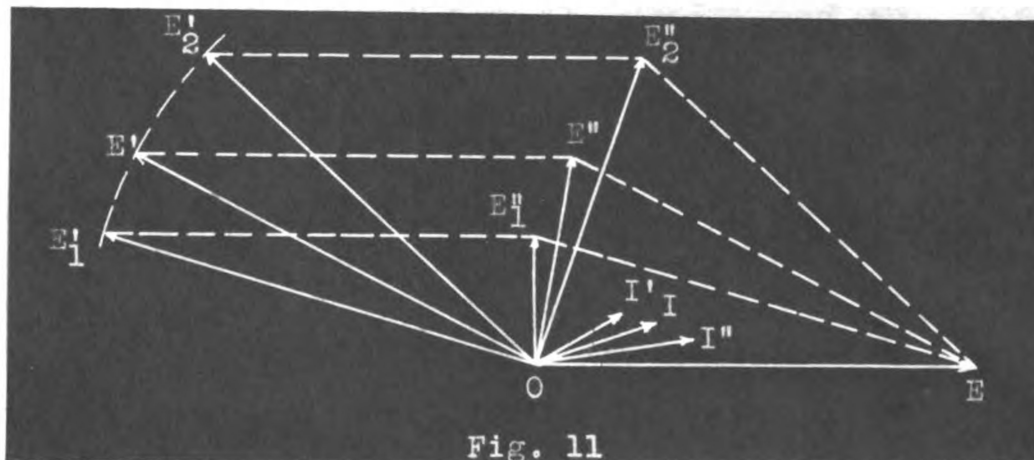


Fig. 11

Fig. 11 Vector diagram showing the effects of hunting.

E is the impressed voltage and is considered

constant both in magnitude and phase position; E' is the counter-voltage and is constant in magnitude but not in phase position; E^* is the resultant voltage causing the current I in the armature and varies both in magnitude and phase position. I also varies in magnitude and phase position.

Now let the load on the motor be reduced to a lower value where the normal conditions would be represented by the voltage parallelogram $EOE'E^*$ and the current vector OI . However, these conditions would not be satisfied immediately because the speed of the rotor must increase slightly in order to reach this new position. Then, due to the inertia of the rotor, it would be carried on past the correct operating position so that the counter-voltage would take the position as shown by the vector OE'_1 . This, of course, will change the resultant voltage to OE^*_1 which has moved forward in phase position. The voltage E^*_1 will cause the current to take the new position as shown at OI' . Since the current has become less, the component of the current opposed to the counter-voltage is smaller and the resisting moment of the load being greater than the magnetic torque between the rotor and stator, the extra momentum is absorbed in the mechanical load and the

1. The first step in the process of the development of a new product is the identification of a market need. This is done by conducting market research, which involves gathering information about the current market and the needs of potential customers. The next step is to develop a concept for the new product, which involves creating a detailed description of the product and its features.

2. The second step is to develop a business plan for the new product. This involves determining the costs of production, the expected sales volume, and the potential profit. The business plan also includes a marketing strategy, which outlines how the product will be promoted and sold. Once the business plan is complete, the next step is to secure financing for the project. This can be done through a variety of sources, including banks, venture capitalists, and crowdfunding.

3. The third step is to develop a prototype of the new product. This involves creating a small-scale model of the product that can be used to test its design and functionality. The prototype is typically made from a material that is easy to work with, such as wood or plastic. Once the prototype is complete, the next step is to conduct a series of tests to evaluate the product's performance. These tests may include durability testing, performance testing, and user testing. The results of these tests are used to refine the product design and make any necessary adjustments.

speed is reduced to normal again. But the resisting moment of the load is still too great and the rotor must fall back in phase position. To accomplish this it must momentarily slow down in speed below synchronous. When the normal space-phase position has been reached the speed of the rotor is below normal and it drops back still farther, for instance, to the position OE'_2 . The current also increases to OI'' as the rotor falls back and the magnetic torque is greater than the resisting moment of the load. The rotor again tends to speed up above synchronous speed. The vibrations described above may last for several cycles but finally die out due to the frictional, magnetic, and electrical losses which absorb some of the excess energy of the pendulum action of the rotor.

DAMPING

Hunting may be prevented to a certain extent by damping or by increasing the mass of the rotor with a fly-wheel. Damping may be accomplished by using a shortcircuited, low resistance winding on the field structure. These are sometimes called Amortisseur windings or dampers and are placed in the pole faces of the rotor. When hunting occurs, currents are induced in the Amortisseur winding which according to Lenz's Law oppose the flux producing them. Eddy currents and

hysteresis losses are also produced in the pole faces which help slightly in the damping action. The induced currents in the damper oppose any change in the angular velocity of the rotor. For the most effective damping, the dampers should have as low resistance as possible but if this winding is to be used for starting the motor the resistance which gives the best damping may be too low to give the best starting torque.

STABILITY

Referring to equation (49) the

$$(63) \text{ Maximum } P = (rE'^2)/(r^2+x^2) - EE'/(r^2+x^2)^{\frac{1}{2}}$$

If we assume r , E , E' fixed; then to obtain the value of x that will give the maximum power differentiate equation (63) with respect to x and equate the derivative to zero.

$$(64) \quad \frac{dP}{dx} = \frac{-2xE'^2}{(r^2+x^2)^2} + \frac{\frac{1}{2}(r^2+x^2)^{-\frac{1}{2}} 2x EE'}{(r^2+x^2)^2} = 0$$

Then

$$(65) \quad -2xE'^2 + (r^2+x^2)^{\frac{1}{2}} xEE' = 0$$

Solving for x^2

$$(66) \quad x^2 = r^2 \frac{4E'^2 - E^2}{E^2}$$

If E and E' are equal, then to give the maximum motor power

$$(67) \quad x = r(3)^{\frac{1}{2}} \text{ or } x/r = (3)^{\frac{1}{2}}$$

[illegible]

Then from equation (67) the $\tan B = x/r = (3)^{\frac{1}{2}}$ and therefore this corresponds to a difference in phase between the impressed and excitation voltages of 60° . Breakdown will occur at this value of phase displacement. The counter-voltage will generally be equal to or greater than the impressed voltage as synchronous motors are used at unity or leading power factor. Therefore the ratio x/r should be equal to or greater than 1.732 to obtain maximum motor power. For maximum stability, the change in power developed should be a maximum for a given change in phase. In other words $\frac{dP}{dB}$ should be a maximum. Referring to equation (29)

$$(68) \quad P = \frac{rE'^2 - e(re' + xe'')}{r^2 + x^2}$$

$$= \frac{rE'^2 - EE'(r \cos B + x \sin B)}{r^2 + x^2}$$

Then differentiating, this expression becomes

$$(69) \quad \frac{dP}{dB} = \frac{EE'(r \sin B - x \cos B)}{r^2 + x^2}$$

$\frac{dP}{dB}$ is sometimes called the stability factor.

It can be seen from equation (69) that the stability factor is directly proportional to E' , the excitation voltage. A synchronous motor when over-excited is, therefore, more stable than one when operating under-excited. When $\tan B = x/r$ the motor develops maximum power. Then substituting the corresponding values

1. $\frac{1}{2} \times \frac{1}{3} = \frac{1}{6}$
 2. $\frac{1}{4} \times \frac{1}{5} = \frac{1}{20}$
 3. $\frac{1}{6} \times \frac{1}{7} = \frac{1}{42}$
 4. $\frac{1}{8} \times \frac{1}{9} = \frac{1}{72}$
 5. $\frac{1}{10} \times \frac{1}{11} = \frac{1}{110}$

6. $\frac{1}{12} \times \frac{1}{13} = \frac{1}{156}$
 7. $\frac{1}{14} \times \frac{1}{15} = \frac{1}{210}$
 8. $\frac{1}{16} \times \frac{1}{17} = \frac{1}{272}$
 9. $\frac{1}{18} \times \frac{1}{19} = \frac{1}{342}$
 10. $\frac{1}{20} \times \frac{1}{21} = \frac{1}{420}$
 11. $\frac{1}{22} \times \frac{1}{23} = \frac{1}{506}$
 12. $\frac{1}{24} \times \frac{1}{25} = \frac{1}{600}$
 13. $\frac{1}{26} \times \frac{1}{27} = \frac{1}{702}$
 14. $\frac{1}{28} \times \frac{1}{29} = \frac{1}{812}$
 15. $\frac{1}{30} \times \frac{1}{31} = \frac{1}{930}$

$$\frac{1}{32} \times \frac{1}{33} = \frac{1}{1056}$$

$$\frac{1}{34} \times \frac{1}{35} = \frac{1}{1190}$$

$$\frac{1}{36} \times \frac{1}{37} = \frac{1}{1332}$$

16. $\frac{1}{38} \times \frac{1}{39} = \frac{1}{1482}$
 17. $\frac{1}{40} \times \frac{1}{41} = \frac{1}{1640}$
 18. $\frac{1}{42} \times \frac{1}{43} = \frac{1}{1806}$
 19. $\frac{1}{44} \times \frac{1}{45} = \frac{1}{1980}$
 20. $\frac{1}{46} \times \frac{1}{47} = \frac{1}{2162}$
 21. $\frac{1}{48} \times \frac{1}{49} = \frac{1}{2352}$
 22. $\frac{1}{50} \times \frac{1}{51} = \frac{1}{2550}$
 23. $\frac{1}{52} \times \frac{1}{53} = \frac{1}{2756}$
 24. $\frac{1}{54} \times \frac{1}{55} = \frac{1}{2970}$
 25. $\frac{1}{56} \times \frac{1}{57} = \frac{1}{3192}$

for $\sin B$ and $\cos B$ in equation (69) , $\frac{dP}{dB}$ becomes zero as it should. When $\tan B$ is greater than x/r , $\frac{dP}{dB}$ is positive , and according to our notation (since motor power is negative) it represents a decrease in motor power. Therefore when $\tan B$ exceeds x/r the motor will fall out of step.

To make the stability factor a maximum, the relative magnitude of x and r can be found by equating the derivative of $\frac{dP}{dB}$ with respect to x to zero.

$$(70) \quad \frac{d}{dx} \left(\frac{dP}{dB} \right) = EE' \frac{2x^2 \cos B - (r^2 + x^2) \cos B - 2xr \sin B}{(r^2 + x^2)^2} = 0$$

Then simplifying

$$(71) \quad x^2 \cos B - r^2 \cos B - 2xr \sin B = 0$$

Hence

$$(72) \quad x/r = \tan B \pm (1 + \tan^2 B)^{\frac{1}{2}}$$

Since x can never be negative, the minus sign before the radical $(1 + \tan^2 B)^{\frac{1}{2}}$ has no meaning. If the value of $\tan B$ in equation (72) is greater than or equal to x/r the condition of operation is unstable. For maximum stability the ratio of x/r is unity when $B = 0$, but this condition can never be obtained because at no load E' must fall back enough to compensate for the losses in the motor. As B increases, the ratio x/r also increases for the condition of maximum stability.

1. 在 1950 年，中国人口为 5.5 亿，到 1955 年增加到 5.8 亿，1960 年达到 6.2 亿。这一时期，中国人口增长迅速，主要是由于出生率较高，死亡率较低。

2. 1960 年，中国人口为 6.2 亿，到 1965 年增加到 6.5 亿，1970 年达到 7.0 亿。这一时期，中国人口继续增长，主要是由于出生率仍然较高，死亡率进一步降低。

3. 1970 年，中国人口为 7.0 亿，到 1975 年增加到 7.3 亿，1980 年达到 7.8 亿。这一时期，中国人口增长速度有所放缓，但仍保持较快增长。

4. 1980 年，中国人口为 7.8 亿，到 1985 年增加到 8.0 亿，1990 年达到 8.5 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

5. 1990 年，中国人口为 8.5 亿，到 1995 年增加到 8.8 亿，2000 年达到 9.2 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

6. 2000 年，中国人口为 9.2 亿，到 2005 年增加到 9.5 亿，2010 年达到 9.8 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

7. 2010 年，中国人口为 9.8 亿，到 2015 年增加到 10.0 亿，2020 年达到 10.2 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

8. 2020 年，中国人口为 10.2 亿，到 2025 年增加到 10.5 亿，2030 年达到 10.8 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

9. 2030 年，中国人口为 10.8 亿，到 2035 年增加到 11.0 亿，2040 年达到 11.2 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

10. 2040 年，中国人口为 11.2 亿，到 2045 年增加到 11.5 亿，2050 年达到 11.8 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

11. 2050 年，中国人口为 11.8 亿，到 2055 年增加到 12.0 亿，2060 年达到 12.2 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

12. 2060 年，中国人口为 12.2 亿，到 2065 年增加到 12.5 亿，2070 年达到 12.8 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

13. 2070 年，中国人口为 12.8 亿，到 2075 年增加到 13.0 亿，2080 年达到 13.2 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

14. 2080 年，中国人口为 13.2 亿，到 2085 年增加到 13.5 亿，2090 年达到 13.8 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

15. 2090 年，中国人口为 13.8 亿，到 2095 年增加到 14.0 亿，2100 年达到 14.2 亿。这一时期，中国人口增长速度进一步放缓，但仍保持较快增长。

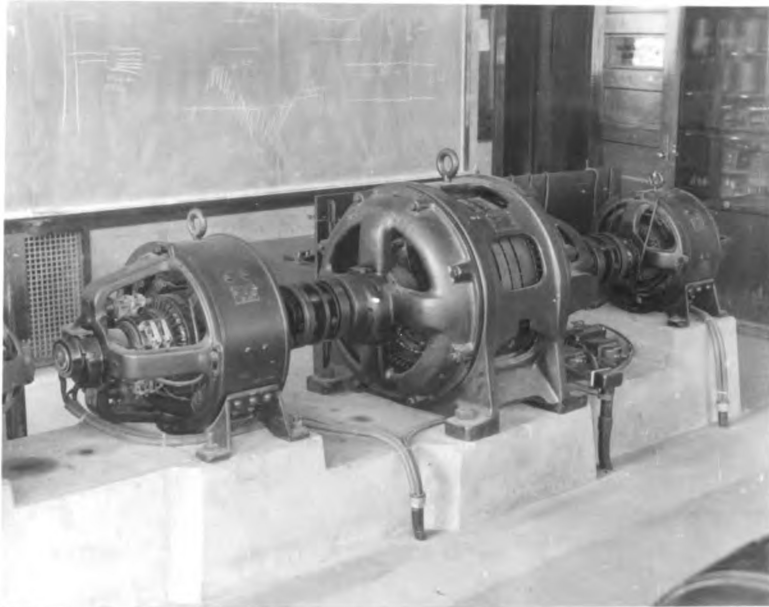
The damper windings will affect these conditions slightly making the ratio x/r greater than that derived above.

CHAPTER II

METHOD OF PROCEEDURE

CHAPTER II

NAME PLATE DATA



Synchronous Motor-Generator Set M - 4

Westinghouse Synchronous Motor

No. 4507244

50 Horse Power	1200 R.P.M.
2200 Volts	Exciting Amperes = 17
14 Amperes	Exciting Volts = 125
80 % Power Factor	100 % Load
3 Phase	24 Hours Continuous
60 Cycle	40° C. Temperature Rise.

Westinghouse Direct Current Generator

No. 4507242

Compound Wound	1200 R.P.M.
15 Kilowatts	100 % Load
125 Volts	24 Hours Continuous
120 Amperes	40° C. Temperature Rise

Westinghouse Direct Current Generator

No. 4507246

Compound Wound	1200 R.P.M.
20 Kilowatts	100 % Load
250 Volts	24 Hours Continuous
80 Amperes	40° C. Temperature Rise.

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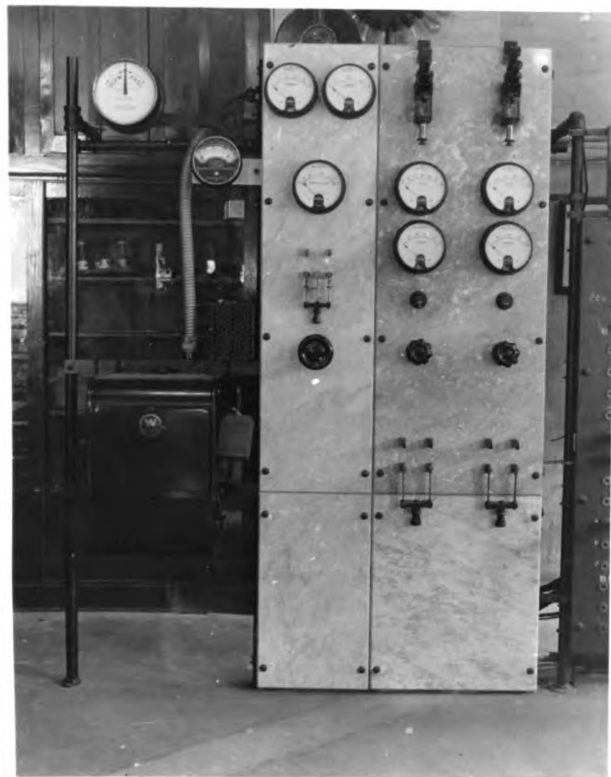
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Instrument Transformer Connections



Panels of Motor-Generator Set M-4



Meter Connections

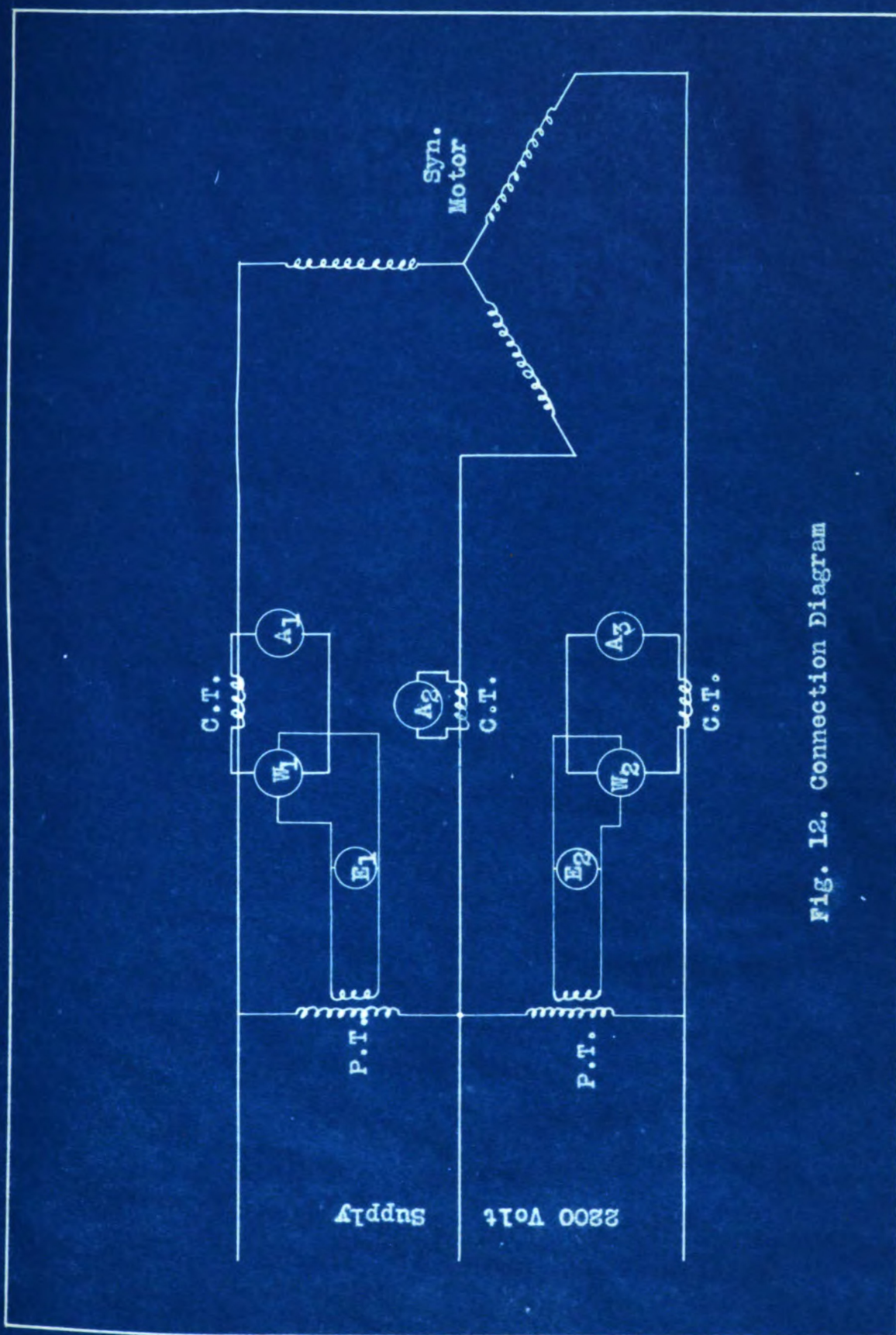


Fig. 12. Connection Diagram

METHOD OF PROCEEDURE

GENERAL

Before proceeding with any tests that required the operation of the machines, particular care was taken to see that the bearings were properly oiled and that the oil rings were functioning; also all meters were set at the zero reading and after the test was completed the meters were calibrated. A multiplier was used in conjunction with the potentiometer for calibrating the voltmeters and a standard shunt in conjunction with the potentiometer for calibrating the ammeters. All measurements of power were taken by means of the two-wattmeter method.

A speed counter was made from a small Direct Current fan motor driven as a generator with separate excitation. It was driven from the coupling on the shaft of the M-G set by a small belt. A voltmeter was connected across the armature terminals and calibrated by a precision tachometer to read in R.P.M.

STATIC TEST

The insulation of the three machines was first tested by means of a megger. The test consisted of measuring the approximate resistance between separate parts of the machine and between different parts of the machine and ground. Measurements were

made from ground to slip rings, one end of field, one end of stator, other machines, conduit, one end of interpole winding, one end of shunt field winding, one end of series field winding, all segments on armature, and between commutator segments.

RESISTANCE MEASUREMENTS

The resistances of the different field windings and armature were found for the generators. Likewise measurements were made for the terminal resistance of the stator windings and field winding of the synchronous motor. These measurements were determined by the voltmeter-ammeter method in all cases, the voltmeter measured the drop over the resistance only. The resistance of the voltmeter used was determined by the use of the Wheatstone Bridge and standard resistances. When the resistance measurements were made on the windings that had considerable inductance, the voltmeter leads were disconnected before the current was interrupted.

DETERMINATION OF LOSSES

Losses were determined by the retardation method. The machine under test was run until the bearings were warmed sufficiently to make frictional losses constant. The generators were mechanically disconnected from the motor. Each generator was tested under the

4. The fourth part of the document discusses the implications of the findings. It suggests that the results have significant implications for the field of study and may lead to further research in this area.

5. The fifth part of the document concludes the study. It summarizes the key findings and provides a final statement on the importance of the research.

6. The sixth part of the document includes a list of references to the sources used in the study. It also includes a list of figures and tables that are included in the document.

7. The seventh part of the document includes a list of appendices. These appendices provide additional information and data that are not included in the main body of the document.

8. The eighth part of the document includes a list of footnotes. These footnotes provide additional information and clarification on the content of the document.

9. The ninth part of the document includes a list of acknowledgments. These acknowledgments thank the individuals and organizations that provided support and assistance during the study.

10. The tenth part of the document includes a list of contact information. This information provides a way for readers to contact the author for more information or to request a copy of the document.

following conditions, i.e. the machine was brought up to rated speed as a motor and the power input recorded. Then it was speeded up above rating about one hundred R.P.M. at which time the power was shut off, the brushes raised immediately, and the armature allowed to come to rest. During this coasting period the instantaneous R.P.M. was recorded at equal short intervals of time. The above was repeated with brushes down and no field current; also with brushes down and with different values of field current.

To find the corresponding losses in the synchronous motor, it was driven by one of the generators operating as a motor. Tests were run on the synchronous motor for the same conditions as those used for the generators. The input to the driving motor at the rated R.P.M. was recorded in all cases, a constant value of field current was used on the driving motor. By knowing the losses and input of the driving motor, the losses in the synchronous motor could be determined.

For determining the efficiency of each machine the equation $(\text{Input} - \text{Losses}) / (\text{Input})$ was used. The losses were those determined as above in addition to the I^2R losses of the machines.

SATURATION CURVES

The other generator was connected to the synchronous motor mechanically. The saturation curve of the synchronous motor was determined by driving it as

an alternator at the rated speed, by reading terminal volts at different values of field current and recording both. The field was demagnetized before running this test. Saturation curves were determined for the generators in a like manner.

TEST FOR SHAFT CURRENT

A high reading ammeter was connected with one end grounded to the frame and the other end bearing on the shaft through low resistance leads. If no current was noticed a smaller ammeter was used.

SYNCHRONOUS IMPEDANCE

The armature was shorted through suitable ammeters, first including the current transformers and second with the transformers cut out. The machine was driven at normal speed and sufficient field current applied to produce a good reading on the ammeters. Several readings were taken for values of armature current from zero to 150 % of rating.

Attention was given to balancing of the phases at the same time. The synchronous impedance curve was plotted with field current as abscissa and armature current as ordinates.

PHASE CHARACTERISTICS

Different mechanical loads were applied to the motor by loading the generators. V curves were taken for several different loads on the motor. The excitation was varied, for a definite load, from a very low value to approximately 160 % rated value. The armature current and field current were recorded for each variation. The wattmeter and voltage readings were also recorded. To determine the power factor, the ratio of the wattmeter readings was taken. V curves were plotted with field current as abscissa and armature current as ordinates.

LOAD VOLTAGE CURVES OF GENERATORS

Water barrel rheostats were used to load the generators. The generators were loaded by increments and readings of voltage and current taken at each increment. This was done at the same time that the V curves were obtained. Plotting load current as abscissa and terminal voltage as ordinates, the load voltage curves were determined.

STATIC TORQUE

An iron bar was fastened rigidly to the coupling on the shaft between the machines. This was used as a lever arm and a set of scales used to determine the pounds pressure exerted by the lever arm. The tare

was set permanently on the scales. For the various reduced voltages applied, readings of volts, line amperes, watts, and scale pounds were taken. By plotting the data obtained on logarithmic paper and the curve extrapolated for the starting voltage, the starting torque may be determined provided the function is a straight line. Another method is to construct the circle diagram corresponding to an induction motor from which approximate results may be obtained.

RUNNING TORQUE

The running torque was determined for the various loads by using equation

$$(73) \quad T = \frac{7.04 \text{ Watts}}{\text{R.P.M.}} \text{ in pound-feet.}$$

Output watts are used in the above equation.

PULL - OUT TORQUE

The pull out torque was determined by loading the generators to approximately three times rated full load. At the instant of pull-out, readings of watts, voltages, line amperes, and field amperes of the motor were taken. The pull-out torque may be determined from equation (73).

STARTING TESTS

The center of one pole on the rotor was aligned with the center of the frame. Then, two-thirds of the distance between pole centers was divided into five equal parts., On each one of these divisions the center-line of the marked pole was placed and the motor started under reduced voltage in each of the five positions. Readings were taken of volts, line amperes, and watts on the A.C. side. The power was shut off as soon as the machine started.

CAUTION: Enough time was allowed between readings so as not to over-heat the machine and the current left on only long enough to obtain a reading.

WAVE FORM

The wave form of the voltage and current of the motor for all conditions from starting to running inclusive, were taken by means of the oscillograph.

HUNTING AND DAMPING

For sudden changes of load within the rating of the motor no effects of hunting were noticed. It might be concluded from this that the damping was very effective.

CHAPTER III

DATA AND RESULTS

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CHAPTER III

DATA AND RESULTS

Static Test

Evershed Megger Test Set No. 120661

500 volts, 1000 Megohms.

Synchronous Motor No. 4507244

From	To	Megohms
Ground on frame	Slip rings	1000 +
"	One end of field	Infinity -
"	One end of stator	1000
"	Other generators	0
"	Conduit	0

D.C. Generator No. 4507242

From	To	Megohms
Ground on frame	One end of Interpole field winding	1000
"	One end of shunt field winding	Infinity-
"	One end of series field winding	Infinity-
"	Armature	900
"	Commutator segments	900

D.C. Generator No. 4507246

From	To	Megohms
Ground on frame	One end of Inter-pole field	900
"	One end of shunt field	Infinity-
"	One end of series field	Infinity-
"	Armature	900
"	Commutator segments	900

RESISTANCE MEASUREMENTS

Synchronous Motor No. 4507244

Phase	E	I	R	Average R
1.	17.5	4.59	3.82	3.79
	30.8	8.03	3.74	
	43.6	11.41	3.81	
2.	17.15	4.59	3.74	3.83
	31.75	8.03	3.95	
	43.6	11.41	3.81	
3.	17.6	4.59	3.82	3.81
	30.7	8.03	3.74	
	44.2	11.5	3.88	

Average R of the three phases = 3.81 ohms

D.C. Generator No. 4507242

Part	E	I	R	Av.	R
	132.9	2.84	43.3		
	65.2	1.40	45.7		
Shunt	75.6	1.60	47.1	45	ohms
field	64.2	1.40	43.3		
	43.3	.96	45.4		
(E in millivolts)	46.3	8.65	.00524		
	40.	7.58	.00528		
Series field including shunt.	33.9	6.36	.00533	.00526	ohms
	26.9	5.07	.00530		
	19.1	3.70	.00515		
	.034	3.71	.00916		
	.046	5.07	.00910		
Interpole field.	.057	6.39	.00898	.00908	ohms
	.068	7.59	.00909		
	1.30	2.66	.496		
Armature + Brushes.	1.64	4.04	.411	.415	ohms
	1.80	5.34	.339		
	.294	5.43	.0541		
	.417	7.73	.0540		
Armature.	.220	4.04	.0545	.0541	ohms
	.154	2.66	.0579		
	.330	6.59	.0502		

D.C. Generator No. 4507246

Part	E	I	R	Av. R
Shunt	114.2	.81	141.	
field.	116.8	.84	139.5	138.9 ohms
	130.1	.96	136.2	
	.035	3.64	.00967	
Series	.048	5.04	.00958	
field +				.00956 ohms
shunt.	.060	6.35	.00952	
	.071	7.50	.00948	
	.022	1.37	.0157	
Interpole	.042	2.66	.0158	.0158 ohms
field.	.056	3.60	.0154	
	1.80	3.58	.5055	
Armature	1.40	2.60	.5500	.5670 ohms
+ Brushes	0.80	1.36	.5960	
	.080	1.33	.0601	
Armature	.180	2.60	.0694	.0648 ohms
only	.230	3.55	.0648	

Date	To		By	
	Particulars	Dr.	Cr.	
1900				
Jan 1	Balance		100.00	
Jan 15	By Cash	50.00		
Jan 20	To Cash		25.00	
Jan 25	By Cash	75.00		
Jan 30	To Cash		100.00	
Feb 5	By Cash	125.00		
Feb 10	To Cash		50.00	
Feb 15	By Cash	75.00		
Feb 20	To Cash		100.00	
Feb 25	By Cash	125.00		
Feb 28	To Cash		50.00	
Mar 5	By Cash	75.00		
Mar 10	To Cash		100.00	
Mar 15	By Cash	125.00		
Mar 20	To Cash		50.00	
Mar 25	By Cash	75.00		
Mar 30	To Cash		100.00	
Apr 5	By Cash	125.00		
Apr 10	To Cash		50.00	
Apr 15	By Cash	75.00		
Apr 20	To Cash		100.00	
Apr 25	By Cash	125.00		
Apr 30	To Cash		50.00	
May 5	By Cash	75.00		
May 10	To Cash		100.00	
May 15	By Cash	125.00		
May 20	To Cash		50.00	
May 25	By Cash	75.00		
May 30	To Cash		100.00	
Jun 5	By Cash	125.00		
Jun 10	To Cash		50.00	
Jun 15	By Cash	75.00		
Jun 20	To Cash		100.00	
Jun 25	By Cash	125.00		
Jun 30	To Cash		50.00	
Jul 5	By Cash	75.00		
Jul 10	To Cash		100.00	
Jul 15	By Cash	125.00		
Jul 20	To Cash		50.00	
Jul 25	By Cash	75.00		
Jul 30	To Cash		100.00	
Aug 5	By Cash	125.00		
Aug 10	To Cash		50.00	
Aug 15	By Cash	75.00		
Aug 20	To Cash		100.00	
Aug 25	By Cash	125.00		
Aug 30	To Cash		50.00	
Sep 5	By Cash	75.00		
Sep 10	To Cash		100.00	
Sep 15	By Cash	125.00		
Sep 20	To Cash		50.00	
Sep 25	By Cash	75.00		
Sep 30	To Cash		100.00	
Oct 5	By Cash	125.00		
Oct 10	To Cash		50.00	
Oct 15	By Cash	75.00		
Oct 20	To Cash		100.00	
Oct 25	By Cash	125.00		
Oct 30	To Cash		50.00	
Nov 5	By Cash	75.00		
Nov 10	To Cash		100.00	
Nov 15	By Cash	125.00		
Nov 20	To Cash		50.00	
Nov 25	By Cash	75.00		
Nov 30	To Cash		100.00	
Dec 5	By Cash	125.00		
Dec 10	To Cash		50.00	
Dec 15	By Cash	75.00		
Dec 20	To Cash		100.00	
Dec 25	By Cash	125.00		
Dec 30	To Cash		50.00	
Total		1000.00	1000.00	

RETARDATION CURVES

Synchronous Motor No. 4507244

The following data contains the windage, bearing friction, brush friction, and eddy current losses of D.C. Generator No. 4507242 in addition to the heading losses of the test.

Windage of Syn. motor		Windage + Brush Friction	
Time in Min.	R.P.M.	Time in Min.	R.P.M.
0.0	1364	0.0	1345
.05	1281	.05	1281
.1	1235	.10	1218
.15	1158	.15	1153
.2	1090	.20	1090
.25	1031	.25	1047
.3	983	.30	990
.35	927	.35	951
.4	855	.40	897
.45	820	.45	849
.5	770	.50	803
.55	727	.55	764
.6	685	.60	719
.65	642	.65	685
.7	610	.70	650
.75	578	.75	620
.8	535	.80	578

1. The first part of the report is a general introduction to the project, which includes a brief history of the project and a description of the objectives.

2. The second part of the report is a detailed description of the methodology used in the study, which includes a description of the data collection methods and the statistical analysis techniques used.

3. The third part of the report is a presentation of the results of the study, which includes a description of the findings and a discussion of the implications of the results.

4. The fourth part of the report is a conclusion, which summarizes the main findings of the study and provides recommendations for future research.

The following table shows the results of the study, which are presented in terms of the number of cases and the percentage of cases for each category.

Category	Number of Cases	Percentage of Cases
Category 1	10	10.0%
Category 2	20	20.0%
Category 3	30	30.0%
Category 4	40	40.0%
Category 5	50	50.0%
Category 6	60	60.0%
Category 7	70	70.0%
Category 8	80	80.0%
Category 9	90	90.0%
Category 10	100	100.0%
Category 11	110	110.0%
Category 12	120	120.0%
Category 13	130	130.0%
Category 14	140	140.0%
Category 15	150	150.0%
Category 16	160	160.0%
Category 17	170	170.0%
Category 18	180	180.0%
Category 19	190	190.0%
Category 20	200	200.0%

The following data consists of the aforementioned losses of the D.C. Generator No. 4507242 and the windage, and brush friction of the synchronous motor, and the eddy current losses due to the current rating flowing in the field winding as designated.

Time in Minutes

Field Current = .5 amp.

Time	R.P.M.
0.0	1335
.05	1281
.10	1230
.15	1175
.20	1111
.25	1062
.30	1005
.35	962
.40	919
.45	862
.50	823
.55	787
.60	749
.65	706
.70	663

Input at 1200 R.P.M.

= 2115 Watts

Field Current = 1 amp

Time	R.P.M.
0.0	1345
.05	1290
.10	1240
.15	1175
.20	1111
.25	1058
.30	1005
.35	962
.40	913
.45	855
.50	813
.55	770
.60	738
.65	706
.70	666

Input at 1200 R.P.M.

= 2270 Watts

Field Current = 3 amps

Time	R.P.M.
0.0	1320
.05	1260
.15	1183
.20	1111
.25	1047
.30	983
.35	940
.40	876
.45	813
.50	770
.55	717
.60	674
.65	641
.70	588
.75	556

Input at 1200 R.P.M

= 2510 Watts

Field Current = 5 amps

Time	R.P.M.
0.0	1326
.05	1260
.1	1175
.15	1090
.20	1025
.25	961
.30	898
.35	834
.40	770
.45	706
.50	663
.55	620
.60	577
.65	535
.70	481

Input at 1200 R.P.M.

= 2756 Watts

Field Current = 8 amps

Time	R.P.M.
0.0	1370
.05	1281
.1	1174
.15	1068
.20	990
.25	908
.30	834
.35	748
.40	685
.45	620
.50	547
.55	492
.60	428
.65	374
.70	332

Input at 1200 R.P.M.

= 3380 Watts

Field Current = 10 amps

Time	R.P.M.
0.0	1368
.05	1281
.10	1163
.15	1048
.20	958
.25	845
.30	749
.35	663
.40	598
.45	513
.50	449
.55	385
.60	321
.65	257
.70	214

Input at 1200 R.P.M.

= 3810 Watts

Field Current = 12 amps

Time	R.P.M.
0.0	1347
.05	1240
.10	1132
.15	1025

Field Current = 14 amps

Time	R.P.M.
0.0	1341
.05	1240
.10	1132
.15	1025

Field Current = 12 amps

Time	R.P.M.
.20	919
.25	813
.30	727
.35	637
.40	545
.45	492
.50	406
.55	342
.60	278
.65	214
.70	171

Input at 1200 R.P.M.
= 4020 Watts.

Field Current = 16 amps

Time	R.P.M.
0.0	1331
.05	1220
.10	1111
.15	1005
.20	897
.25	802
.30	717
.35	620
.40	539
.45	471

Field Current = 14 amps

Time	R.P.M.
.20	919
.25	812
.30	727
.35	642
.40	577
.45	492
.50	428
.55	364
.60	299
.65	246
.70	192

Input at 1200 R.P.M.
= 4000 Watts

Field Current = 17 amps

Time	R.P.M.
0.0	1335
.05	1219
.10	1090
.15	984
.20	877
.25	791
.30	706
.35	620
.40	535
.45	449

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Field Current = 16 amps.

Time	R.P.M.
0.50	406
.55	342
.60	278
.65	214

Input at 1200 R.P.M.

= 4110 Watts

Field Current = 17 amps.

Time	R.P.M.
.50	385
.55	321
.60	257
.65	192

Input at 1200 R.P.M.

= 4115 Watts

Field Current = 18 amps

Time	R.P.M.
0.0	1350
.05	1240
.10	1130
.15	1005
.20	897
.25	802
.30	717
.35	627
.40	545
.45	470
.50	406
.55	342
.60	267
.65	214

Input at 1200 R.P.M.

= 4176 Watts.

Field Current = 20 amps.

Time	R.P.M.
0.0	1325
.05	1196
.10	1069
.15	965
.20	855
.25	749
.30	652
.35	566
.40	492
.45	406
.50	342
.55	267
.60	203
.65	150

Input at 1200 R.P.M.

= 4420 Watts

Direct Current Generator No. 4507242

In each test the time interval is in minutes.

Windage + Bearing Friction		Windage + Bear. Fr.+ Brush Friction.	
Time	R.P.M.	Time	R.P.M.
0.0	1380	0.0	1355
.05	1317	.05	1189
.10	1250	.10	1061
.15	1168	.15	955
.20	1104	.20	867
.25	1047	.25	764
.30	976	.30	680
.35	941	.35	595
.40	866	.40	516
.45	824	.45	465
.50	764	.50	382
.55	722	.55	310
.60	680	.60	234
.65	638	.65	197
.70	603	.70	106
Field Current = 0 amps		Field Current = 0 amps.	

The following data includes the losses of Windage, Bearing friction, and Brush friction, in addition to the loss incurred due to the field current flowing and thus causing an eddy current loss.

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Field Current = 1.11 amps Field Current = 1.22 amps.

Time	R.P.M.	Time	R.P.M.
0.0	1380	0.0	1355
.05	1253	.05	1189
.10	1103	.10	1061
.15	986	.15	935
.20	850	.20	807
.25	740	.25	680
.30	616	.30	573
.35	499	.35	468
.40	403	.40	356
.45	255	.45	248
.50	191	.50	166
.55	85	.55	64
.60	0	.60	0

Input at 1200 R.P.M.

= 421 Watts

Input at 1200 R.P.M.

= 443 Watts.

Field Current = 1.42 amps. Field Current = 1.63 amps.

Time	R.P.M.	Time	R.P.M.
0.0	1294	0.0	1294
.05	1146	.05	1125
.10	998	.10	934
.15	828	.15	754
.20	701	.20	595
.25	569	.25	467

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Field Current = 1.42 amps Field Current = 1.63 amps

Time	R.P.M.	Time	R.P.M.
.30	446	.30	346
.35	319	.35	217
.40	212	.40	85
.45	106	.45	0

Input at 1200 R.P.M.

= 495 Watts

Input at 1200 R.P.M.

= 564 Watts

Field Current = 1.73 amps Field Current = 1.84amps.

Time	R.P.M.	Time	R.P.M.
0.0	1300	0.0	1380
.05	1130	.05	1168
.10	938	.10	977
.15	769	.15	786
.20	619	.20	648
.25	458	.25	488
.30	337	.30	361
.35	192	.35	212
.40	77	.40	85

Input at 1200 R.P.M.

= 620 Watts

Input at 1200 R.P.M.

= 630 Watts

Field Current = 1.94 amps Field Current = 2.05 amps

Time	R.P.M.	Time	R.P.M.
0.0	1295	0.0	1339
.05	1082	.05	1147
.10	871	.10	956
.15	702	.15	744
.20	532	.20	574
.25	383	.25	404
.30	255	.30	255
.35	106	.35	128
Input at 1200 R.P.M.		Input at 1200 R.P.M.	
= 640 Watts		= 690 Watts	

Field Current = 2.161 amps

Time	R.P.M.
0.0	1320
.05	1170
.10	956
.15	744
.20	553
.25	383
.30	255
.35	106
Input at 1200 R.P.M.	
= 700 Watts	

Direct Current Generator No. 4507246

Time interval in minutes.

Windage & Bearing Friction		Windage, Bear. friction and Brush friction	
Time	R.P.M.	Time	R.P.M.
0.0	1342	0.0	1300
.05	1283	.05	1163
.10	1223	.10	1000
.15	1162	.15	885
.20	1098	.20	776
.25	1028	.25	694
.30	959	.30	623
.35	928	.35	552
.40	863	.40	474
.45	816	.45	408
.50	776	.50	347
Field Current = 0 amps.		Field Current = 0 amps.	

The following data will include the Windage, Bearing and Brush friction losses as well as that loss caused by eddy currents due to the field current as stated.

Field Current = .48 amps		Field Current = .61 amps.	
Time	R.P.M.	Time	R.P.M.
0.0	1315	0.0	1305
.05	1203	.05	1204

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Field Current = .48 amps Field Current = .61 amps

Time	R.P.M.	Time	R.P.M.
.10	1110	.10	1120
.15	959	.15	960
.20	867	.20	853
.25	775	.25	735
.30	675	.30	633
.35	583	.35	551
.40	490	.40	449
.45	408	.45	368
.50	343	.50	298

Input at 1200 R.P.M.

= 592 Watts

Input at 1200 R.P.M.

= 653.7 Watts

Field Current = .7 amps. Field Current = .86 amps

Time	R.P.M.	Time	R.P.M.
0.0	1325	0.0	1300
.05	1192	.05	1160
.10	1058	.10	1020
.15	915	.15	878
.20	796	.20	756
.25	673	.25	634
.30	572	.30	531
.35	469	.35	429
.40	368	.40	337
.45	286	.45	225
.50	204	.50	153

Input at 1200 R.P.M.

= 714.4 Watts

Input at 1200 R.P.M.

= 800 Watts

Field Current = .92 amps

Time	R.P.M.
------	--------

0.0	1330
-----	------

.05	1182
-----	------

.10	1020
-----	------

.15	877
-----	-----

.20	735
-----	-----

.25	613
-----	-----

.30	490
-----	-----

.35	388
-----	-----

.40	286
-----	-----

.45	200
-----	-----

Input at 1200 R.P.M.

= 900 Watts

Field Current = 1.03 amps

Time	R.P.M.
------	--------

0.0	1310
-----	------

.05	1162
-----	------

.10	1000
-----	------

.15	837
-----	-----

.20	694
-----	-----

.25	562
-----	-----

.30	437
-----	-----

.35	323
-----	-----

.40	214
-----	-----

.45	122
-----	-----

Input at 1200 R.P.M.

= 948 Watts

Field Current = 1.29 amps

Time	R.P.M.
------	--------

0.0	1308
-----	------

.05	1122
-----	------

.10	943
-----	-----

.15	776
-----	-----

.20	633
-----	-----

.25	470
-----	-----

.30	348
-----	-----

Field Current = 1.54 amps

Time	R.P.M.
------	--------

0.0	1330
-----	------

.05	1122
-----	------

.10	925
-----	-----

.15	735
-----	-----

.20	572
-----	-----

.25	429
-----	-----

.30	286
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Field Current = 1.29 amps

Time R.P.M.

.35 245

.40 133

Input at 1200 R.P.M.

= 1024 Watts

Field Current = 1.54 amps

Time R.P.M.

.35 163

.40 61.3

Input at 1200 R.P.M.

= 1180 Watts

Field Current = 1.81 amps

Time R.P.M.

0.0 1350

.05 897

.10 694

.15 511

.20 347

.25 225

.30 97

.35 0

Input at 1200 R.P.M.

= 1270 Watts

Field Current = 2.06 amps

Time R.P.M.

0.0 1302

.05 1080

.10 837

.15 613

.20 428

.25 296

.30 143

.35 20.4

Input at 1200 R.P.M.

= 1360 Watts

SATURATION CURVES

Synchronous Motor No. 4507244

Field	Terminal	Field	Terminal
Current	Volts	Current	Volts
0.0	0		
2.8	824.4	14.0	2436
4.2	1176	15.05	2486
5.05	1402	16.05	2492
6.25	1592	17	2588
7.0	1740	18.08	2626
8.0	1910	19.1	2672
9.0	2042	20.1	2720
10.1	2134	21.1	2750
11.0	2210	22	2766
12.0	2314	23	2786
13.0	2372	24	2794

Direct Current Generator No. 4507242

Field	Terminal	Field	Terminal
Current	Volts	Current	Volts
00	00.0	1.10	88
.226	18.5	1.25	97
.460	38	1.47	111
.552	46	1.595	120
.727	60	1.775	129
.829	67.5	2.00	139
.945	77	2.24	149

2019年12月15日

2019年12月15日

姓名	性别	年龄	职业
张三	男	25	教师
李四	女	30	医生
王五	男	35	工程师
赵六	女	40	会计
孙七	男	45	经理
周八	女	50	护士
吴九	男	55	工人
郑十	女	60	农民
冯十一	男	65	公务员
陈十二	女	70	教授
林十三	男	75	作家
黄十四	女	80	画家
宋十五	男	85	音乐家
李十六	女	90	科学家
王十七	男	95	哲学家

2019年12月15日

姓名	性别	年龄	职业
张三	男	25	教师
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冯十一	男	65	公务员
陈十二	女	70	教授
林十三	男	75	作家
黄十四	女	80	画家
宋十五	男	85	音乐家
李十六	女	90	科学家
王十七	男	95	哲学家

Direct Current Generator No. 4507246

Field Current	Terminal Volts	Field Current	Terminal Volts
0.00	000.0	.87	202
.45 9	120	.93	215
.529	133	.98	224
.562	142	1.04	235
.617	152	1.18	247.5
.671	166	1.313	265
.75	182	1.38	270
.823	192	1.53	280
		1.63	288

TEST FOR SHAFT CURRENT

I = 0 For this test no current was found to flow between the shaft and the ground on the frame of the motor.

SYNCHRONOUS IMPEDANCE

Synchronous Motor No. 4507244

Field Current	Phase 1 Current	Phase 2 Current	Phase 3 Current
9.48	21	21.8	21.2
8.00	17.9	18.8	18.
7.1	15.85	16.6	16.

Field Current	Phase #1 Current	Phase #2 Current	Phase #3 Current
6.2	13.9	14.55	14
5.45	12.2	13.05	12.3
4.45	9.95	11.15	10.1
3.5	8.00	9.00	8.05
2.75	6.35	7.25	6.3
2.0	5.00	5.83	4.95

PHASE CHARACTERISTICS OF SYNCHRONOUS MOTOR

Synchronous Motor No. 4507244

The following data has been obtained by experiment, using the generators for a means of obtaining a steady load.

Mechanical Load = 0 Watts						
E_1	E_2	I_1	I_2	I_3	W_1 (watts) W_2	Field Current.
2260	2260	18.1	17.8	17.8	24000 -17000	1.0
2260	2260	16.1	15.7	15.8	21500 -15100	2.0
2260	2260	13.1	12.7	12.8	17300 -12200	3.8
2280	2280	9.1	8.8	8.8	13000 -8100	6.0
2300	2300	6.2	5.8	5.8	9000 -4800	8.0
2300	2300	3.5	3.2	3.2	6000 -1800	10.0
2320	2320	1.0	.8	.6	2500 +1300	12.0
2360	2360	2.0	2.1	2.1	- 200 4200	14.0
2360	2360	4.0	4.6	4.6	- 3000 7800	16.0
2300	2300	6.8	7.3	7.3	- 6000 10200	17.0
2300	2300	8.2	8.6	8.6	- 7000 12000	18.0
2320	2320	9.8	10.3	10.3	- 10000 14500	20.0

Mechanical Load = 2 Kw.							
E_1	E_2	I_1	I_2	I_3	W_1	$(KW) \cdot W_2$	Field Current
2280	2280	16.8	16.4	16.4	24	-14.	2.0
2300	2300	13.3	13.1	13.1	19.13	-10.8	4.0
2320	2320	12.5	10.0	10.0	16	-7.3	6.0
2330	2330	7.2	6.9	6.9	12	-4.0	8.0
2360	2360	4.8	4.3	4.2	9	- .8	10.0
2280	2280	2.0	2.2	2.2	3.5	+2.3	12.0
2290	2290	3.5	4.0	4.0	0.0	8.0	14.0
2300	2300	5.7	6.0	6.0	-2.2	12.	16.0
2310	2310	7.8	8.3	8.3	-5.0	13.8	18.0
2300	2300	9.7	10.0	10.2	-7.0	16.0	20.0

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Mechanical Load = 11.3 Kw.									
E_1	E_2	I_1	I_2	I_3	W_1 (Kw)	W_2	Field Current		
2280	2280	17.5	17.4	17.4	27.8	-11.8	2		
2290	2290	13.8	13.5	13.5	23.2	-7.4	4		
2280	2280	9.65	9.8	9.8	17.8	-2.3	6		
2300	2300	7.6	7.2	7.2	15.	0.00	8		
2310	2310	5.3	5.2	5.0	12.	+3.1	10		
2330	2330	3.9	3.8	3.8	8.0	7.0	12		
2340	2340	4.0	4.3	4.3	5.0	10	14		
2300	2300	7.0	7.4	7.4	.5	15	16		
2260	2260	9.4	10.2	10.2	-2.5	18.2	18		
2280	2280	11.1	11.8	11.8	-4.8	21	20		

Mechanical Load = 18.3 Kw.

E ₁	E ₂	I ₁	I ₂	I ₃	W ₁ (Kw)	W ₂	Field Current
2170	2170	17.5	17.2	17.2	29	-6	2
2180	2180	13.5	13.3	13.3	25	-2.2	4
2200	2200	10.4	10.3	10.3	20.5	+1.4	6
2220	2220	7.7	7.6	7.4	16.8	5	8
2240	2240	6.1	6.1	6.2	13.5	8.1	10
2260	2260	5.7	5.8	5.7	10.2	11.6	12
2280	2280	6.2	6.2	6.2	7.2	14.8	14
2300	2300	7.5	7.8	7.8	4.5	18	16
2310	2310	8.4	9.6	9.6	2.	20.7	18
2340	2340	10.8	11.1	11.2	0	23	20

Mechanical Load = 27.1 Kw.

E ₁	E ₂	I ₁	I ₂	I ₃	W ₁ (Kw)	W ₂	Field Current
2220	2220	15.4	15.2	15.2	-10	29.5	4
2230	2230	12.1	12.1	12.1	+3.8	25.5	6
2260	2260	9.6	9.6	9.5	7.1	21	8
2280	2280	7.8	7.8	7.8	10.5	18	10
2280	2280	7.4	7.4	7.4	14.9	15	12
2300	2300	7.6	7.8	7.8	17.8	11.5	14
2300	2300	8.9	9.1	9.1	21.1	8.5	16
2320	2320	10.	10.2	10.2	23.1	5.2	18
2310	2310	12.1	12.5	12.5	27	2	20

Mechanical Load = 29.6 Kw.

E_1	E_2	I_1	I_2	I_3	W_1 (Kw)	W_2	Field Current
2160	2160	16.2	16	16.2	32	2	4
2180	2180	13.3	13	13.2	27.5	6.2	6
2180	2180	11.1	10.9	11	24.6	11	8
2200	2200	10.9	10.7	10.8	24	10	10
2220	2220	9.3	9.1	9.1	20	13.5	12
2200	2200	8.8	8.6	8.6	17	16.8	14
2290	2290	9.	9	8.9	13.5	20	16
2300	2300	10	11	9.9	11.5	23	18
2330	2330	12.2	12.5	12.5	6	27.8	20

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[illegible]

• **Stressors** are the environmental factors that cause stress. Stressors can be physical, chemical, biological, or psychological. Examples of stressors include noise, pollution, crowding, and social isolation.

[illegible]

MECHANICAL LOAD = 34.2 Kw.

E ₁	E ₂	I ₁	I ₂	I ₃	W ₁ (Kw)	W ₂	Field Current
2180	2180	18.3	18	18.2	36.5	3.1	4
2300	2300	15	14.6	14.8	32.3	7	6
2320	2320	12.6	12.2	12.4	28.5	10.5	8
2320	2320	10.6	10.4	10.5	24.5	14	10
2320	2320	9.6	9.5	9.5	20.5	17.9	12
2330	2330	9.7	9.6	9.6	17.2	21	14
2300	2300	10.6	10.6	10.5	24.8	24.6	16
2300	2300	12.2	12.1	12.1	11.5	27.5	18
2300	2300	13	13	13	10	30.1	20

Mechanical Load = 43.3 Kw.

E ₁	E ₂	I ₁	I ₂	I ₃	W ₁ (Kw)	W ₂	Field Current
2190	2190	17.2	16.9	17	36	11.8	6
2200	2200	14.6	14.2	14.3	31.8	15.8	8
2250	2250	12.9	12.7	12.8	27.5	19	10
2240	2240	12.1	12	12	25.3	22.5	12
2220	2220	12.2	12.3	12.4	22	26.3	14
2280	2280	13	13.1	13.2	18	29.6	16
2235	2235	13.9	13.8	13.8	16.3	32.6	18
2280	2280	14.7	14.8	14.8	14.6	34	19.5

EFFICIENCY OF SYNCHRONOUS MOTOR

Synchronous Motor No. 4507244

Input in KW.	Input - Losses in KW	Efficiency in Percent
5.8	2	34.5
15	11.3	75.5
21.8	18.3	84
29.9	27.1	90.5
33.8	29.6	87.6
38.2	34.2	89.5
48.3	44.3	91.8

$$\text{Efficiency} = \frac{\text{Input} - \text{Losses}}{\text{Input}}$$

Values above taken for unity power factor.

LOAD-VOLTAGE CURVES OF GENERATORS

Direct Current Generator No. 4507242

Field Current = 1.43 amps

E	I	Watts	E	I	Watts
119	0	0	125	76	9500
125.5	16	2010	125	86	10740
124	29	3600	125	99	12370
123	46	5660	124	112	13800
124	65.5	8125	120	124	14900
			120	138	16580

Direct Current Generator No. 4507246

Field Current = 1.21

E	I	Watts	E	I	Watts
258	0	0	255	62	15800
256	17.5	4480	252	72	18120
258	29.5	7620	251	84	21050
257	39	10020	248	98	24520
255	50	12750			

STATIC TORQUE

Torque on Synchronous Motor No. 4507244

E ₁	E ₂	I ₁	I ₂	I ₃	W ₁ (Watt)	W ₂	Torque lb.-ft.
492.6	492.6	21.5	22	23.3	21.2	1.	22.5
554	554	23.6	24.7	26.2	24.6	1.6	33
605.4	605.4	25.8	27.1	29.5	30.4	3	51

Static torque taken with blocked rotor and reduced voltage. Tare on scales = 45.5 lbs. Torque measured with synchronous motor operating as an induction motor with rotor blocked.

CIRCLE DIAGRAM OF SYNCHRONOUS MOTOR OPERATING AS AN INDUCTION MOTOR

Motor running idle on starting position of compensator.

E_1	E_2	I_1	I_2	I_3	W_1 (KW)	W_2
1820	1800	15.5	15.5	15.4	18	- 1

By using the data from the Static Test in conjunction with this given above, the circle-diagram may be constructed.

$E = 1780$ volts per phase

$I_o = 15.5$ amps

$\theta = 63^\circ 16'$ or P.F. = .45

$I_{br} = 78$ amps (Blocked Rotor current)

$\theta = 55^\circ 57'$

Primary copper loss = $(78)^2 \times 2.191 = 13,350$ watts

Exciting watts at no load = 8000

Total loss at blocked rotor = 84,000 watts

Secondary copper loss = 62,650 "

Thus the starting torque = $\frac{7.04 \times 62,650}{1200}$
= 368 lb. ft.

RUNNING TORQUE

Synchronous Motor No. 4507244

Torque derived from the equation

$$T = \frac{7.04 \times (\text{watts})}{\text{Syn. R.P.M.}}$$

Load in Watts	Torque in lb.-ft.
2000	11.7
11,300	66.4
18,300	107.2
27,100	159
29,600	173.5
34,200	200
44,300	260

PULL-OUT TORQUE

Synchronous Motor No. 4507244

Field Current = 14.5 amps

E ₁	E ₂	I ₁	I ₂	I ₃	W ₁ (Kw)	W ₂
2000	2000	64	66	60	98	57
2000	2000	64	66	60	98	57

Unity Power Factor

Pull-out torque = 908 lbs.-ft. (maximum possible without consideration of losses).

STARTING TESTS ON SYNCHRONOUS MOTOR

Conditions at starting compensator

Position	E	Condition
0	2340	Open line voltage.
1 st	2250	Starter on starting position.
2 nd.	2340	Field put on (14.5 amps) with auto on starting position.

Position	E	Condition
3 rd.	2360	Auto starter in running position, no load on motor.
4 th.	2050	Supply line voltage when motor pulled out of step due to loading.

Conditions at motor with Auto on starting
position : (motor running as an induction motor)

E_1	E_2	I_1	I_2	I_3	W_1 (Kw)	W_2
1780	1780	71	73	76	94	9.4

Starting tests with reduced voltage for the
different positions of the field poles.

E_1	E_2	I_1	I_2	I_3	W_1 (Kw)	W_2	Field Current A.C.
500	530	24	23.5	21.3	10	1	3.4
500	520	23.4	24	21.5	10	2	3.4
450	550	20.4	21.2	20	7.4	1.6	3.06
480	440	20.1	21.6	20.5	8	1.2	3.1
500	440	20.5	21	22	8.1	1.2	3.12
520	460	21.5	20.5	22.5	9.8	1.4	3.22
440	480	21.5	20	19.5	9	1.8	3.05

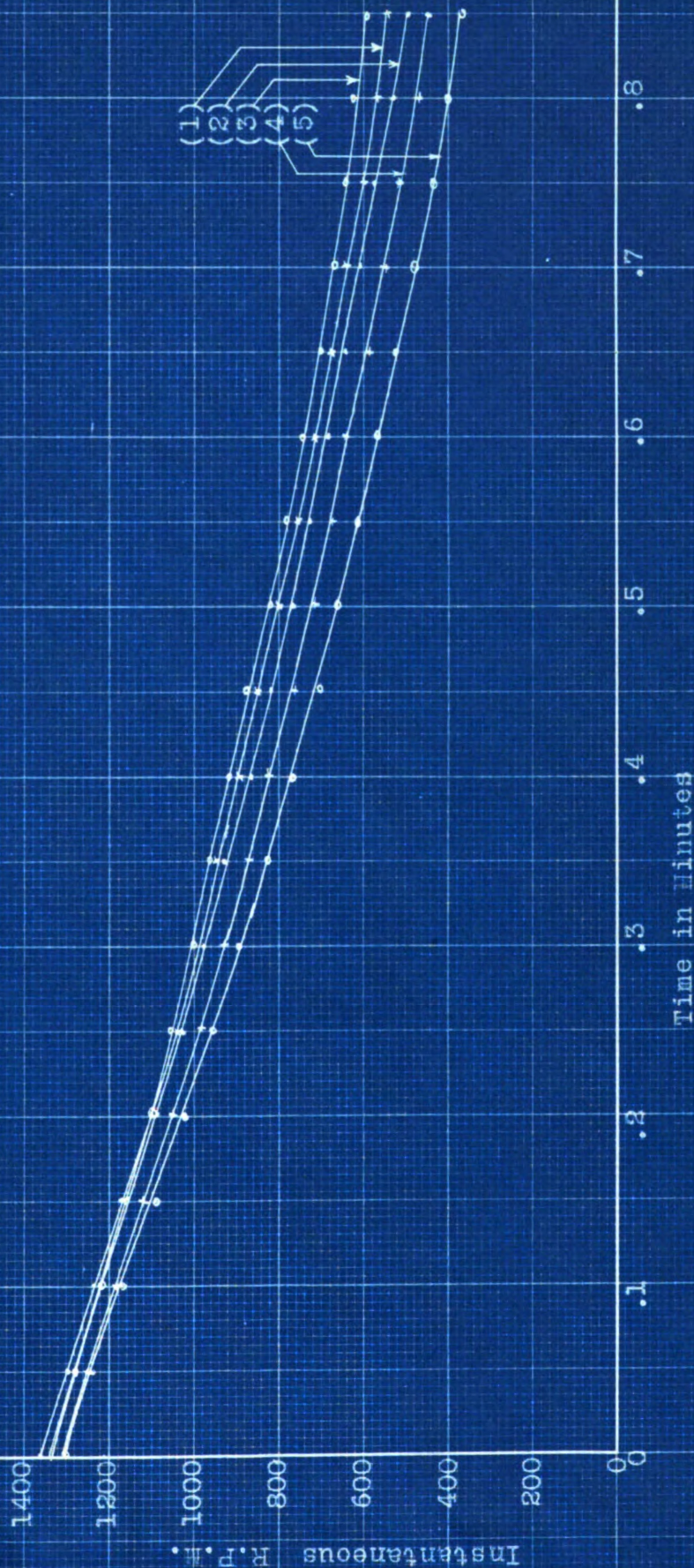
Field shorted through 48.4 ohms resistance.

CHAPTER IV

GRAPHS

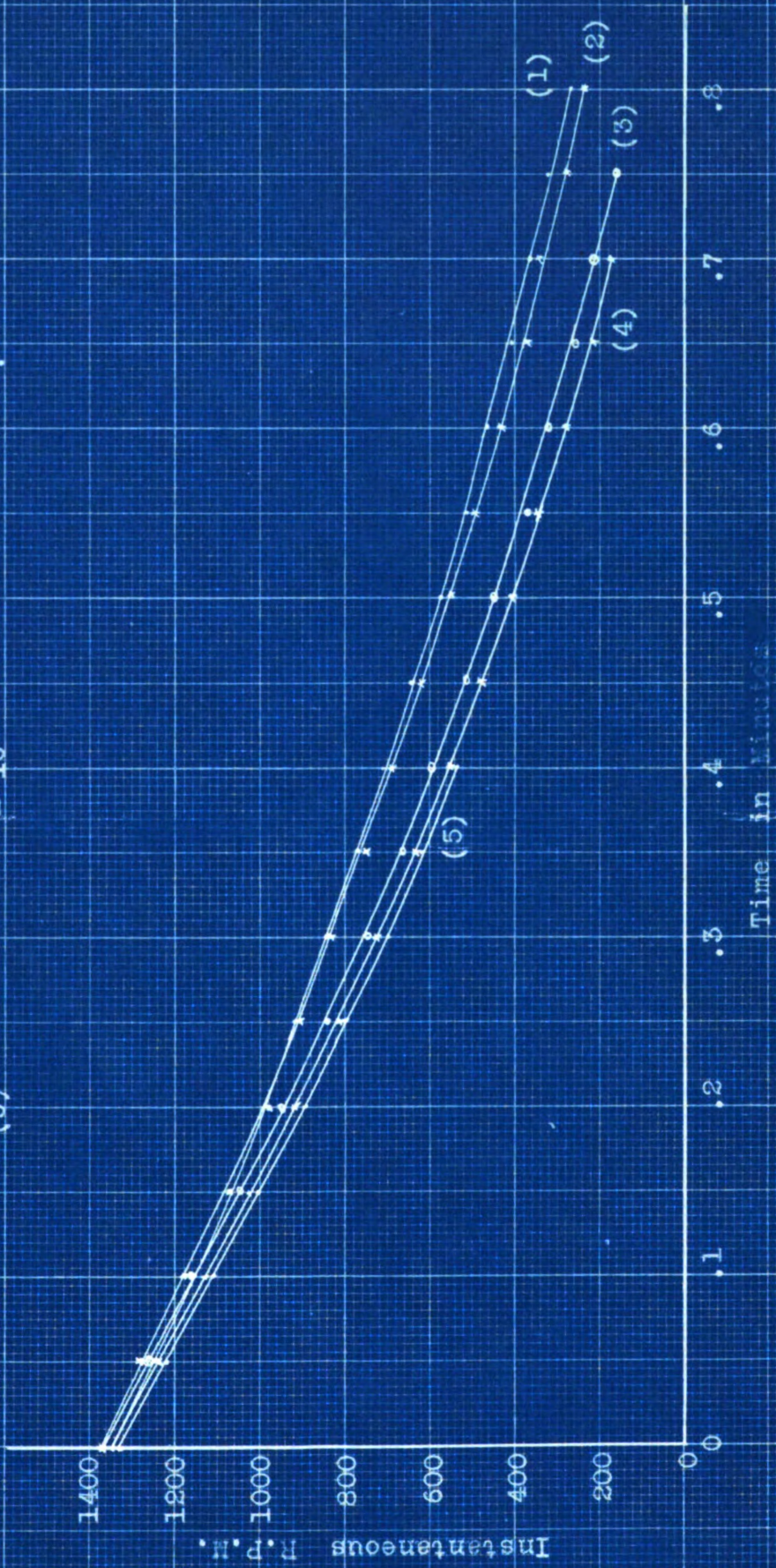
Retardation Curves of Synchronous Motor No. 4507244

(1)	Field Current	= 0	Brushes up.
(2)	"	= 0	Down.
(3)	"	= 1 amp.	"
(4)	"	= 3	"
(5)	"	= 5	"



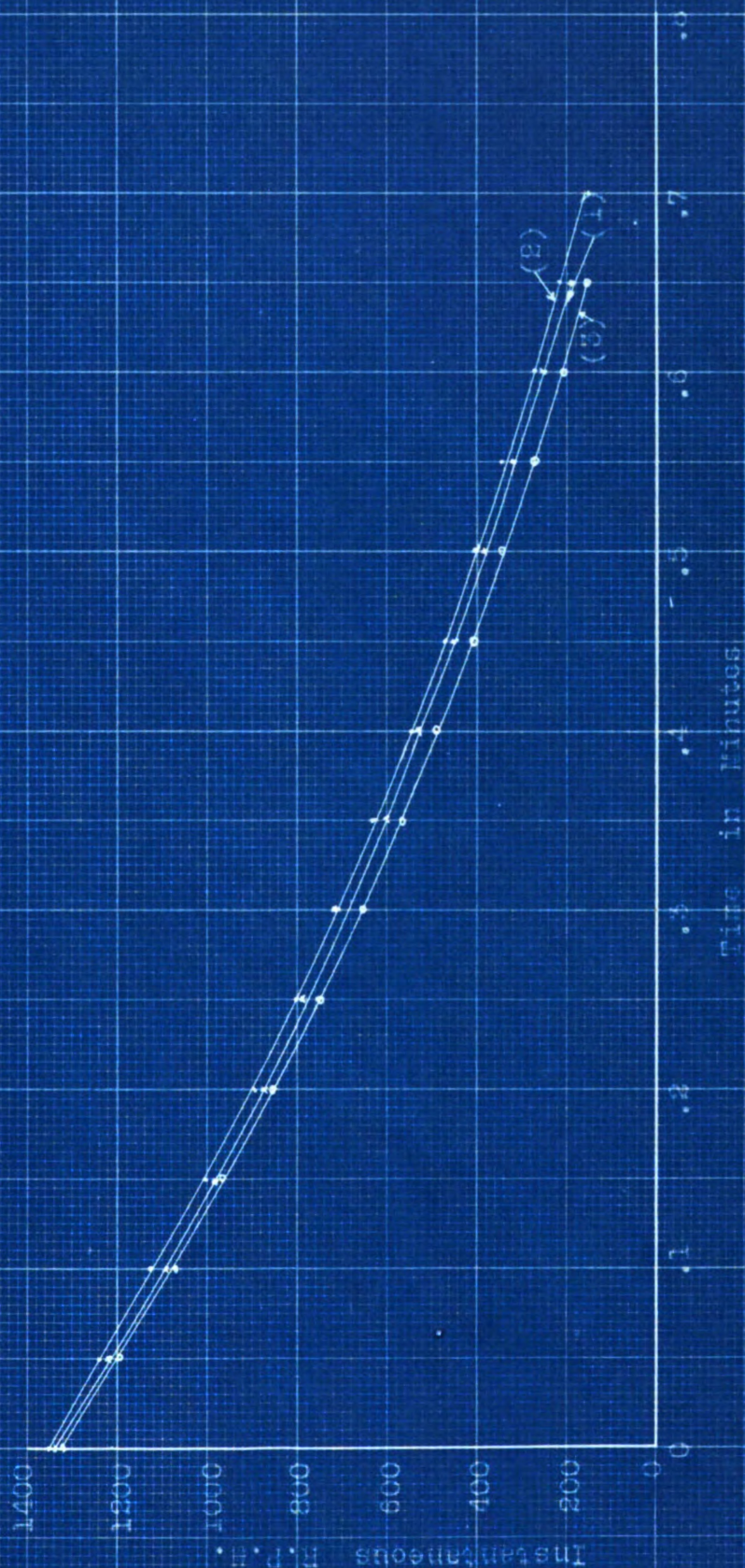
Retardation Curves of Synchronous Motor No. 4507244

(1)	Field current = 6 Amps.	Brushes Down.
(2)	" " = 8 " "	" " " "
(3)	" " = 10 " "	" " " "
(4)	" " = 12 " "	" " " "
(5)	" " = 16 " "	" " " "



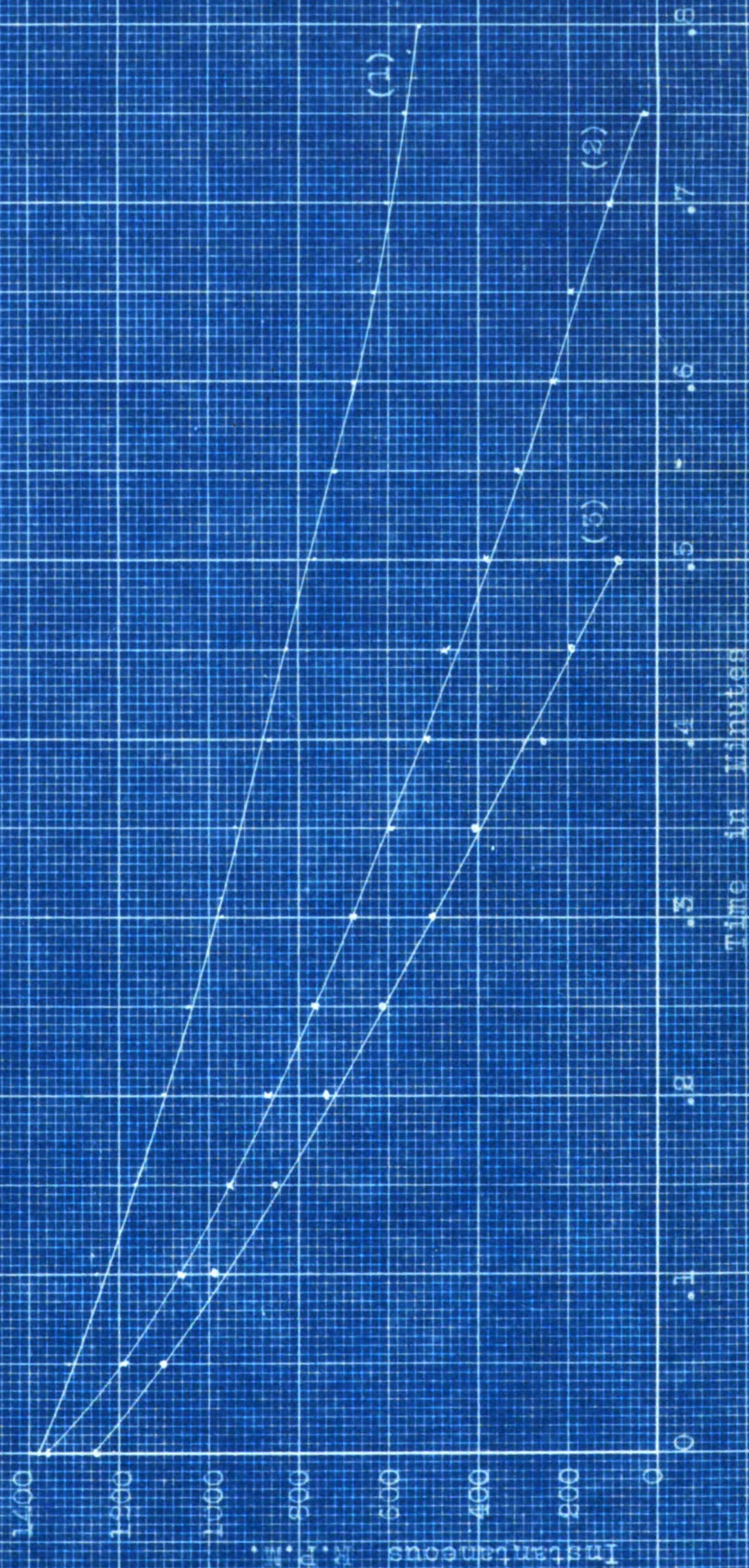
Retardation Curves of Synchronous Motor No. 4507244

- (1) Field Current = 17 Amps. Brushes Down.
- (2) " " = 18 " " "
- (3) " " = 20 " " "



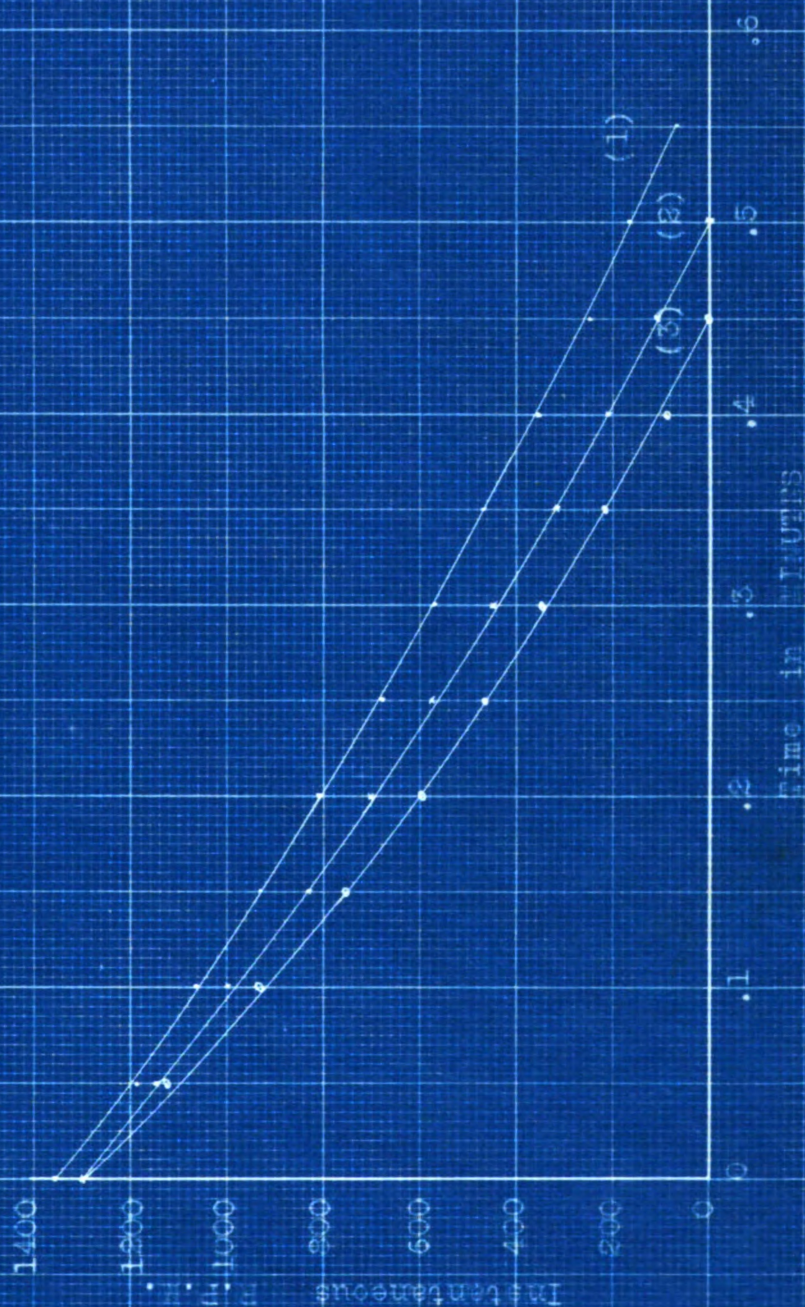
Retardation Curves of Generator No. 4507242

(1) Field current = 0.000 Amps. Brushes Up.
 (2) " " = 0.000 " " Down.
 (3) " " = 1.110 " " "



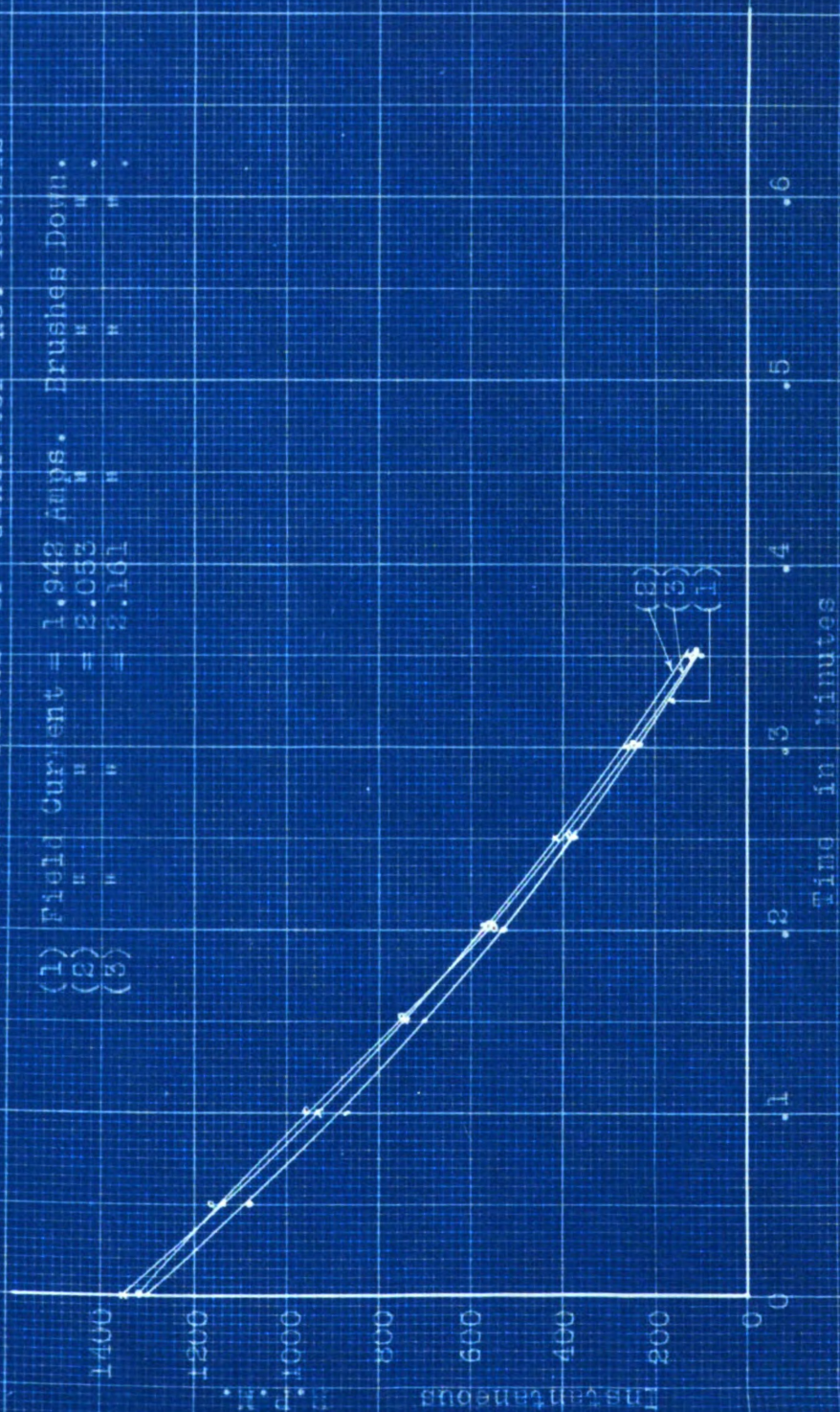
Retardation Curves of Generator No. 4507242

(1) Field current = 1.220 Amps. Brushes Down.
 (2) " " = 1.420 " "
 (3) " " = 1.627 " "



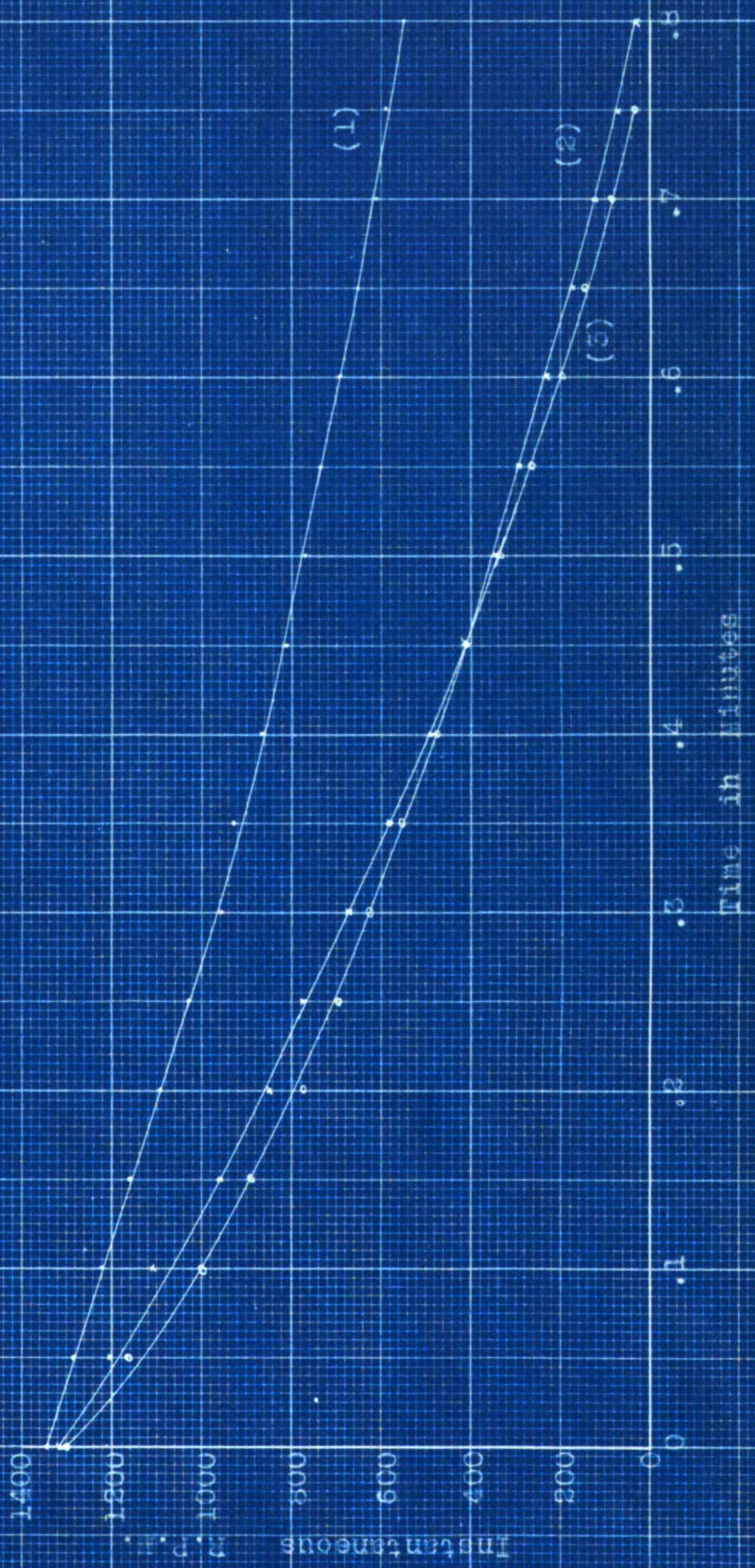
Retardation Curves of Generator No. 450724E

(1) Field Current = 1.948 amps. Brushes Down.
 (2) " " = 2.053 " "
 (3) " " = 2.161 " "



Tetration Curves of Generator No. 4507246

- (1) Field current = 0 Brushes Up.
- (2) " " = 0 Amps. Brushes Down.
- (3) " " = .485 Amps. Brushes Down.

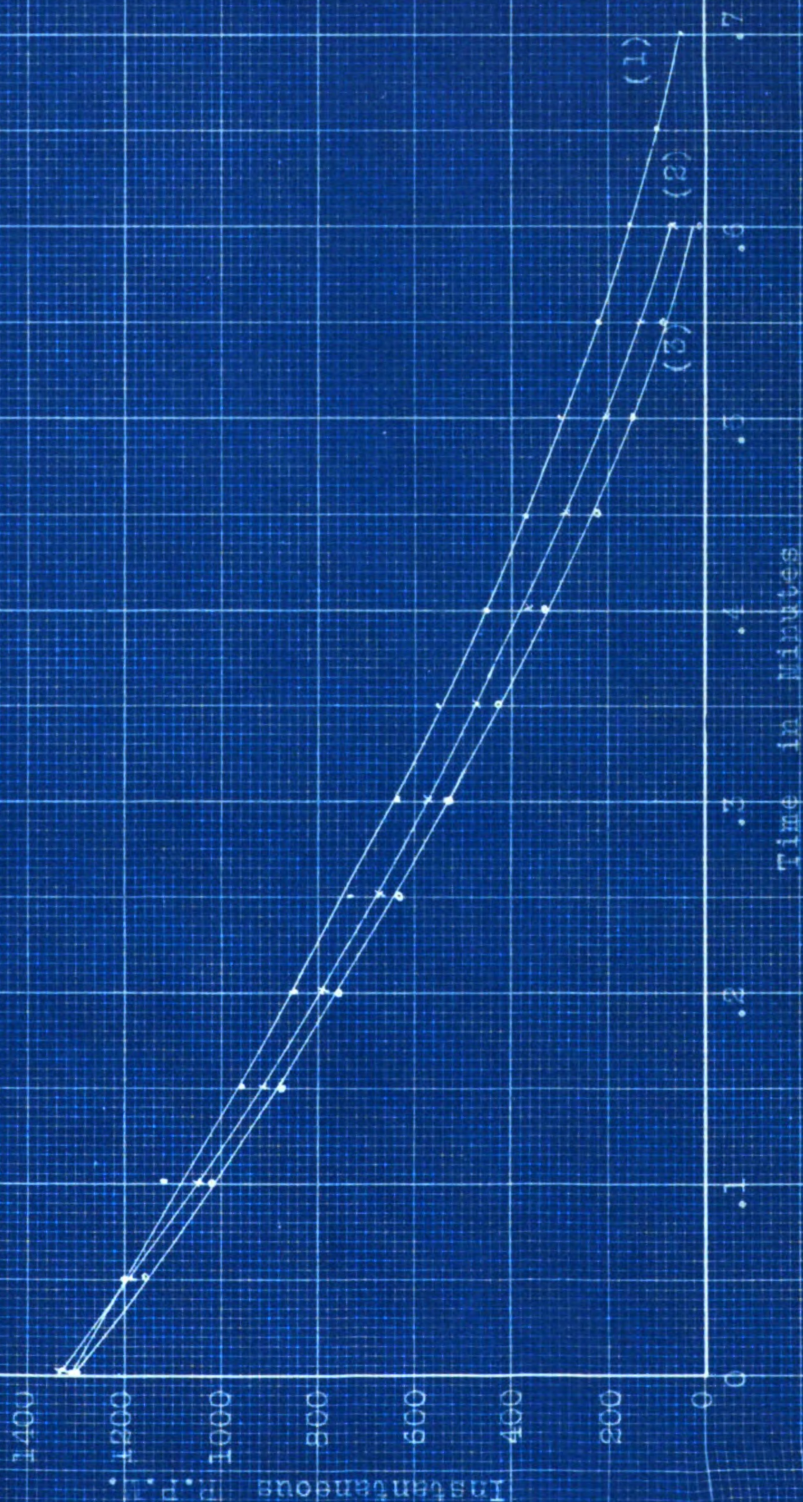


Retardation Curves of Generator No. 4507246

(1) Field Current = 0.610 Amps. Brushes Down.

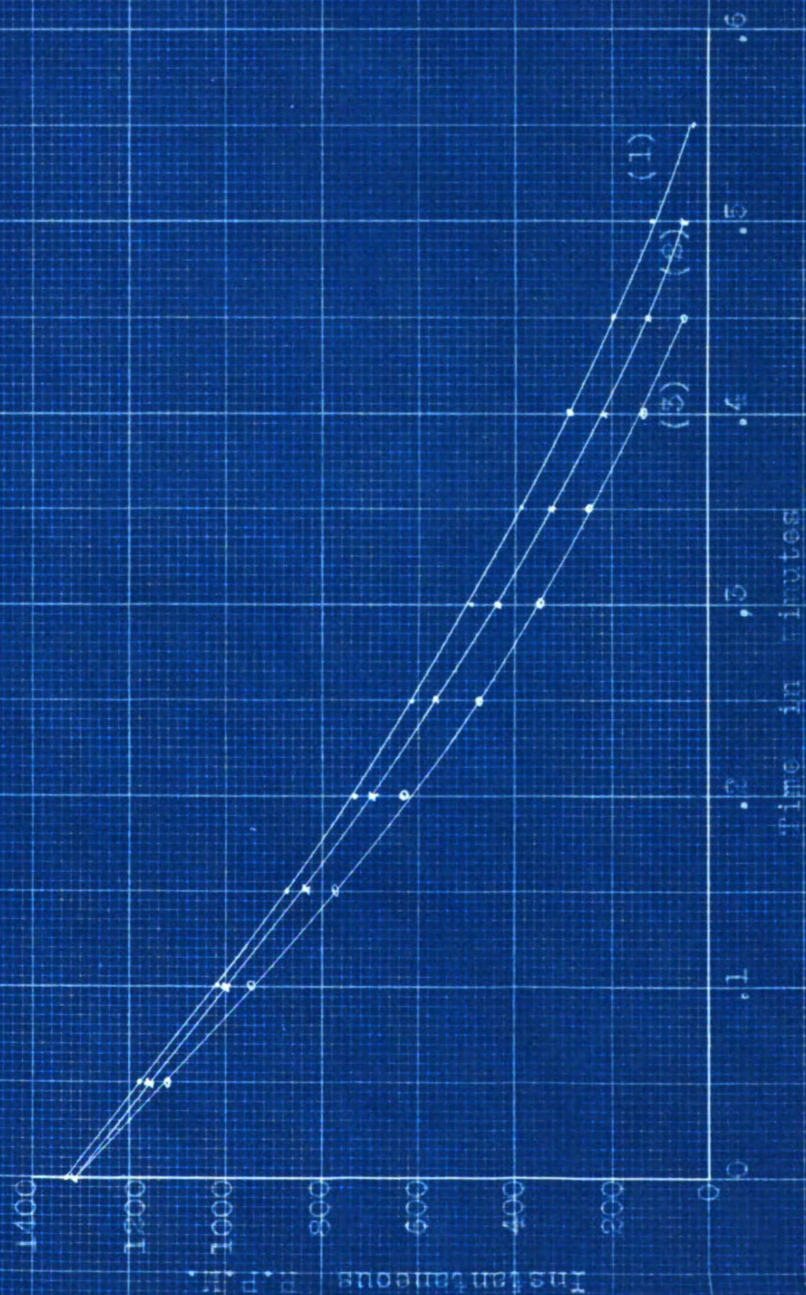
(2) " " = 0.700 " " "

(3) " " = 0.861 " " "



Retardation Curves of Generator No. 4507246

(1) Field Current = 0.993 Amps. Brushes Down.
 (2) " " = 1.034 " "
 (3) " " = 1.285 " "



1. The first part of the report is a general introduction to the subject of the study. It discusses the importance of the problem and the objectives of the research.

2. The second part of the report is a detailed description of the methods used in the study. It includes a discussion of the experimental design, the data collection procedures, and the statistical analysis.

3. The third part of the report is a presentation of the results of the study. It includes a discussion of the findings, a comparison of the results with previous research, and a conclusion.

4. The fourth part of the report is a discussion of the implications of the study. It includes a discussion of the limitations of the study, the strengths of the findings, and the potential for future research.

5. The fifth part of the report is a summary of the study. It includes a brief overview of the main findings and a final conclusion.

6. The sixth part of the report is a list of references. It includes a list of the books, articles, and other sources used in the study.

7. The seventh part of the report is an appendix. It includes a list of the tables, figures, and other supplementary material used in the study.

8. The eighth part of the report is a glossary. It includes a list of the terms and abbreviations used in the study.

9. The ninth part of the report is a list of acknowledgments. It includes a list of the people and organizations that provided assistance and support during the study.

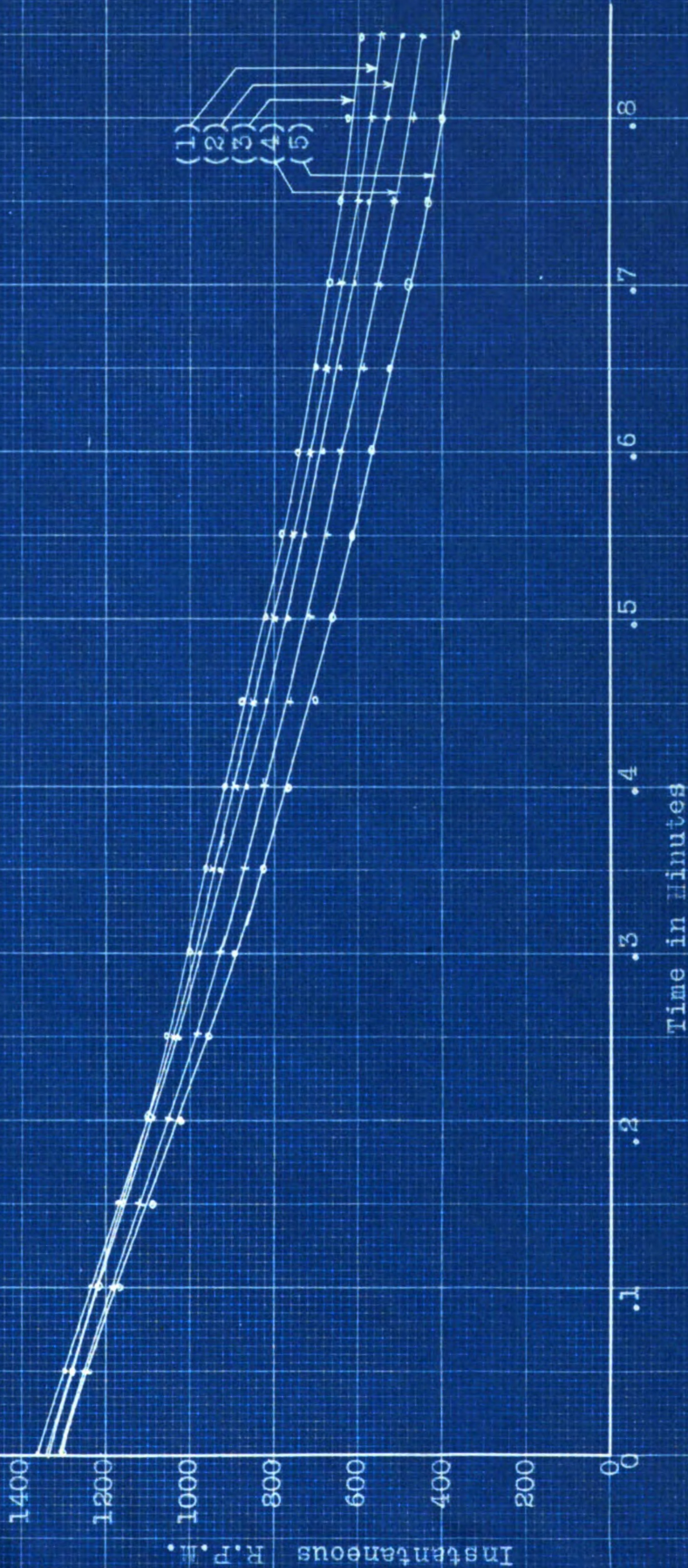
10. The tenth part of the report is a list of appendices. It includes a list of the tables, figures, and other supplementary material used in the study.

CHAPTER IV

GRAPHS

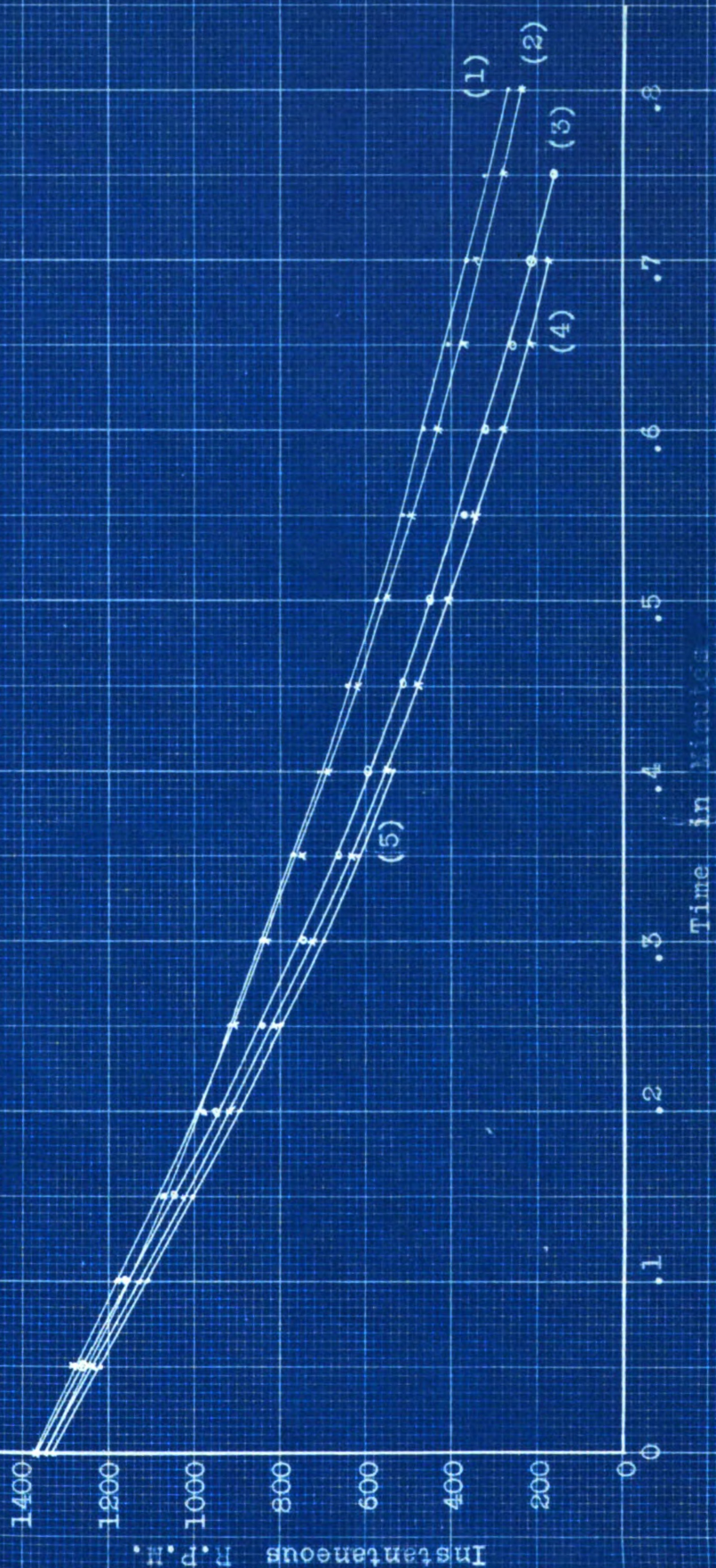
Retardation Curves of Synchronous Motor No. 4507244

(1)	(2)	(3)	(4)	(5)
Field Current	"	"	"	"
= 0	"	"	"	"
Brushes up.	"	"	"	"
Down.	"	"	"	"
1 amp.	"	"	"	"
3	"	"	"	"
5	"	"	"	"



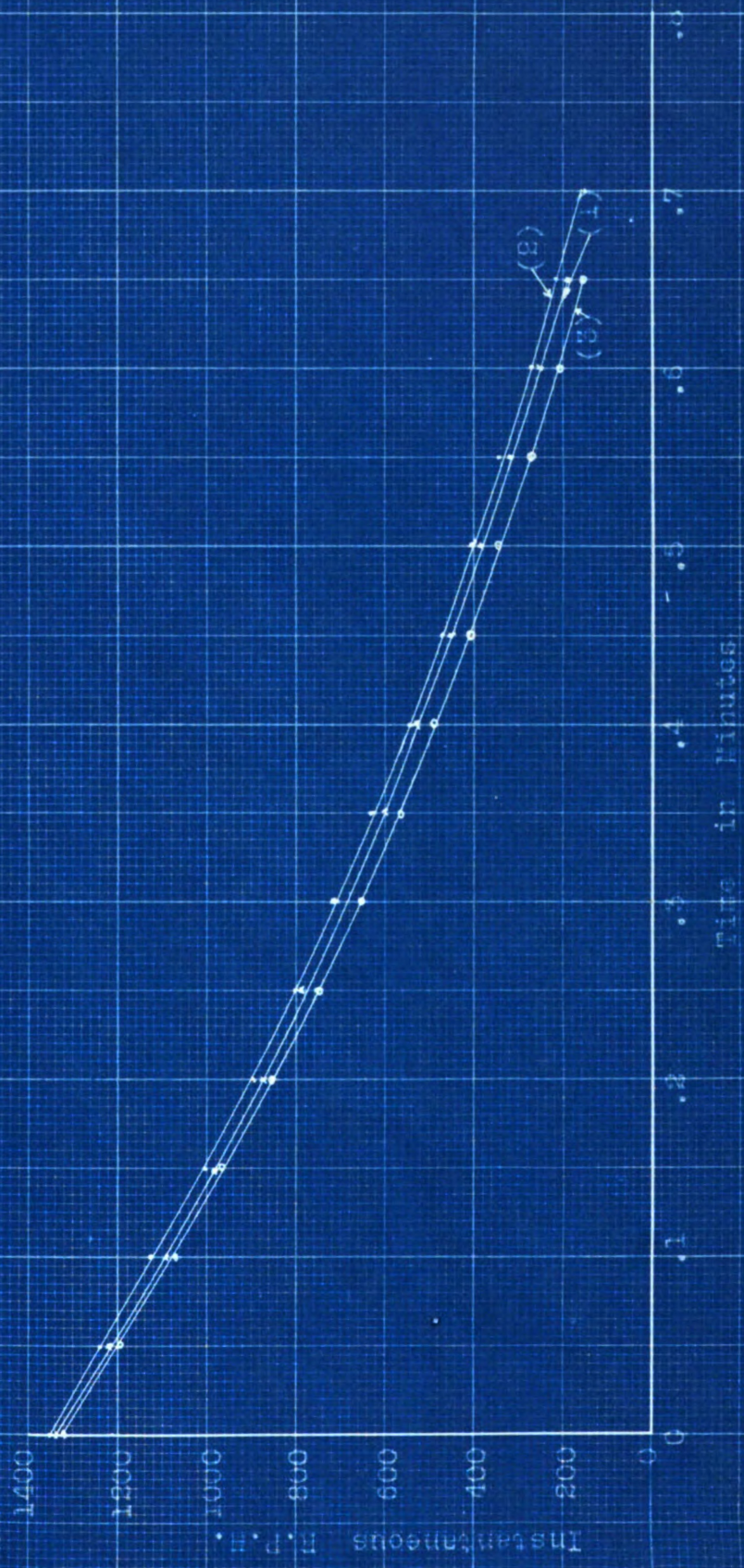
Retardation Curves of Synchronous Motor No. 4507244

	(1)	(2)	(3)	(4)	(5)
Field Current	= 6	= 8	= 10	= 12	= 16
Amps.	"	"	"	"	"
Brushes Down	"	"	"	"	"



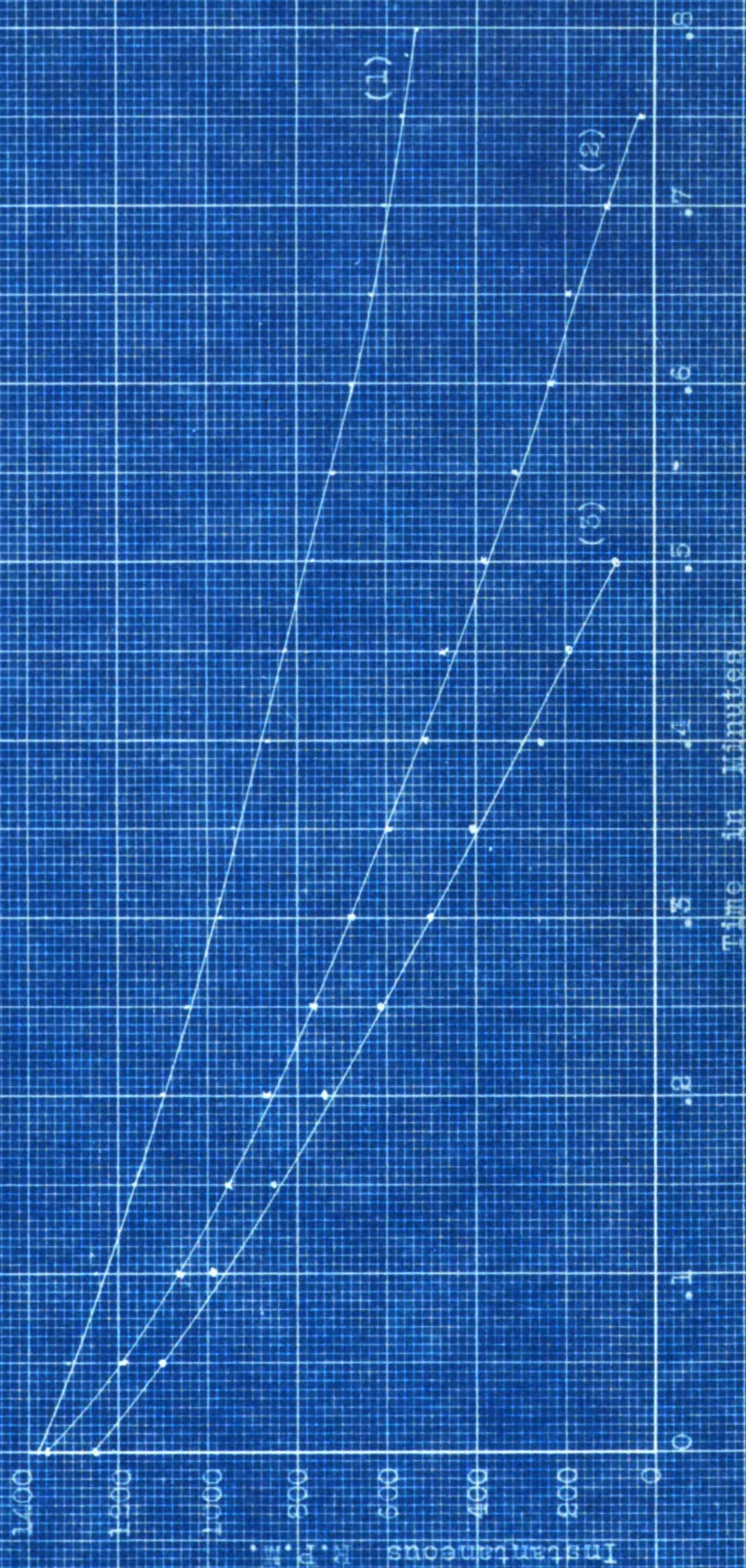
Retardation Curves of Synchronous Motor No. 4507244

- (1) Field Current = 17 Amps. Brushes Down.
- (2) " " = 18 " " "
- (3) " " = 20 " " "



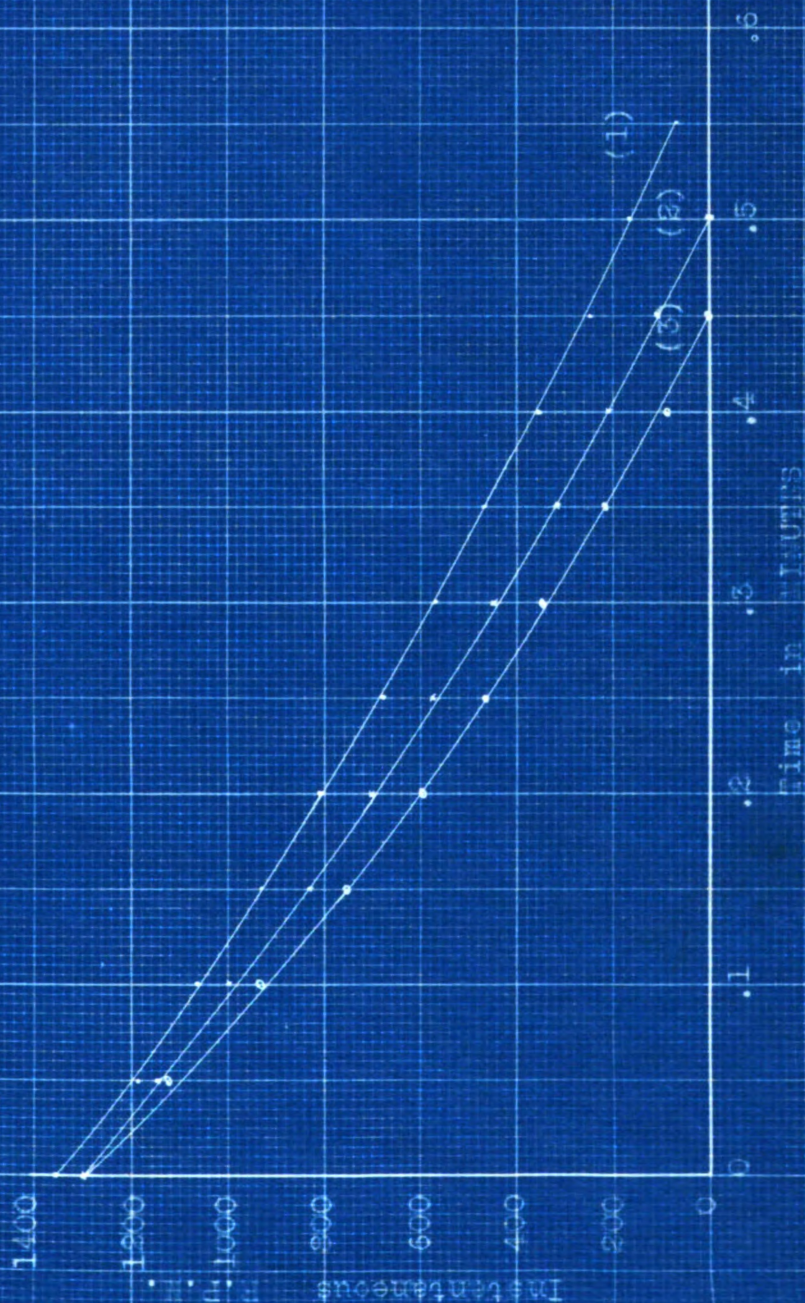
Retardation Curves of Generator No. 4507842

(1) Field Current = 0.000 Amps. Brushes Up.
 (2) " " = 0.000 " " Down.
 (3) " " = 1.110 " " " "



Retardation Curves of Generator No. 4507242

(1) Field Current = 1.240 Amps. Brushes Down.
 (2) " " = 1.420 " " "
 (3) " " = 1.627 " " "



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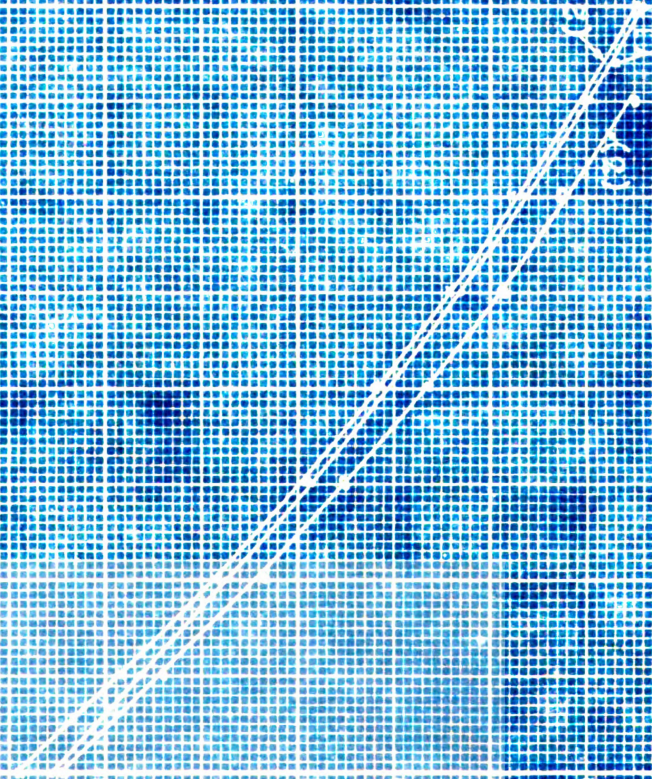
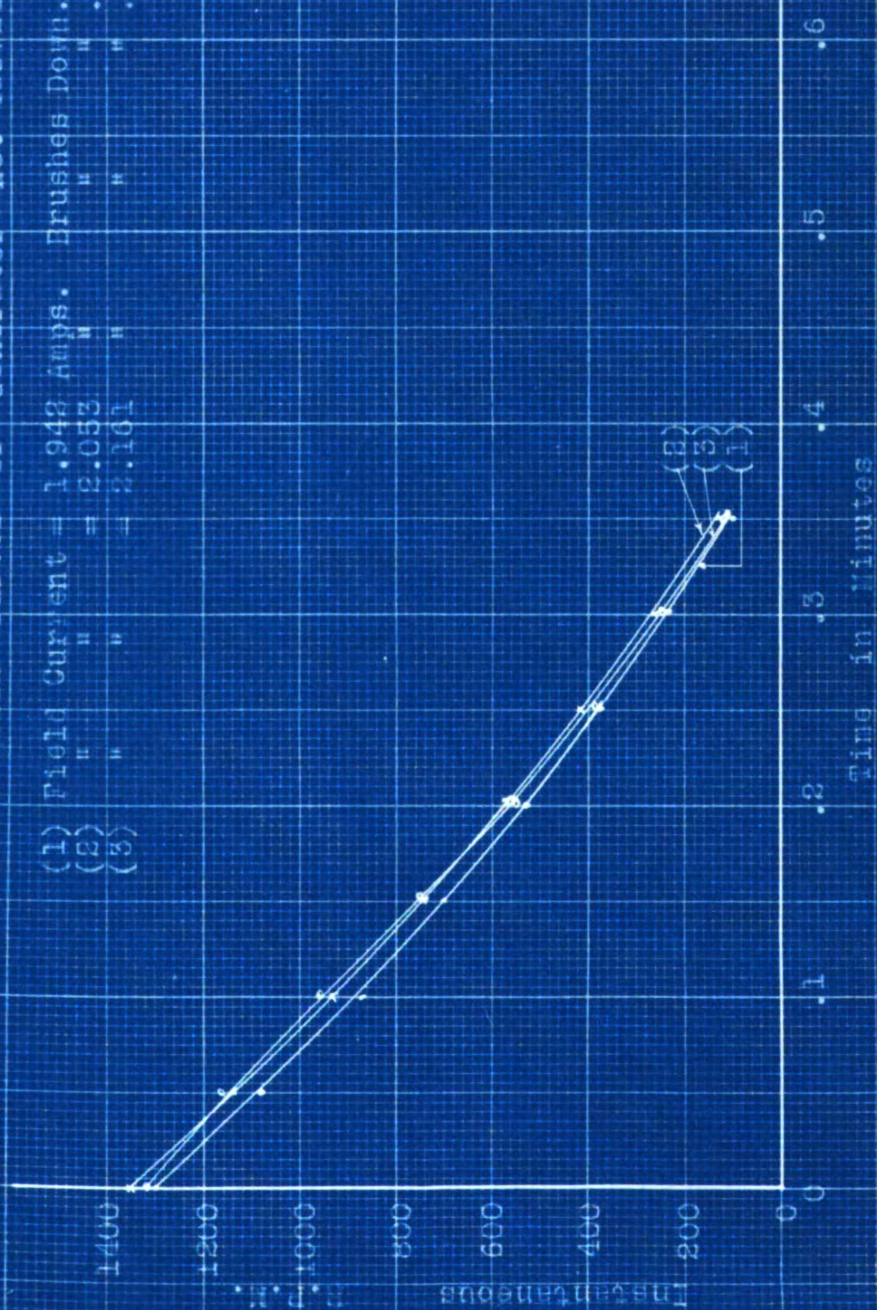


Figure 1: A line graph showing two data series over time.

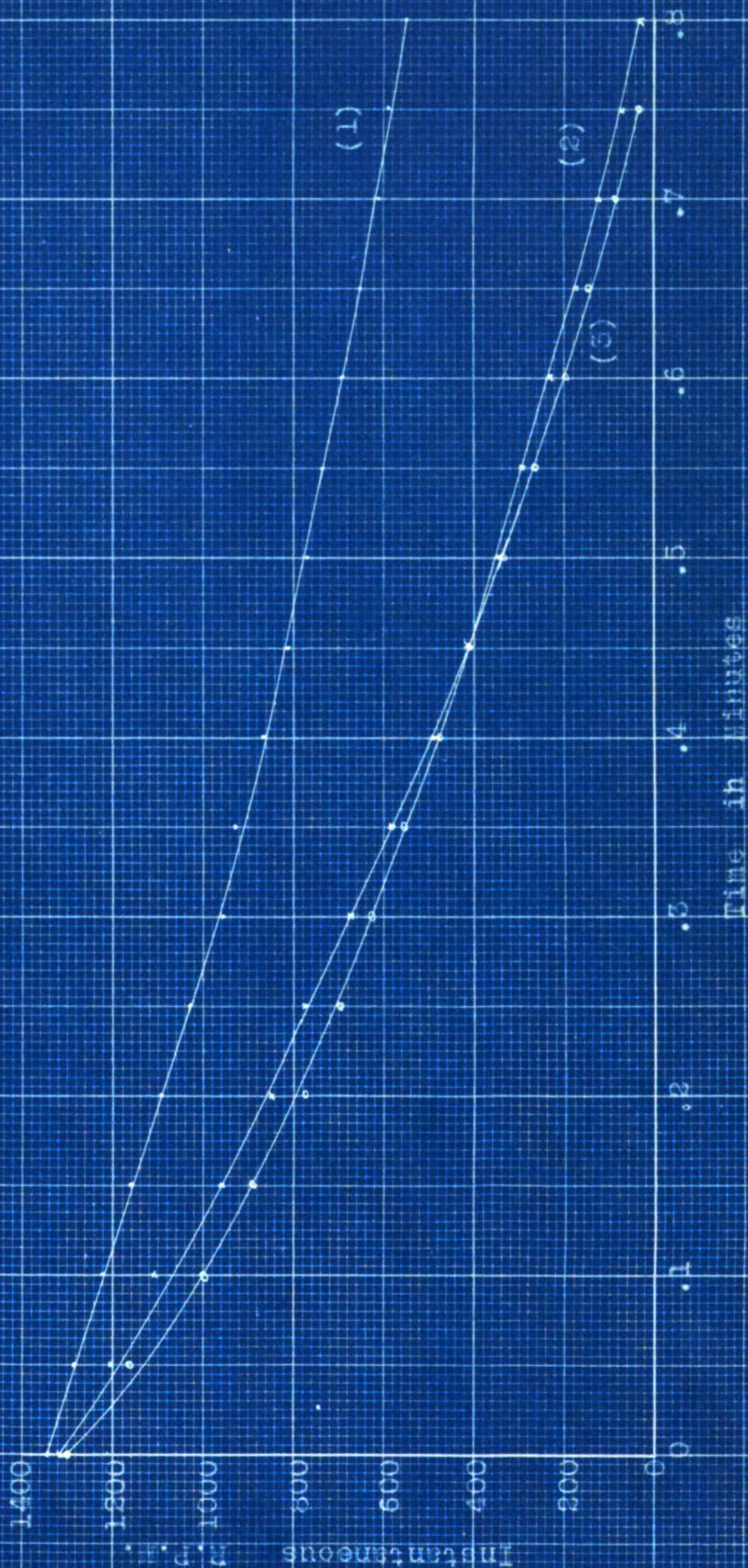
Retardation Curves of Generator No. 450724E

(1) Field Current = 1.942 Amps. Brushes Down.
 (2) " " = 2.053 " "
 (3) " " = 2.161 " "



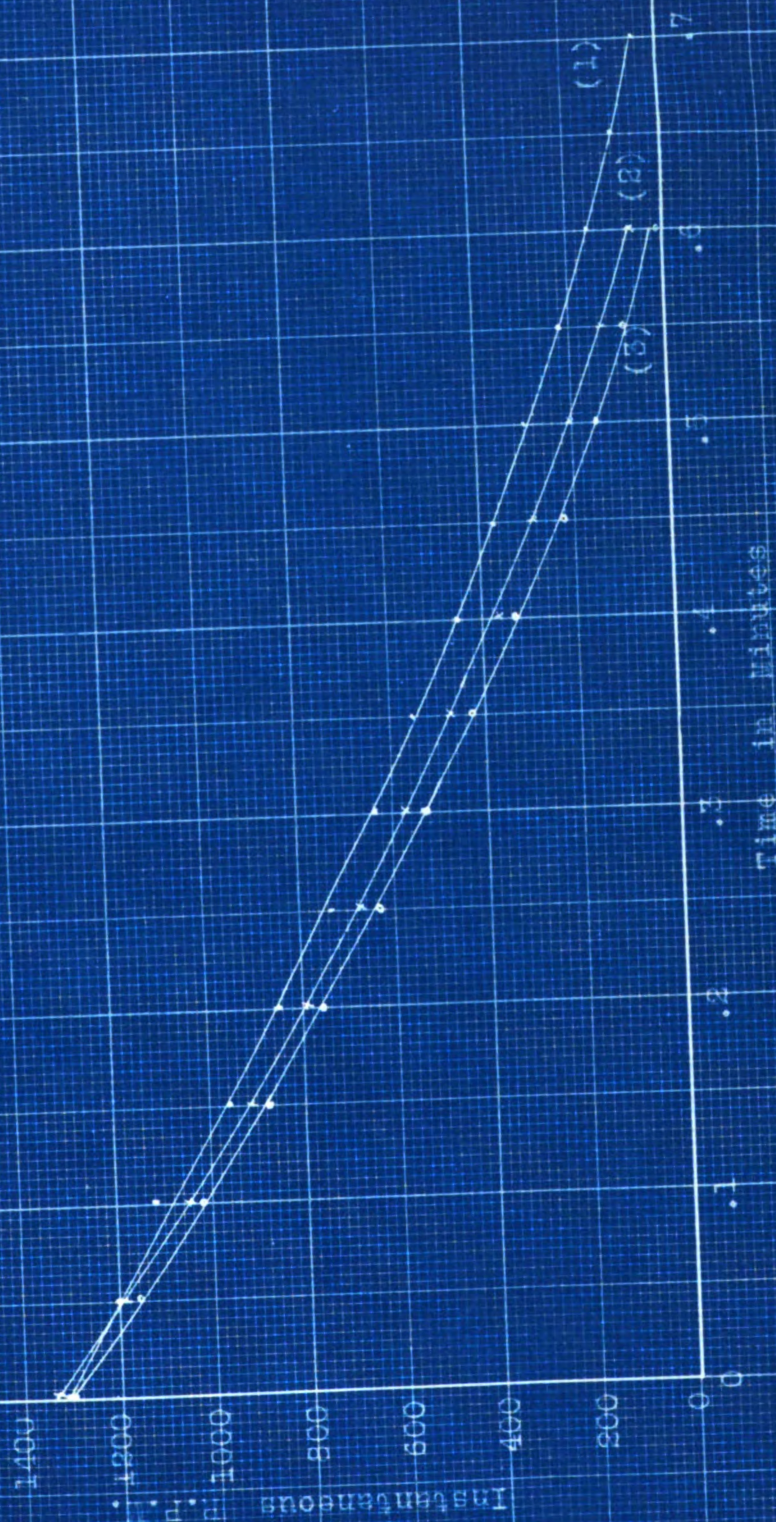
Retardation Curves of Generator No. 4507246

- (1) Field current = 0 Brushes Up.
- (2) " " = 0 Amps. Brushes Down.
- (3) " " = .485 Amps. Brushes Down.



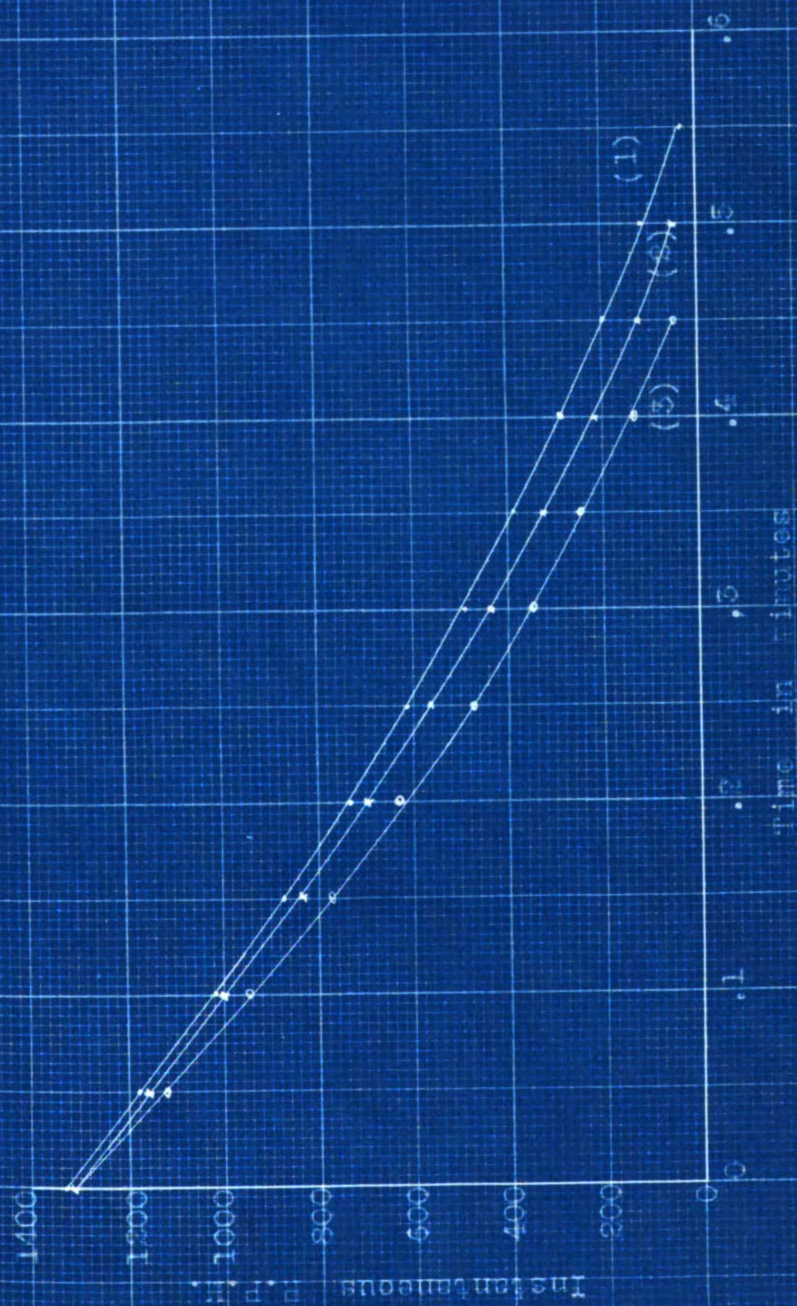
Retardation Curves of Generator No. 4507240

(1) Field Current = 0.610 Amps. Brushes Down.
 (2) " " = 0.700 " " "
 (3) " " = 0.861 " " "



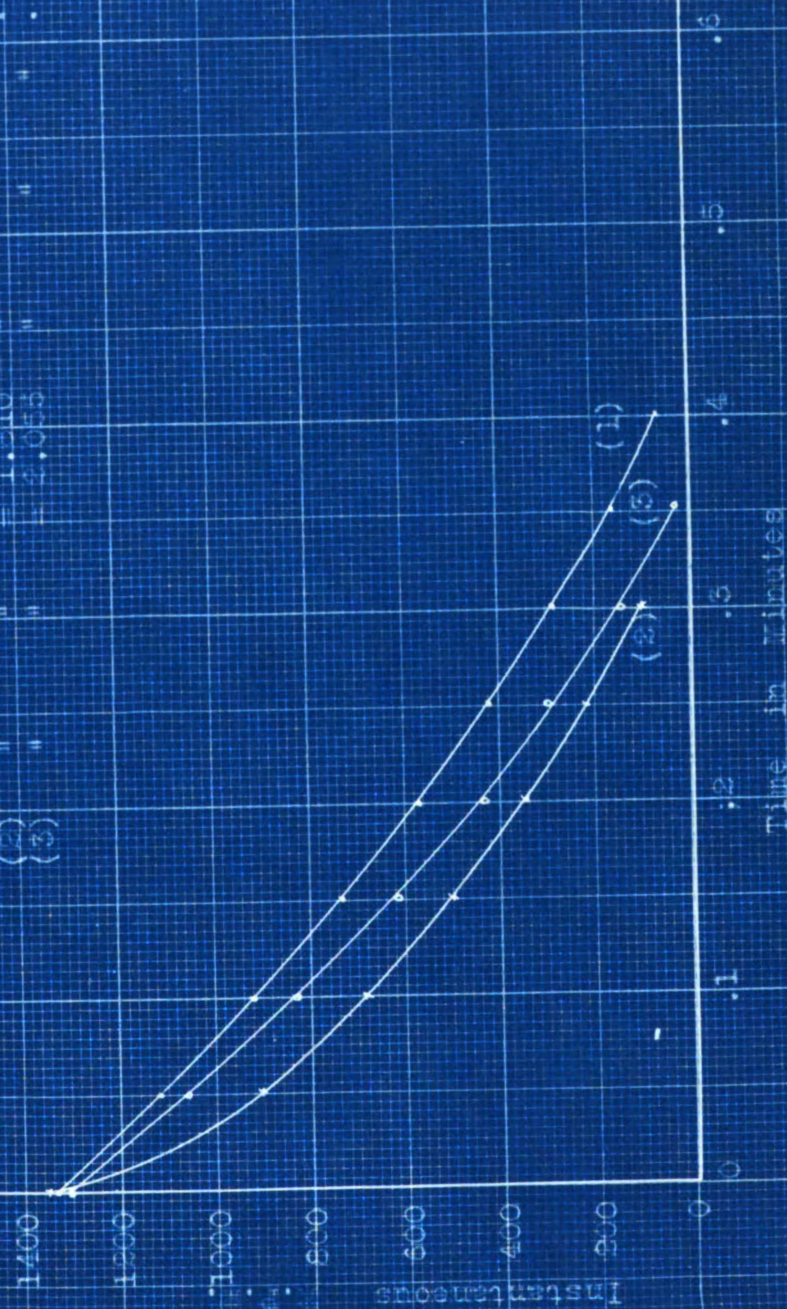
Retardation Curves of Generator No. 4807246

(1) Field Current = 0.927 Amps. Brushes Down.
 (2) " " = 1.074 " "
 (3) " " = 1.295 " "



Retardation Curves Of Generator No. 4507246

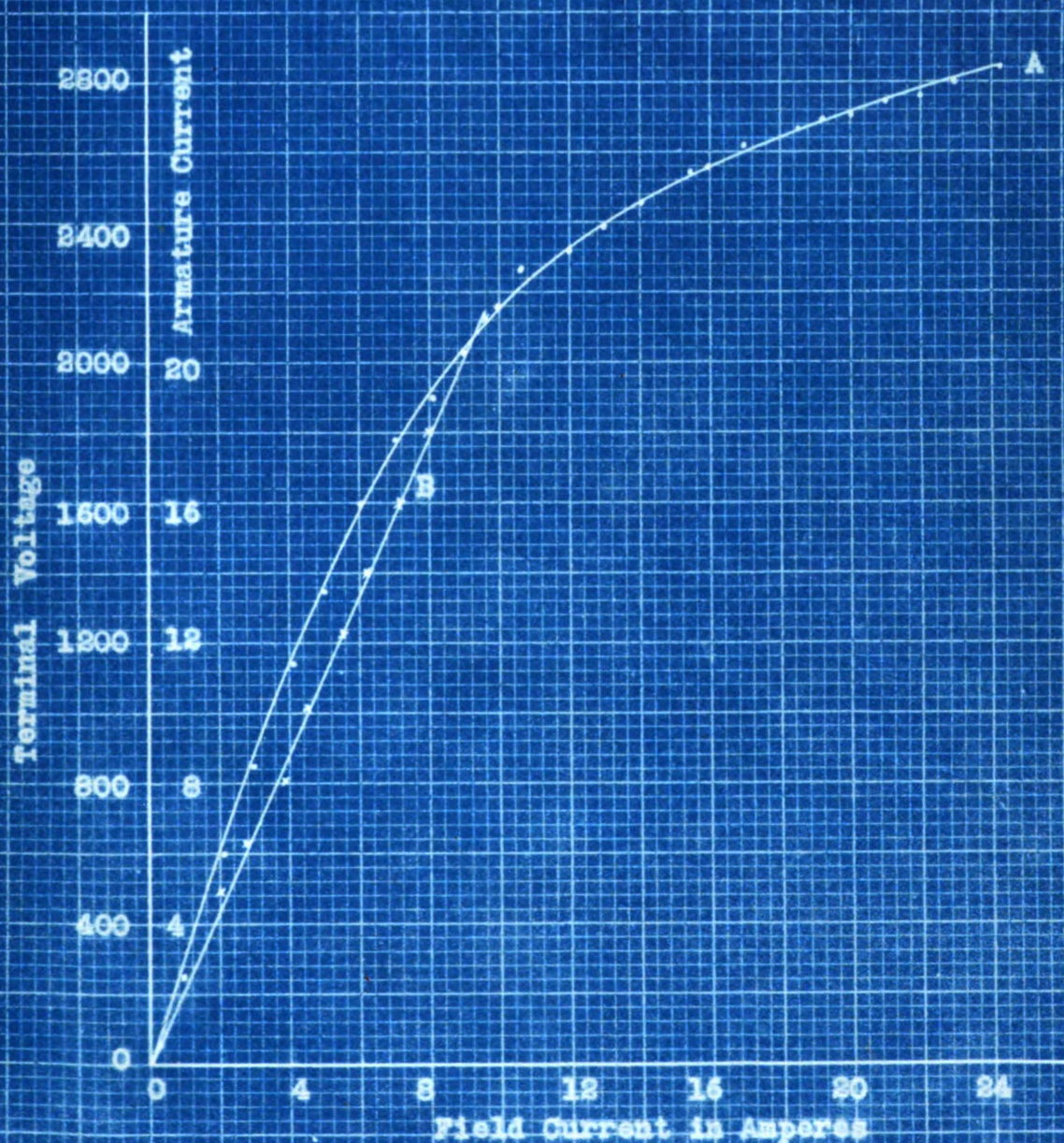
(1) Field current = 1.540 Amps. Brushes Down.
 (2) " " = 1.510 " " "
 (3) " " = 2.055 " " "



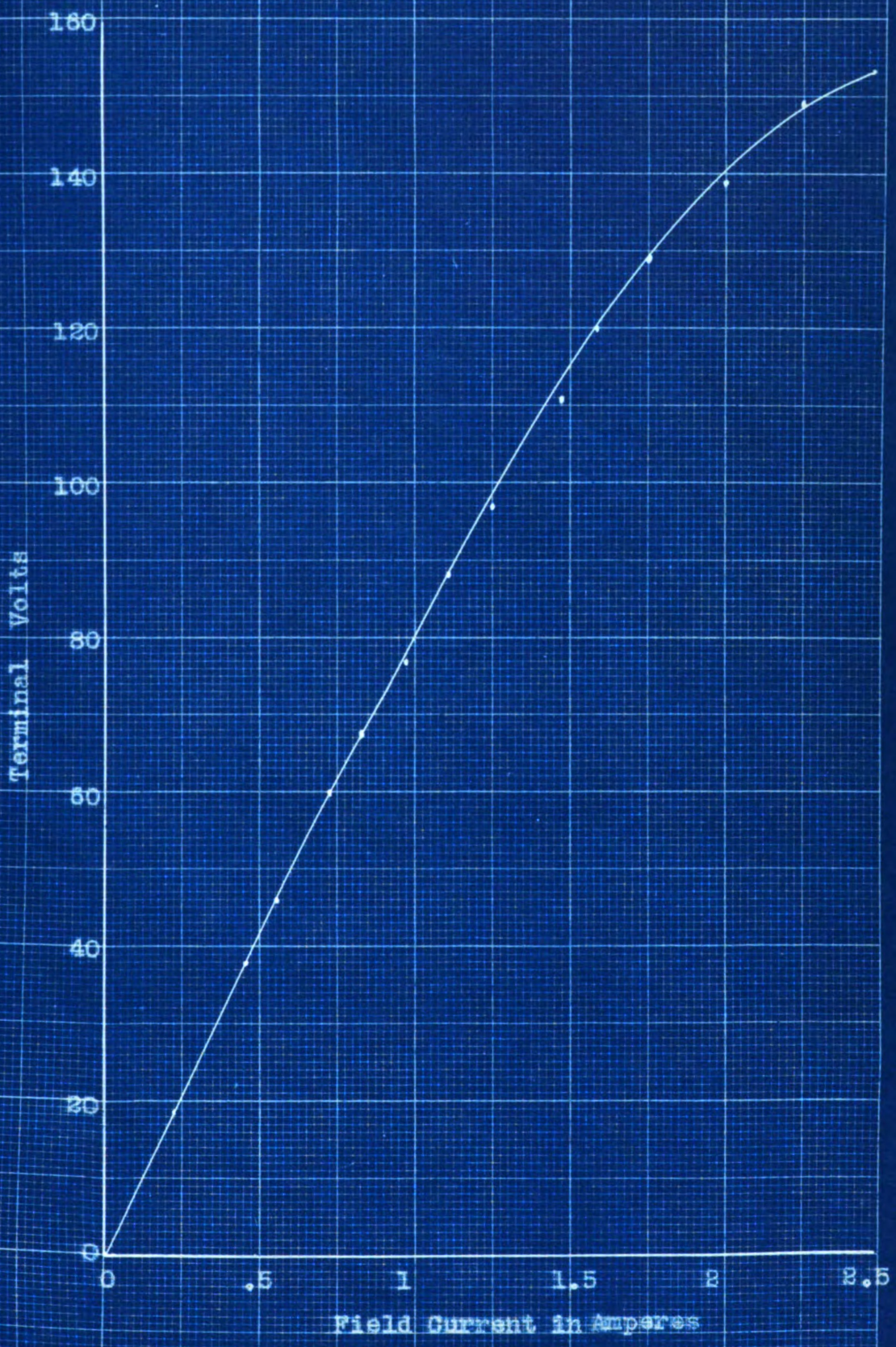
SATURATION CURVE AND SYNCHRONOUS IMPEDANCE CURVE
OF SYNCHRONOUS MOTOR No. 4507244

A. Saturation Curve.

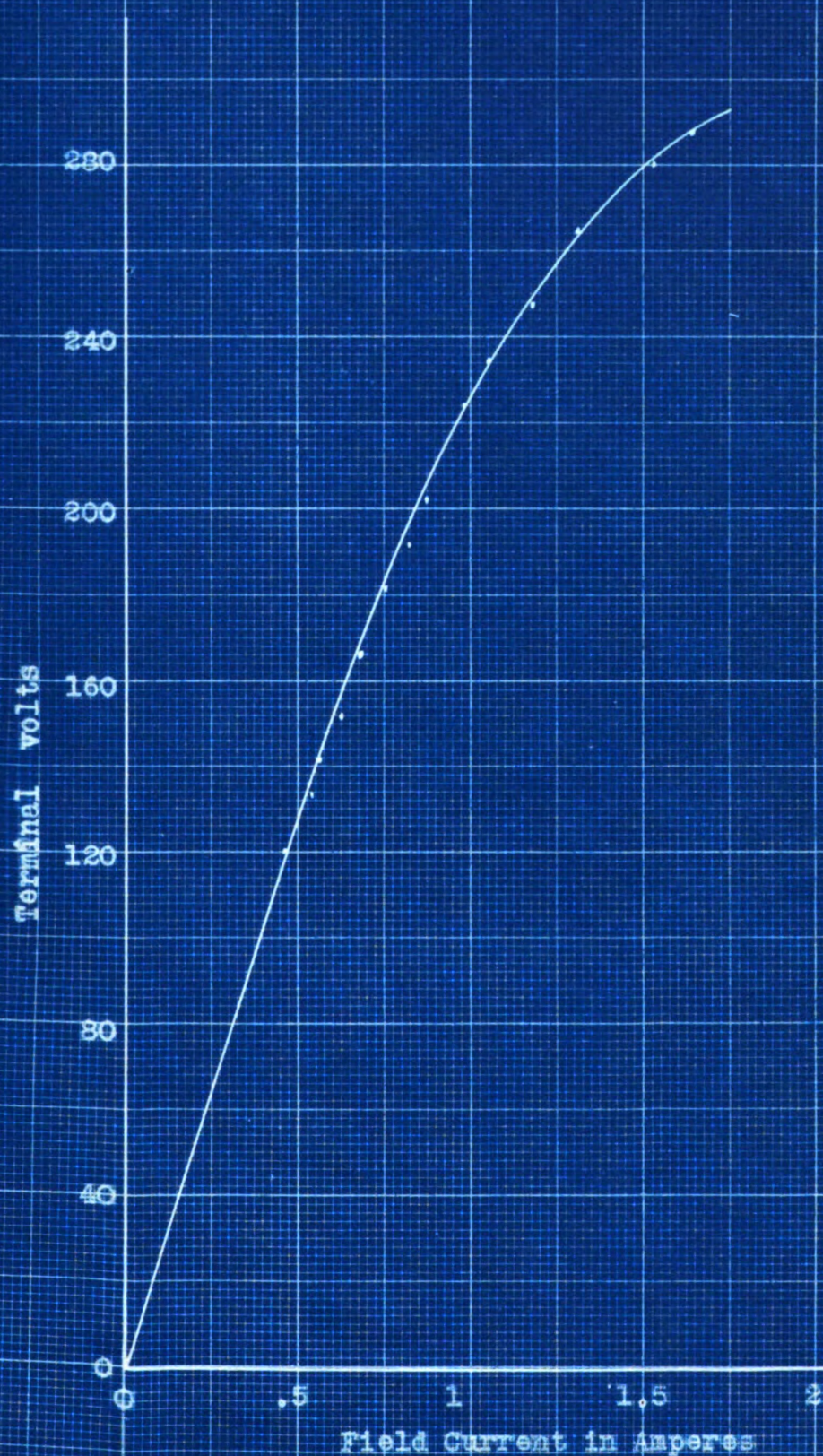
B. Synchronous Impedance Curve.



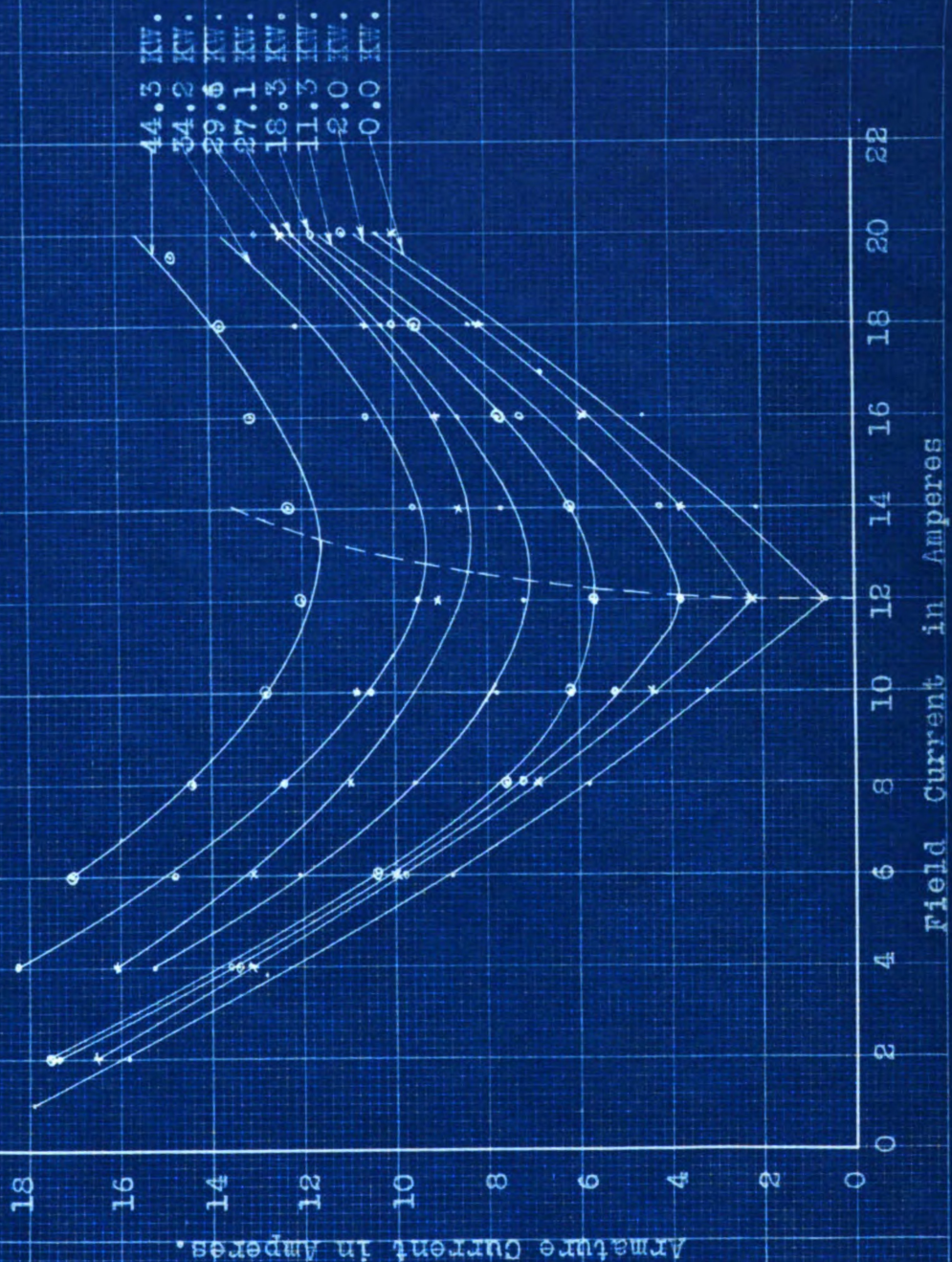
SATURATION CURVE
OF GENERATOR No. 4507242



SATURATION CURVE
OF GENERATOR No. 4507246



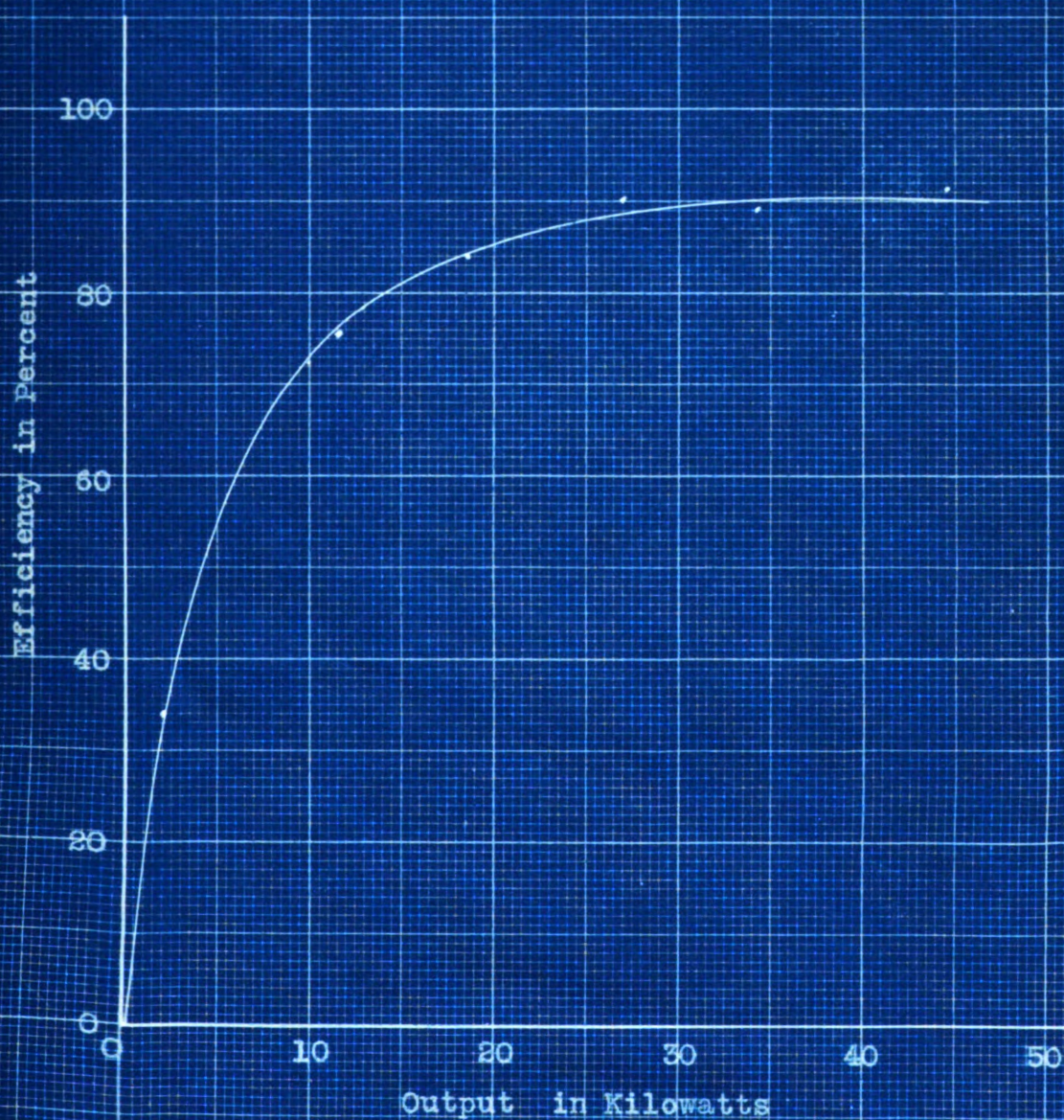
Phase Characteristics of Synchronous Motor No. 4507244



Efficiency Curve of Synchronous Motor

No. 4507244

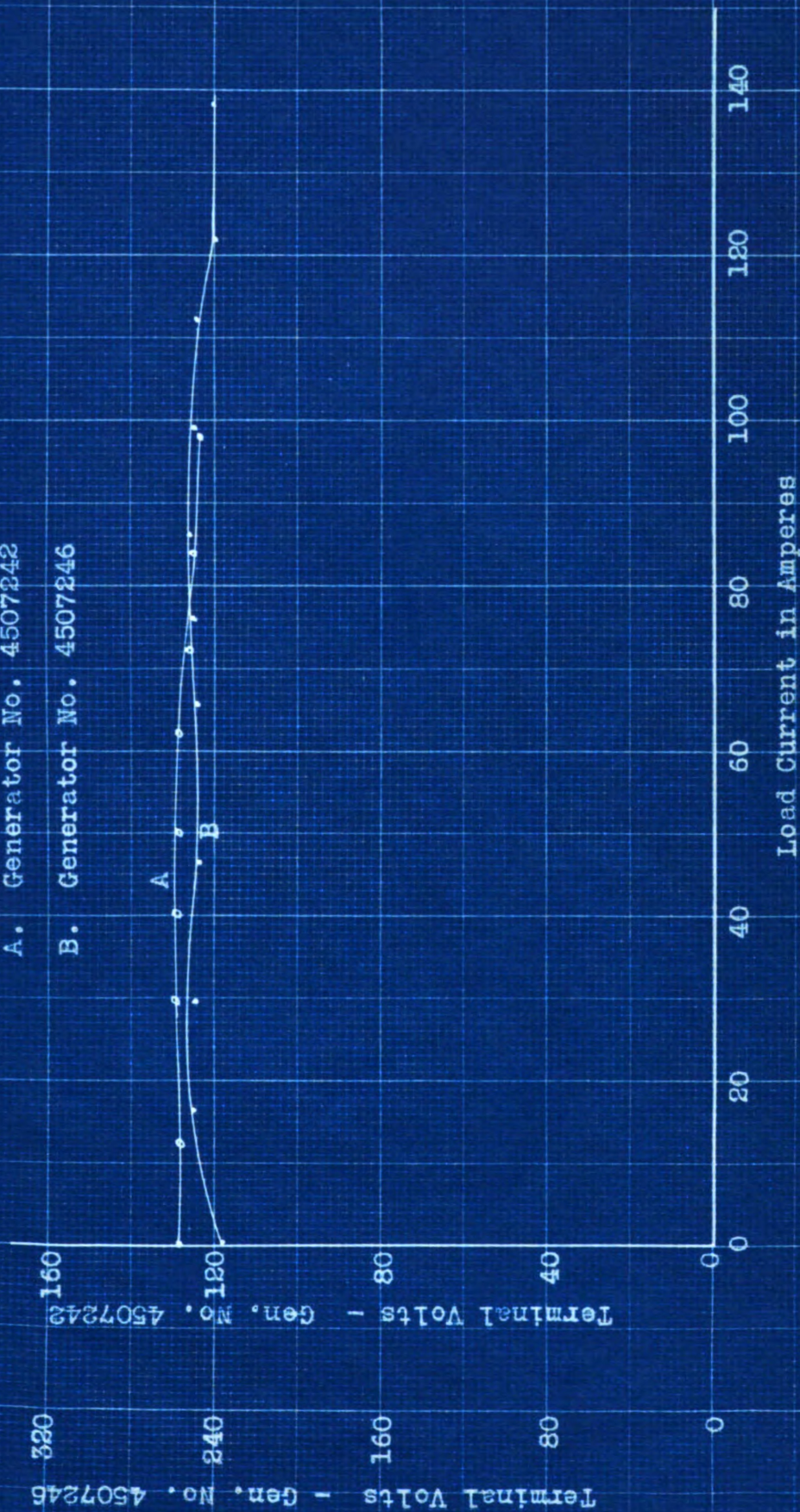
At Unity Power Factor



LOAD VOLTAGE CURVES
OF DIRECT CURRENT GENERATORS

A. Generator No. 4507242

B. Generator No. 4507246

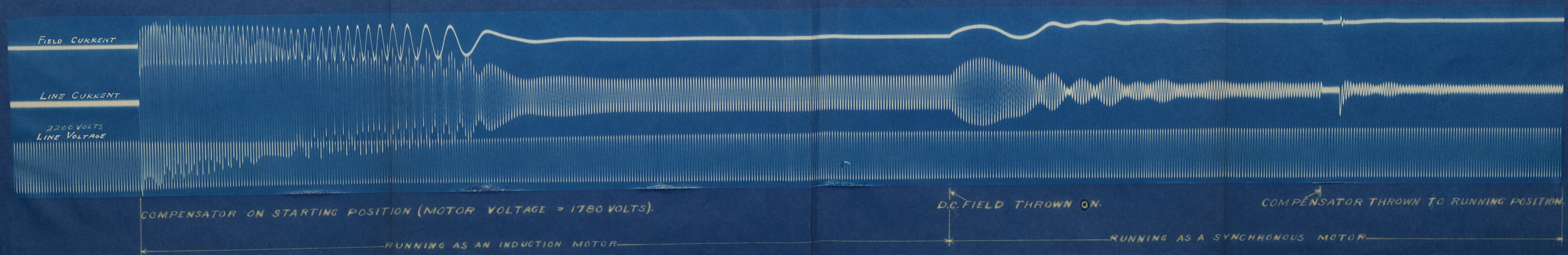
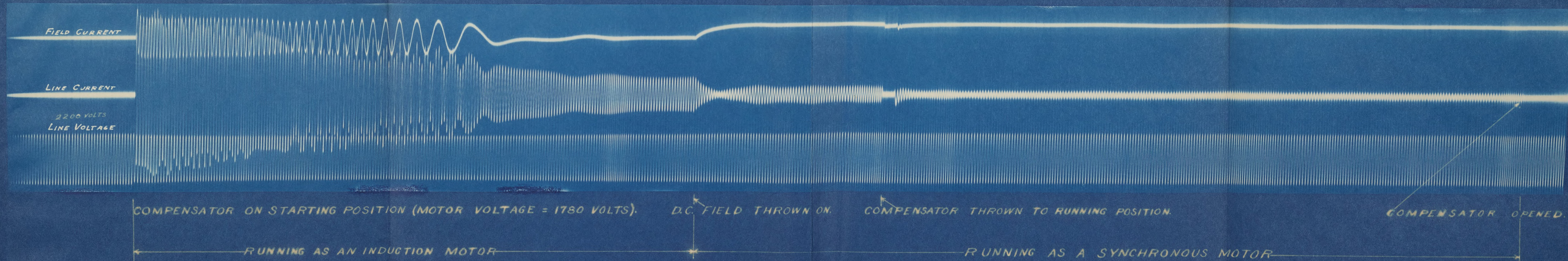


No. 4507244


$$I_{DQ} = 78 \text{ amps.}$$

Scale: 1 inch = 20 amperes.

Starting Torque = 368 lb.-ft.





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