AN ACCEPTANCE TEST AND ANALYSIS OF THE SPECIAL MOTOR GENERATOR SET NO. M 24 AND M. 25. IN THE DIRECT CURRENT LABORATORY OF THE MICHIGAN STATE COLLEGE

Thesis for the Degree of B. S.

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OF THE

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A THESIS

SUBMITTED TO THE FACULTY

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P R E F A C E

As the authors are extremely interested in the application of electrical energy to machinery, it was thought to be an excellent opportunity to supplement the regular four year Electrical Engineering Course at M. S. C. with an extended test on the special motor generator set donated to the engineering department by the Consumers Power Company.

The characteristics of this set were entirely unknown to the engineering department. Therefore the tests were conducted along the same lines as a commercial acceptance test. It is hoped that the tests taken will be sufficient and accurate enough to answer most questions which may arise in more experimental tests which may be conducted at some later date on the set.

The authors take this time to thank all those that had contact with the tests, either directly or indirectly and wish it to be known that all aid was greatly appreciated.

I N T R O D U C T I O N

Probably a more clear conception may be obtained as to the reason for conducting the tests on the special generator set if one has a brief review of the history connected with the set. The set had been originally used as a part of the equipment of the Grand Rapids-Kalamazoo division of the Michigan Electric Railways. At the beginning of the operation of this line the operating voltage was 2400 d.c. This particular set had been installed at a point where only 2400 volt d.c. from a third rail was available to furnish a.c. power for a part of the signal system. At a later date the Monteith Substation was built with a 5000 volt a. c. circuit to take care of the signal system through transformers at the various signal locations. Consequently, the special motor generator set was no longer needed.

The set consists of a 2400 volt d.c. motor with compound and commutating field windings, a double wound armature with a double commutator, permitting series or multiple connection and making it possible to operate either on 2400 volts or 1200 volts. The capacity of the d.c. end is 7.4 amps. at 2400volts or 18.76 Kw.

The a.c. end of the unit consist of a 3 phase, 60 cycle, 35 ampere, 220 volt, 13.32 kva revolving field generator, with an operating speed of 1200 R. P. M.

Both the d.c. and a.c. ends of the unit are equipped with individual exciters mechanically connected to the one main shaft of the unit, each exciter being compound wound, although each has slightly different characteristics.

It should be borne in mind that the a.c. machine was designed as a generator and the d.c. machine was designed as a motor, but at present, conditions are reversed; i.e., the a.c. generator is being run as a synchronous motor while the 2400 volt d.c. motor is being operated as a generator. The above change is caused by not having 2400 volt d.c. available on the campus. For this reason, in all tests the d.c. machine is referred to as a generator and the a.c. machine as a synchronous motor. The authors are aware of the fact that the unit probably is not as efficient running in this manner as it would be if operation was as intended; also, it might be inferred and was readily proven, that the a.c. generator is not an ideal synchronous motor due to its hunting characteristics caused by no amortisseur winding being present.

Due to the fact that no amortisseur winding is present in the synchronous motor, its starting capabilities are limited and the set is brought up to synchronous speed by the exciter on the a.c. end operating as a shunt motor. This subjects it to an overload of short duration which proves not to be harmful.

All measurements were taken with considerable care in regards to accuracy. All meters were calibrated and when any great difference might result from the relative position of meters in the circuit, utmost care was placed on this factor. Before all tests the machine was run for a short time so that friction conditions would become stable.

Considerable care was exercised in eliminating all danger of electrical shock, especially from the 2400 volt d.c. generator. The frame of the unit and one side of the d.c. line was grounded making it possible, in most tests, for the operator to keep free of all ungrounded circuits.

THEORY OF A DIRECT CURRENT GENERATOR

An electric generator is a machine for converting mechanical work into electrical energy, while an electric motor is a machine for converting electrical energy into mechanical work. Contrary to a common belief, the electrical construction of the two machines are nearly identical and the mechanical features may be said to be exactly so; however, a machine designed strictly as a generator has characteristics which make it a more desirable machine for its particular work than a motor would have when operating as a generator. As all of the D. C. machines on the particular set tested were run as generators, only the theory of the direct current generator will be discussed.

The fundamental principle involved in the construction and operation of any type of dynamo electric machine is the production of an electromotive force in one or more conductors by the relative motion of these conductors and a magnetic field. Probably this may be more easily explained if reference is made to Fig. 1.

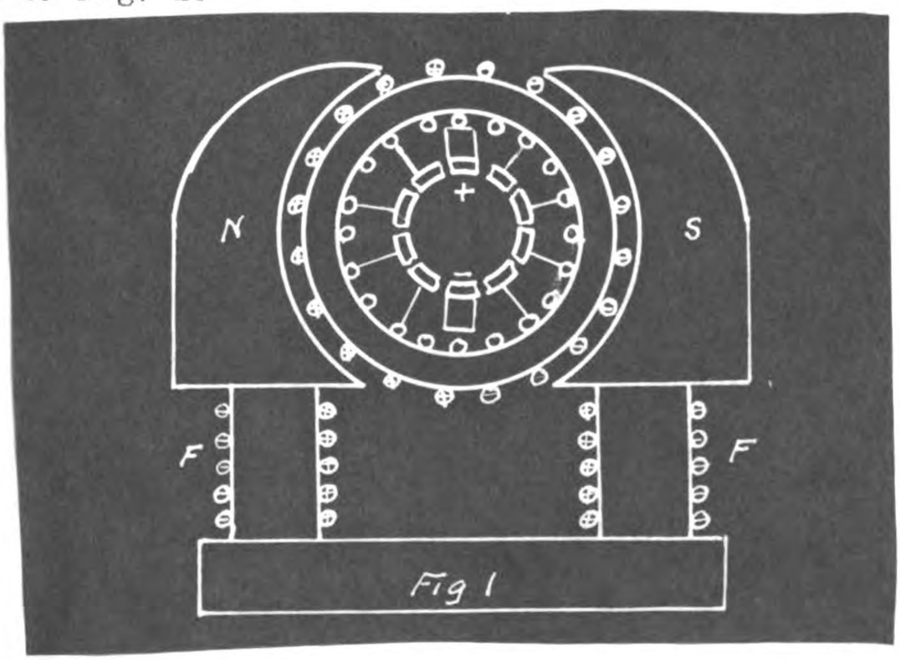


Fig 1

In the broadest sense of the word, it is seen that a dynamo consists of two major parts; that is, a magnetic field and a number of revolving conductors. Assuming the rotation of the armature conductors is as shown, an electromotive force or voltage is induced in the conductor which causes a current to flow in the direction shown, according to Lenz's Law. This induced voltage depends, with other things, on the rate at which the lines of force are cut, which is proportional to the flux density and the rate at which the armature is rotated.

When the conductors are uniformly spaced about the armature, it is evident that when one side of a coil is under a south pole, the other side will be under the north pole, and the electromotive forces induced in the two conductors will be equal and opposite.

However, an inspection of Fig. 1 will show that between the two brushes on one side of the armature, the electromotive forces are all in the same direction. Similarly the electromotive forces on the other side are all in the same direction, both sides tending to cause a rise of potential between the two brushes. This plane in which the brushes should be stationed in an ideal machine is known as the neutral plane.

As the conductors pass from one side of the neutral plane to the other the electromotive force changes within them as they come under the influence of opposite field

polarity. With respect to the brushes the direction of the electromotive force in this conductor remains unchanged. At this point the commutator plays an important role.

The commutator is a cylinder formed of metal segments insulated from each other, each segment being connected to equally spaced segments in the armature winding. Its function, as may be inferred, is to rectify the electromotive forces in the armature, keeping the resultant force between the two brushes in the same direction.

As a reversal of electromotive force takes place in each armature coil every time the two commutator segments to which it is connected pass under a brush, likewise there is a reversal of current. Unless certain precautions are observed this reversal of current will cause sparking at the brushes which is brought about by the breaking down of the air film in immediate contact with the commutator. As a segment leaves a brush the difference of potential between the brush and the segment is equal to the resistance drop across the surface of contact. As this contact area becomes smaller and smaller the resistance becomes greater and the current approaches zero. The degree of perfect commutation is controlled by the manner in which the current dies down in the short circuited coil, and if the value of this I R drop is less than enough to break down the contact resistance, sparking will not occur.

At this point it is well to point out the difficulty in obtaining a reliable reading for the effective contact resistance of the brushes while the machine is in rotion. Even in the same machine with the same current output the brush drop measured at different brush arms and at different times may vary 100% or more. This is due, or is very likely to be increased by high mica, unequal division of the current among the brushes and brush arms, vibration or chattering of brushes, and, by far the most important, by the commutation and strength of the magnetic fields in which the short circuited coils are commutated. So for the purposes of this experiment the resistance of brushes and contacts were taken at standstill.

In a further discussion of commutation it is well to bear in mind the effect of the self induced voltage set up in the armature coils which is caused and tends to oppose the dying out of the current in the coils. Unless the self induced voltage is neutralized the current in the coil will change so rapidly in the coil at the end of the short circuiting period that sparking at the brush contacts will result.

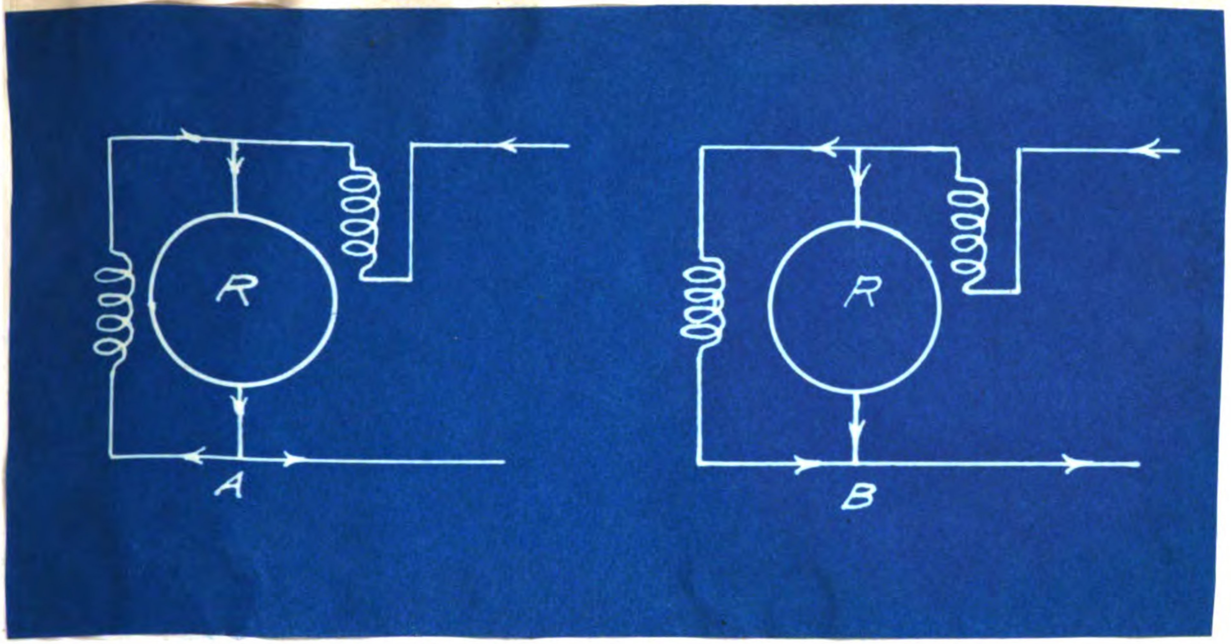
Various methods have been devised to overcome the self induced voltage but in all machines of present design, the interpole is universally used. The interpole or commutating pole, as it is sometimes called, forms a magnetic field which is cut by the armature conductors as they are commutated. This induces a voltage in the conductor which should be of such a value that the current in the conductor will die down at such a rate so as to obtain what is known as straight line commutation or an approximation of it.

As the operation of a generator depends on a magnetic field being cut by armature conductors it is justifiable in explaining the different ways in which fields are excited. Generators may be classed into three main fields in regards to excitation; i.e. series, shunt and compound.

The series generator has a field winding which is in series with the armature , that is, the current flowing in the armature also flows in the field. A shunt generator is excited by a winding which is shunted across the armature; in this case only a fraction of the current flows in the field.

The direct current machines dealt with in this special problem were compound generators. Compound generators may be sub-divided into cumulative compound and differential compound. Each type has both a shunt and series field. The only difference being the relative direction of excitation with respect to each field winding. In a cumulative compound, both fields are excited in the same direction, or in other words, both are tending to make any one pole the same polarity. In a differential compound the two fields oppose each other and the resultant effective flux is less as one field is tending to force flux in one direction, while the other is tending to force flux in the opposite direction.

From an examination of a simple diagram for the connections of a compound generator, it is readily seen that it becomes a differential motor. This may best be explained by referring to the following figure.



A is assumed to be a cumulative compound generator. In this case the source of current is in the armature R. By assuming direction of current, and obeying Kirchoff's Laws, it is seen that the current flows up in the shunt field.

B is assumed to be the same mechanical design with the exception that electrical power is fed in instead of mechanical power. Keeping the direction of line currents the same and obeying Kirchoff's Law as to direction of currents, it is noted that the current in the shunt field is in the opposite direction to what it was in A. Thus if A is a cumulative compounded then B must act differential compounded as the fields are automatically reversed.

The tests on the D. C. machines did not deal with them operating as a motor; however the exciters were used as motors to bring the set up to speed for synchronizing. The differentially compound motors are seldom used in practice due to their poor operating characteristics. Such motors are liable to start up in the wrong direction due to the high inductance of the shunt field caused by a great number of turns. This inductance may so impede the current in the shunt field that the current in the series field, which builds up more rapidly because of the small inductance of that current, may overpower the magnetizing effect of the shunt winding and so reverse the flux and direction of rotation. In the meantime the shunt field current has been building up and when the armature finally stops because of reduced torque, a heavy flow of current through the armature and series field will result because there is now no counter E. M. F. The machine will then start in the right direction, but if the initial current flow is sufficiently great, the series excitation may bring about another reversal of rotation. The same action tends to take place when the machine is under motion and resistance is rapidly cut out of the armature circuit. The sudden increase in current will not build up as fast in the shunt field as in the armature and it will tend to slow down and draw excessive current due to the reduced counter E. M. F. When the shunt field does build up the counter E. M. F. becomes greater and the series current again dies down. This oscillation of current will continue until it becomes so excessive as to render the machine very unstable.

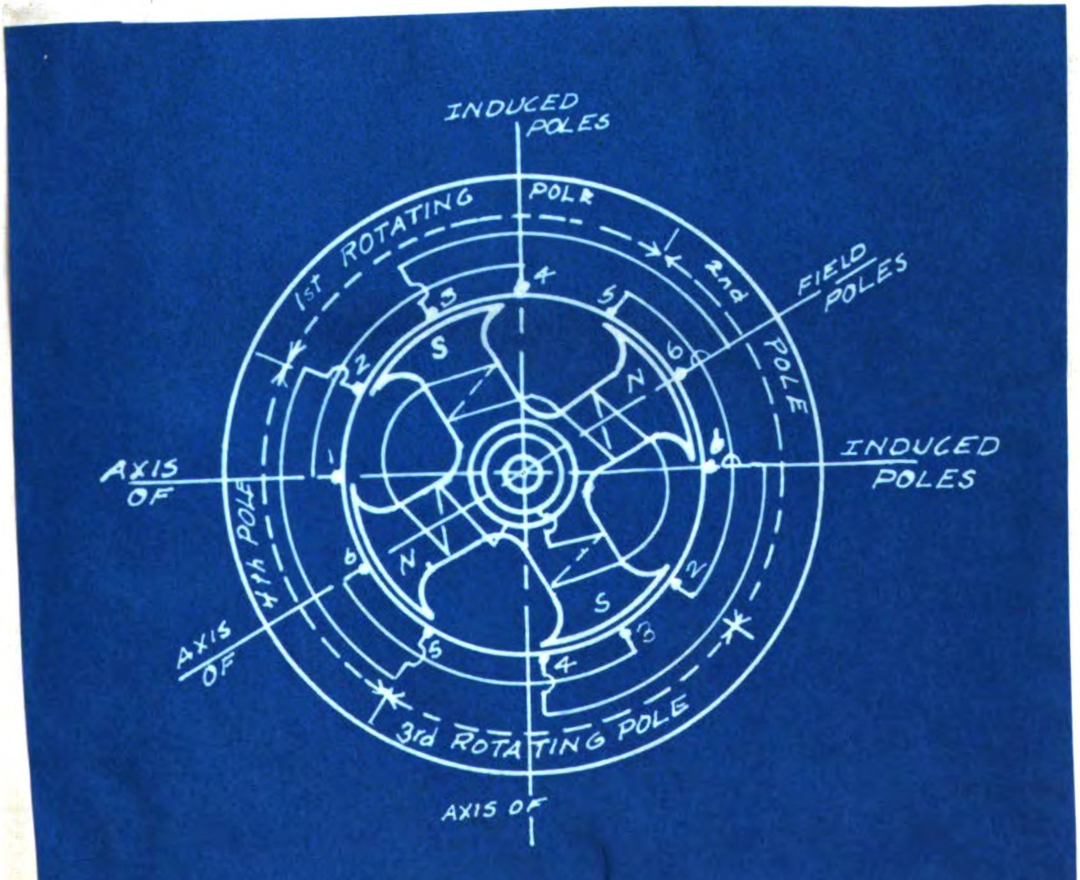
THEORY OF A SYNCHRONOUS MOTOR

An alternating current motor comprises, like any dynamo-electric machine, an inducing magnetic field and its induced circuit, the one turning with respect to the other. But while the field of D. C. motors is constant, that of A. C. motors may be either constant, alternating, or revolving, depending on whether it is produced by direct current, alternating current, or a system of polyphase currents. The class of interest, in this article, is that machine which has a constant field and is known as a synchronous motor.

Constant field motors can be characterized by the fact that the armature rotation can be maintained at a single speed only, which is synchronous with the alternation of the current supplied. It is the above mentioned characteristic which gives this particular machine the name "synchronous motor".

Synchronous motors have the same construction as alternators with the possible exception that synchronous motors are always built with salient poles. However, an alternator, or synchronous generator will run as a synchronous motor; likewise, any synchronous motor will run as a synchronous generator, but, as a rule a synchronous generator will not have an effective damping device to prevent hunting and will not operate satisfactorily as a motor.

Probably the explanation of a synchronous motor may best be introduced by first explaining it from a physical point of view. In the ordinary form of polyphase alternators, the rotor will consist of a crown of iron cores with salient poles excited by coils receiving direct current from a separate exciter. The stator will consist of a circular core of laminated iron having some induced windings placed in slots in such a manner that the wires in successive slots shall have alternating current of different phase passing through them. If a four pole six phase machine is considered, with three slots per pole, the wires in the six slots which cover two poles of the stator, as we follow along the periphery of the latter, will have passing through them, six currents which are out of phase with respect to each other by one sixth of a period.

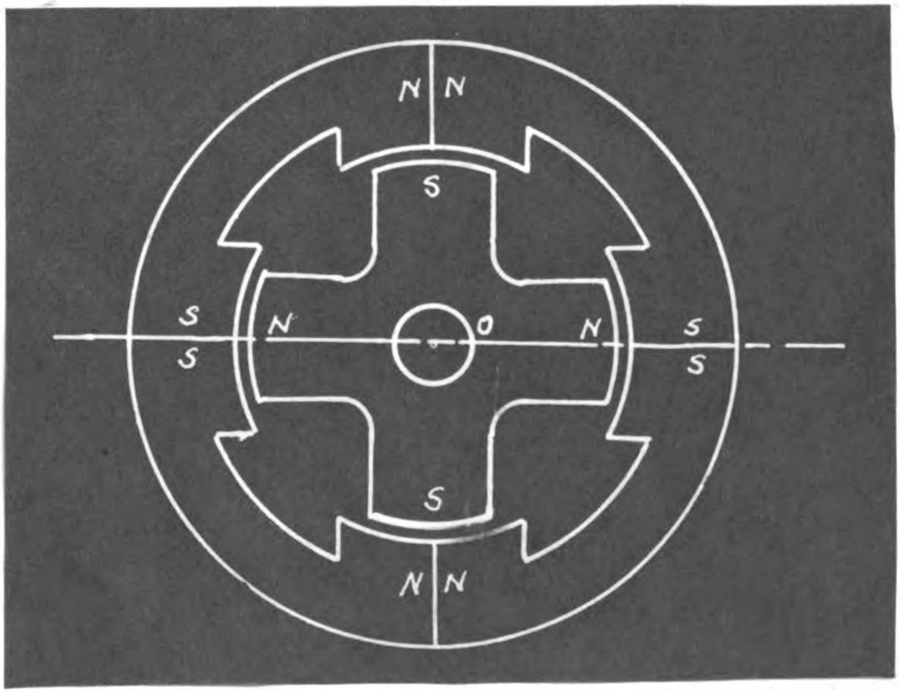


It will be seen that at every one sixth of a period the currents in the stator resume the same values, but the later are displaced one sixth of the width of a double field (2 poles) in the direction in which the currents succeed each other along the stator. Therefore, the axes radiating from the magnetic field produced by the windings of the stator displace themselves around this stator with an angular velocity.

$$\alpha = \frac{\omega}{P} = \frac{2\pi}{PT}$$

Where T = time of alternation of current, P = No. of poles.

The magnetic strength of these fields can be considered practically constant inasmuch as it also resumes the same value every one sixth of a period. Therefore even though the stator is stationary, the result is the same as if it had revolving poles which attract or repel the poles of the field, and we may reason as if we were dealing with the attraction of two systems of magnets presenting the same number of poles which are alternately north and south in polarity.

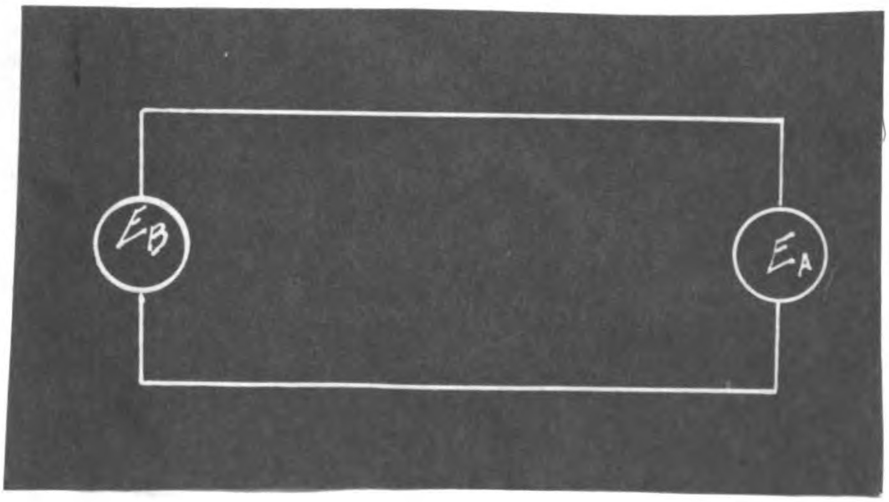


The poles of unlike polarity attract each other; the others repel each other. If the external magnets begin to rotate slowly they will draw the armature with them due to the fact that poles will tend to remain opposite of poles of unlike polarity. This same effect may be obtained by supplying alternating current to the stator winding; however, it must be understood that the armature must come up to speed or be locked into step with the revolving field supplied by A. C.

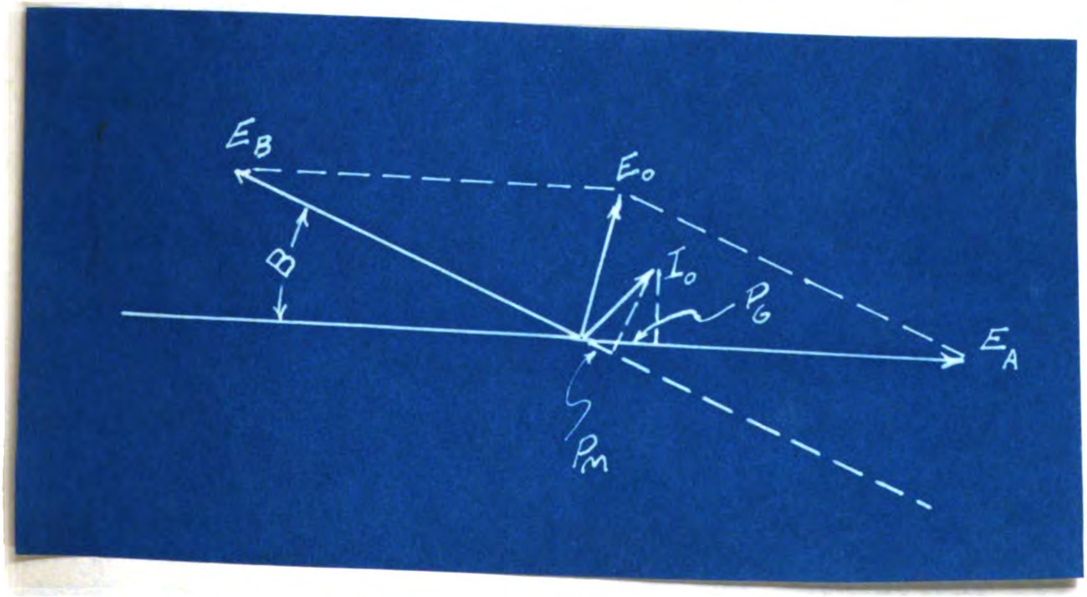
This at once brings up the question of stability of synchronous motors. Refer to pages 20-22

As with many other technical subjects, one may be able to explain the physical action of a machine yet have a very incomplete knowledge of its analytical theory and fundamental equations which enter into calculations connected with the solving of problems concerning that particular machine. With this in mind a few of the more simple and fundamental facts of a synchronous motor will be analized.

From the following figure, suppose E_A and E_B are said to be in synchronism.



From an external standpoint E_A and E_B are in exact synchronism and may be represented by a sine wave, both curves falling on the same points. But if the circuit is opened and viewed internally, E_A and E_B would be found to be opposite and might then be represented by two sine waves, one displaced with respect to the other, by 180°. Now take the prime mover off of B and its voltage vector rotates in a clockwise direction as shown in the following figure.



The amount of load on E_B determines how far the vector will rotate and may best be explained by referring to a direct current motor.

It is common knowledge that current taken by a direct current motor is equal to $\frac{V - E_A}{r_a} = I_A$ where V = impressed voltage, E_A = induced armature voltage or back E. M. F., and r_a = armature resistance. If a load is applied the motor slows down and decreases E_A. It will continue to decrease in speed until the current has increased sufficiently to carry the load. The theoretical limit of load can be readily shown to be reached when $E_A = I_a r_a = \frac{1}{2} V$. Thus it is seen that a direct current motor adjusts itself to a change in load by changing its speed, that is, with constant excitation.

A synchronous motor must run at synchronous speed; it cannot change its average speed to accomodate itself to a change in load or excitation. The current taken by a synchronous motor is equal to $I_a = \frac{V - E_a'}{Z_s}$. Where Z_s is the synchronous impedance V = the impressed voltage. $E_A' =$ the generated voltage.

For a given excitation E_a' is fixed in magnitude, but its phase relation with respect to V may change and alter the current as may be seen by reference to the vector diagram. Therefore, a synchronous motor accommodates itself to a change in load by changing the phase of its generator voltage with respect to the voltage impressed across its terminals. Its average speed does not change, but its instantaneous speed changes long enough to permit the required change in phase to take place.

Referring back to the vector diagram it may be assumed that E_A is constant and may be taken as the reference vector. Then $E_A^O = E_A + jo$.

Suppose E_B is constant in effective value but B is variable. Then $E_B^O = E_B \ (-\cos B + j \sin B)$.

The resultant voltage causing the current is the vector sum between the impressed voltage E_A and the induced voltage E_B.

Therefore $\overset{o}{E}_o = \overset{o}{E}_A + \overset{o}{E}_B$

$$= (E_A + jo) + E_B \quad (-\cos B + j \sin B)$$

$$= E_o \quad (\cos \phi + j \sin \phi)$$

$$\overset{o}{E}_o = E_o + jE_o'.$$

So now the current flowing in the loop and motor is

$$\overset{o}{I}_o = \frac{\overset{o}{E}_o}{z_{loop}} = \frac{E_A - E_B \cos B + jE_B \sin B}{r_{loop} + jx_{loop}.}$$

$$\overset{o}{I}_o = i + ji' = \text{motor current.}$$

As in any circuit the motor power is equal to the product of the real parts of the current and the voltage plus the product of the imaginary parts of the current and the voltage. Therefore in this case the motor power

$$P_M = -iE_B \cos B + i'E_B \sin B.$$

Likewise the generator power $P_G = iE_A + 0$.

Therefore the losses $= P_G - P_M$

$$= -iE_B \cos B + i'E_B \sin B - iE_A$$

HUNTING

In part of this discussion reference has been made to the instantaneous change of speed which takes place in a motor when the phase relation between the generated and impressed voltage changes so that the motor may assume more load. When this action takes place, the motor may overrun and develope too much power. It will then speed up and may again over-run, thus developing too little power. This phenomena is called hunting and all machines in which a change of load is accompanied by a change in phase are subject to this action. It is due largely to the fact that the motor tries to assume more load by a change in speed and the inertia of the revolving parts do not respond to the change in electrical input. Nevertheless a small amount of hunting must always take place when a load on a synchronous motor is changed, but, with a properly designed motor operating under good conditions, it should be small and not noticeable.

DAMPING

Two of the most common ways of diminishing hunting is by increasing the moment of inertia of the rotor by adding a flywheel, and by using a short circuited low resistance winding placed in the pole face. Such a winding is known as a damping or amortisseur winding.

This winding has no effect on the operation of the machine as long as the machine is not hunting and the armature reaction is fixed in space phase with respect to the poles. When, however, hunting starts, the armature reaction sweeps back and forth across the pole face and damping winding. The flux cutting the damping winding induces a voltage which produces a current in such a direction as to oppose the change in angular velocity. Thus its action is similar to the action a viscous fluid has on a pendulum.

METHODS OF STARTING

Besides being of value for its damping characteristics alone, an amortisseur winding is of value in starting a synchronous motor. When the amortisseur winding is made use of in starting, the impressed voltage should be reduced through a compensator or from transformer connections.

Sometimes the eddy current and hysteresis losses in the pole faces caused by the revolving field set up by the armature reaction of a polyphase motor will produce a starting torque which may cause the motor to start without the amortisseur winding. However, the torque produced without the winding would be small and excessive current would be required.

Also high voltage would be induced in the field winding during starting due to the armature reaction flux sweeping across the pole faces. This effect is a maximum at zero speed and zero when synchronous speed is reached, but, in any case extra field insulation should be provided on all self starting synchronous motors. Short circuiting the field winding will reduce the voltage induced in it during starting and will slightly increase the starting torque.

Both of the above methods require special characteristics which are very seldom present in a machine designed for a synchronous generator, and run as a synchronous motor.

Thus where D. C. is available, the motor may be brought up to synchronous speed by its exciter. Or, in some cases special auxiliary motors may be used.

METHODS OF PROCEDURE

As has been stated, this motor generator set had been in the laboratory only a short time and no tests had been taken up to the time this test was started. Under these circumstances the most logical test seemed to be one of determining the wiring diagram of the set. This was accomplished by the use of a bell in connection with a telephone magneto.

After determining the connection diagram of the set, a static test was made by the use of a megohmer. Tests were made between all parts of the machine which were supposed and should be insulated from each other. (A bar to bar test on the commutator of the 2400v machine was not made but care was taken in putting half voltage on the armature as a preliminary test)

The next test undertaken was resistance measurements of all circuits and parts of circuits that were contained within the set. At this stage difficulties were encountered in getting consistent results and one is immediately impressed by the fact that resistance, as spoken of in the class-room, is not always easy to obtain.

The first trials were taken by the "drop of potential method". Due to meter defects all readings were corrected from a calibration curve but consistent results could not be obtained on those resistance measurements whose values were very small. The "Wheatstone bridge method" was finally used and satisfactory results were obtained. It was found that the small values taken by the drop of potential method were in error by 200% to 400%, showing that this method should not be used when reliable results are desired. Care was taken to make good contacts with all circuits or parts of circuits being measured. The importance of this precaution was emphasized when resistance measurements were made on the slip rings. Without sanding the carbon film off the contacting surface or face of the ring, the resistance was found to approach infinity. After sanding the surface and reaching a metalic surface, the resistance was found to be very small.

Before any further tests could be made a method of synchronizing the A. C. motor with the 220 volt campus supply had to be determined. The D. C. exciter No. 437050 was driven as a motor to bring the set up to speed. As no switching or control equipment was present in the laboratory, a four point face plate type starting rheostat was placed in the line connected to the motor. An ammeter was placed in the line so some idea of the load could be obtained. It was found that the exciter became very unstable at the load necessary to bring the set up to speed. This instability was due to the fact that the cumulative compound generator was acting as a differential compound motor and was subject to the characteristics mentioned in the discussion of direct current theory. In all cases it would draw a current which fluxuated to the extent to open the circuit breakers in the line. In one case the motor started in one direction and then reversed, in the machine drawing an excessive current and opening the circuit breakers in the line.

In order to overcome the above mentioned difficulties the line to the motor was connected between the series field and armature thus operating it as a shunt motor. With this connection speed was readily obtained by operating the motor at approximately 130v and 33 amperes with the synchronous motor generating a voltage suitable for synchronizing.

The synchronous motor was separately excited on starting, but excitation was obtained from the D.C. exciter No. 483850 through the medium of a two pole double throw switch when the A. C. motor had been synchronized. Synchronizing was accomplished by the use of two 300 volt meters connected in straight between the 220 volt campus and the A. C. motor. Care was exercised in having the phase rotation such as to be favorable to the direction of rotation caused by the D. C. exciter operating as a shunt motor.

Immediately upon synchronizing, the line switch to the D. C. Exciter no. 483850 was opened and the double throw, double pole switch in the field circuit of the A. C. synchronous motor was operated so that the D. C. exciter No. 483850 was now functioning as a cumulative compound generator. Care was used at this point in making sure that the polarity of the D. C. exciter No. 483850 was the same as that of the separate excitation to the A. C. motor. The excitation of the A. C. motor was controlled from this stage, by varying the voltage on the D. C. exciter by inserting resistance in the field of that machine.

During the testing of the set it was found that the synchronous motor hunted to the extent that it would not stay "in step" when the mechanical coupling between the A. C. synchronous motor and the D. C. 2400v generator was disconnected. The only explanation which sounds reasonable is that the reduced mass, caused by disconnecting the machines from each other, reduced the inertia of the revolving part so that the hunting tendency was not damped out.

Before the above method of synchronizing was attempted the set was started by putting 110 volts A. C. on the synchronous motor. The field was short circuited and the set started with the A. C. motor operating as an induction motor. The set obtained a maximum speed of 600 R. P. M. The A. C. voltage on the synchronous motor was then increased to 220 volts but the speed stayed constant at 600 R. P. M. while the current doubled. No ammeters were placed in the A. C. line but 20 ampere fuse wire was blown on the 2300 volt side of the transformers. It was decided that the synchronous motor did not have good starting characteristics so this method was abandoned.

As soon as the synchronous motor furnished power for the set, the no load saturation and load voltage test of each exciter was taken. Care was taken to adjust the excitation of the synchronous motor so that the power factor would be near unity. All brushes were seated and moved so that black commutation was approached.

At this time it was noted that one bearing was heating and more attention was paid to setting the machine exactly level. This was accomplished by putting a wooden wedge under one corner of the frame.

During the load test of exciter No. 433351, it was found that the rated current of 18 amperes was too high, and from the experience of running the tests it has been decided that probably a current of 8 amperes is more nearly the actual capacity.

While running the no load saturation test, the field current was reduced from a maximum to a minimum value and care was taken not to permit the current to rise above its lowest value at any time; the reason being to eliminate irregularities in the curve due to hysteresis phenomena.

A load voltage test and no load saturation test was also made on the 2400 volt direct current generator No. 434-701. Before high voltage was generated the frame of the machine and one side of the line was grounded as a precaution against shock.

The load necessary for the load voltage test was obtained by connecting to a "water barrel" rheostat. The rheostat consisted of a 15 gallon earthen crock filled with clear tap water. The electrodes consisted of iron rods of 3/16" diameter and were held in a rigid position by being securely fastened to a $\frac{3}{4}$" board at the top. The electrodes were placed 11" apart. No artificial means were employed to cool the water as the load was not on for any great length of time. For any extended operation the "barrel" should be larger and the electrodes placed farther apart. This is deemed necessary due to gas being formed about the ends of the electrodes and ~~water which~~ violent arcing which resulted. The arcing was also accompanied by throwing of water which would make some kind of a cover very adventageous.

Voltage was measured with a 150 volt voltmeter in connection with a multiplier whose multiplying factor was 20. At this time it was noted that the generator was overheating when carrying rated current of 7.4 amperes. It has been decided that probably 6 amperes would be very near the true capacity.

The tests on the synchronous motor consist of a no load saturation test, V curve test, and a short circuit test. The no load saturation test was run using exciter No. 433850 as motive power and separately exciting the synchronous motor.

Due to the hunting characteristics of the motor, it was very hard to obtain accurate readings for the load voltage test. The only way a current reading could be obtained was by approximating a mean value of that part of the scale traversed by the meter needle. In this test the synchronous motor was loaded by the D. C. generator No. 434701 which in turn was loaded on the "water barrel" rheostat.

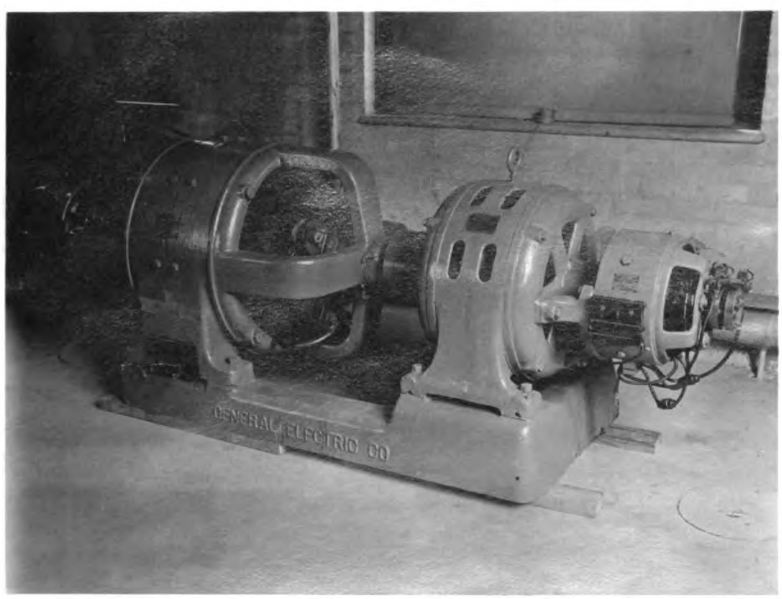
The D. C. exciter No. 433850 operating as a shunt motor was used for motive power for the short circuit test. The phases were shorted through an ammeter and the field current was raised to such a value so as to give a short circuit current slightly above that of the full load rating. The field current was gradually decreased to zero.

The tests which consumed the most time of any other individual test was the retardation run to determine the losses of the set. Several methods of determining the losses of the set were considered but several factors made the retardation method the most feasible. During this test, different values of shunt field current were taken and the speed was run above 1200 R. P. M. Power was taken off the set, and it was allowed to come to a stop while instantaneous speed was read every 5 Sec. In some cases it was found sufficient to take readings only every 10 Sec. With this same field current the power input at some speed below 1200 R. P. M., was taken.

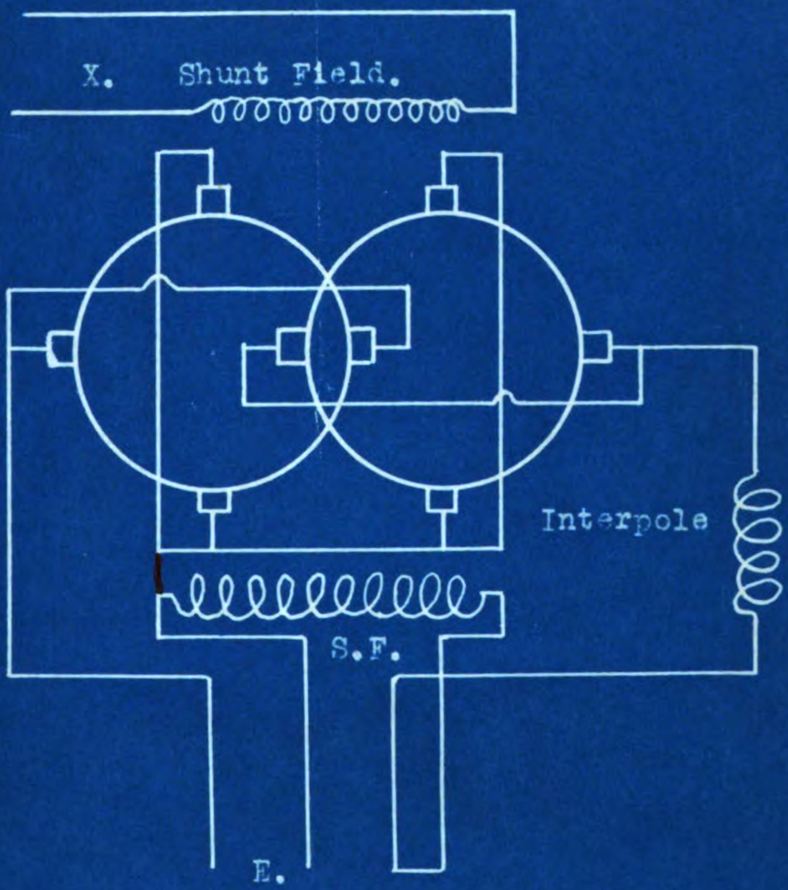
The above test would give the core loss due to that field current plus the windage and friction of the total set. The field current was reduced in steps to zero with a complete set of values being taken for each new current. The last test on each machine consisted of raising the brushes with a zero field current and taking readings as suggested. The above procedure was carried out with each individual machine and the data obtained makes it possible to separate the core loss and brush friction of each machine. No test was made to separate the windage from the bearing loss.

In order to measure the instantaneous speed a D. C. tachometer was constructed from an electric fan motor. Preliminary runs were made to determine the value of field current and voltage best suited for the particular size of motor we were using as a generator. It was found convenient to make the field current of the original fan motor, of such a value so that the voltage generated would read directly as 1/100of the actual speed of the set. Incidentally this gave nearly full scale deflection on a 15 volt voltmeter.

CONNECTION DIAGRAMS.


GENERAL ELECTRIC CO

CONNECTION DIAGRAM FOR D.C. GENERATOR NO. 434701

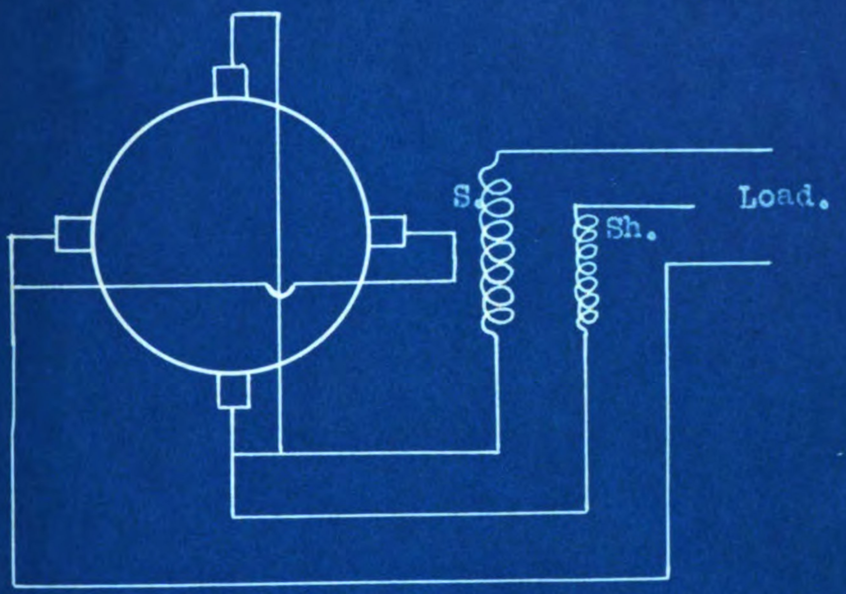


X— Excited by D.C. exciter NO. 433851.

S.F.— Series field.

E-- 2400 volts D.C.

CONNECTION DIAGRAM FOR D.C. EXCITER NO. 433851.

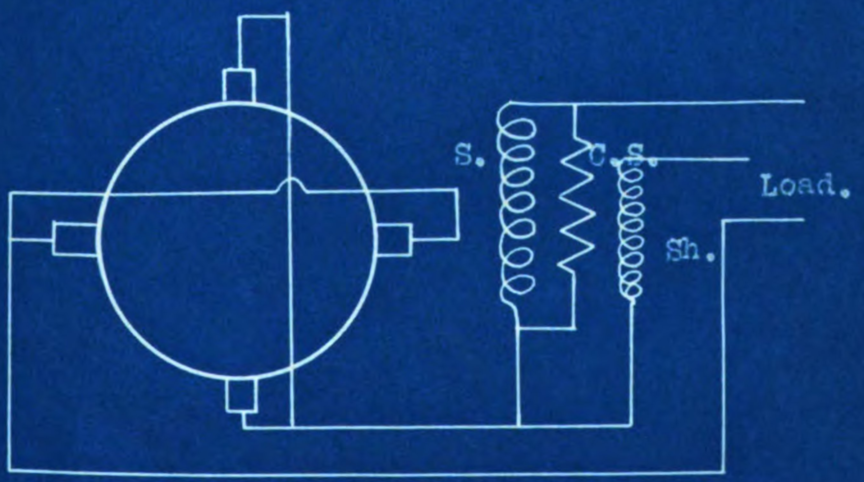


S -- Series field.

Sh. - Shunt field.

Load --Field of D.C. generator NO. 434701.

CONNECTION DIAGRAM FOR D.C. EXCITER NO. 433850.



S-- Series field. C.S.-- Compounding Shunt.

Sh.-- Shunt field.

Load.-- Field of synchronous motor NO.684627.

TABULATED DATA.

Name Plate Data

D.C. Generator No. 433850.

Type MP - 4 - $2\frac{1}{4}$ - 1200 Form P.

Volts no load 125. Full load 125.

Amperes 18. R.P.M. 1200.

D.C. Generator No. 433851.

Type MP - 4 - $2\frac{1}{4}$ - 1200 Form P.

Volts no load 125. Full load 125.

*Amperes 18. R.P.M. 1200.

A.C. Motor No. 684627.

Type ATB - 6 - 13.3 - 1200 Form 6.

K.W. 12 R.P.M. - 1200 P.F. - .9

Amperes 35. Volts full load 220.

D.C. Generator No. 434701.

DLC - 4 Form A Compound winding.

*Amperes 7.4 Volts 2400.

H.P. 19 R.P.M. 1200.

* Note the change recommended in the discussion.

All machines manufactured by General Electric Company.

Static Tests. (insulation resistance)

D.C. Exciter No. 433851.	Resistance.
Between shunt field and frame	Infinity.
Between series field and frame	"
Between brush and frame	"
Between brush and armature core	"
Between series and shunt field	"
D.C. Exciter No. 433850.	
Between shunt field and frame	"
Between series field and frame	"
Between brush and frame	"
Between brush and armature core	"
Between series and shunt fields	"
A.C. Motor No. 684627.	
Between phase 1 and frame	"
Between phase 2 and frame	"
Between phase 3 and frame	"
Between slip rings	"
Either slip ring to frame	"
Between field and frame	"
D.C. Generator 434701.	
Between series and shunt field	"
Between armature winding and armature core	"
Between brush and frame	"
Between interpole winding and frame	"
Between armature windings	"
Between either field winding and frame	"

Circuit resistances.

Temperature at time of test, 70° F.

D.C. Generator No. 433850.

Circuit.	Ohms resistance.
Shunt field.	45.2
Series field.	.121
Compounding shunt.	1.12
Series field in parallel with shunt.	.109
Armature alone.	.517
Armature, brushes, & pig tails.	1.365
Brushes & pig tails alone.	.848

D.C. Generator No. 433851.

Shunt field.	81.5
Series Field.	.265
Armature alone.	.52
Brushes & pig tails & leads.	.92

D.C. Generator No. 434701.

Shunt field.	29.35
Ser ies field.	79.3
Armature near A.C. motor.	3.74
Armature near generator No. 433851.	3.71
Brushes & Leads--A.C. motor end.	.2
Brushes & leads --exciter end.	.76
Interpoles	1.34

A.C. Synchronous motor No. 684627.

Rotating field	12.2
Brushes, pig tails & leads.	2.3
Stator-- per phase. (Y)	.063

Circuit resistances.

Temperature at time of test, 70° F.

D.C. Generator No. 433850.

Circuit.	Ohms resistance.
Shunt field.	45.2
Series field.	.101
Compounding shunt.	1.12
Series field in parallel with shunt.	.109
Armature alone.	.517
Armature, brushes, & pig tails.	1.365
Brushes & pig tails alone.	.848
D.C. Generator No. 433851.	
Shunt field.	81.5
Series Field.	.265
Armature alone.	.52
Brushes & pig tails & leads.	.92
D.C. Generator No. 434701.	
Shunt field.	29.35
Ser ies field.	79.3
Armature near A.C. motor.	3.74
Armature near generator No. 433851.	3.71
Brushes & Leads--A.C. motor end.	.2
Brushes & leads --exciter end.	.76
Interpoles	1.34
A.C. Synchronous motor No. 684627.	
Rotating field	12.2
Brushes, pig tails & leads.	2.3
Stator-- per phase. (Y)	.063

D. C.

Mr.

Per

Volt

138

127

117

104.

97
91
91

80

30

32

8

43

28

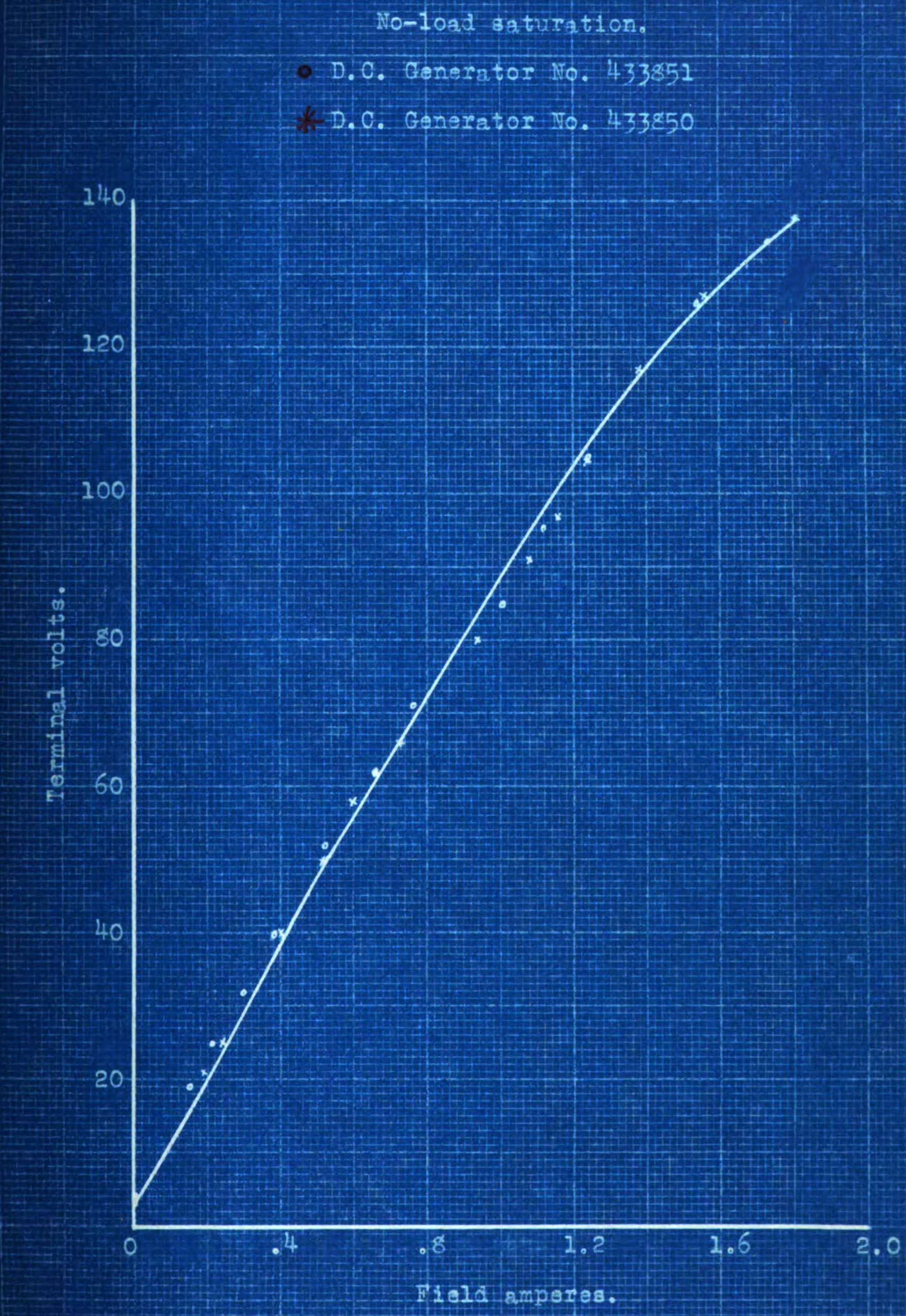
2

No Load Saturation Tests.

D. C. Exciter No. 433850.		D.C. Exciter. No. 433851.	
Terminal Volts.	Field Current	Terminal Volts.	Field Current.
138	1.81	134.5	1.75
127	1.56	126	1.54
117	1.38	116	1.38
104.5	1.24	105	1.24
97	1.16	95.5	1.12
91 91	1.08	85	1.01
80	.84	71.5	.76
66	.73	62	.66
56	.6	52	.52
50	.52	40	.38
40	.40	32	.30
35	.24	25	.215
21	.19	19	.15
3	.00	4	.00

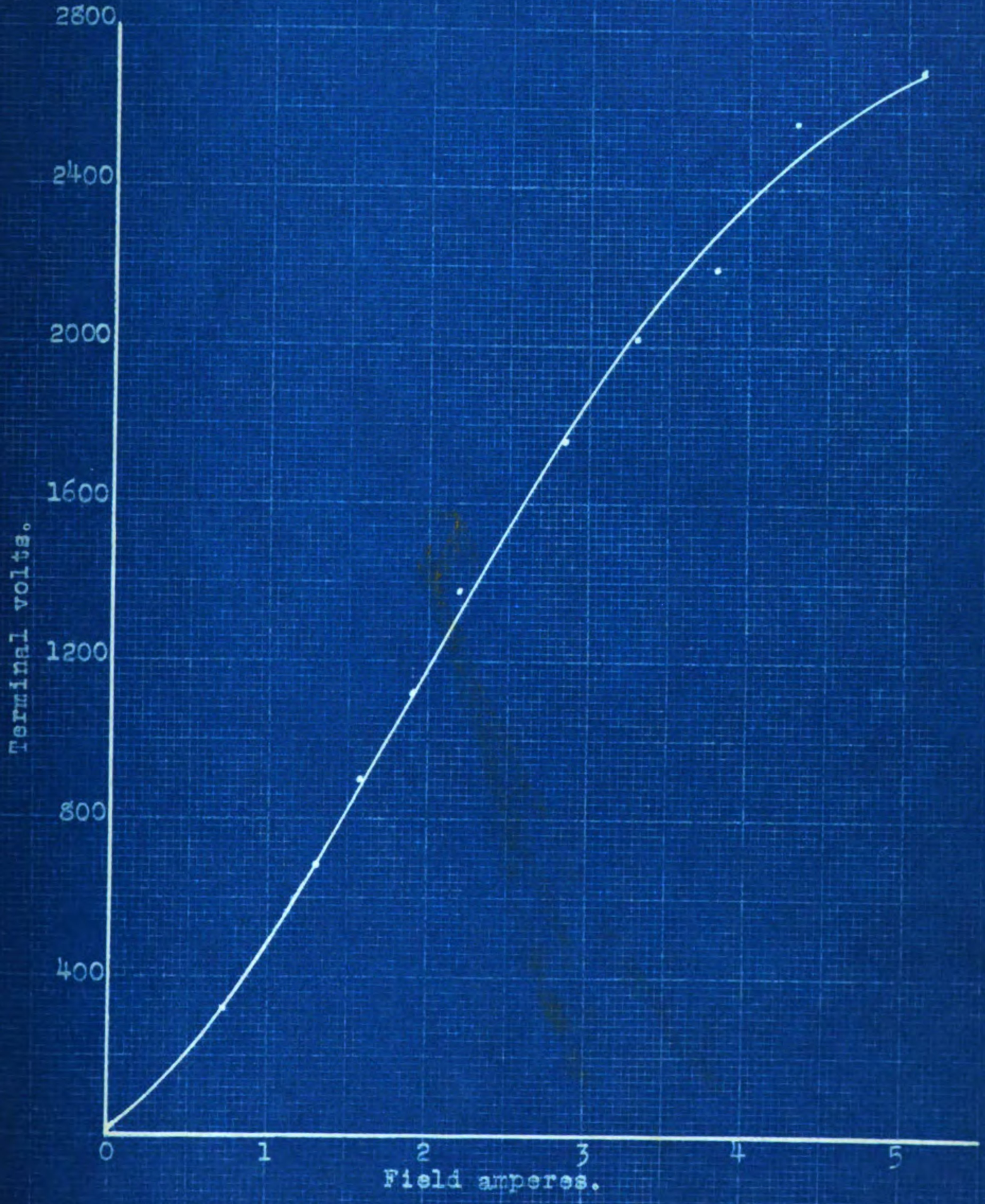
D.C. Generator No. 434701.

Terminal Volts.	Field Current.	Terminal Volts.	Field Current.
2700	5.1	1380	2.3
2570	4.3	1120	1.9
2200	3.8	900	1.57
2020	3.3	620	1.3
1760	2.85	320	.7
		16	.00


No-load saturation.
o D.C. Generator No. 433851
* D.C. Generator No. 433850
140
120
100
80
60
40
20
0
Terminal volts.
.4
.8
1.2
1.6
2.0
Field amperes.

No-load saturation.

D.C. Generator No. 434701.



No load Saturation

of synchronous motor No. 674627.

Terminal Volts.	Field Current.
231.6	5.64
20[illegible].	4.74
1[illegible]9.6	4.3
17[illegible].2	4.
160.4	3.45
1[illegible].2	3.
1[illegible].	2.5
100.	2.
7[illegible].	1.5
56.	1.1
000.0	0.00

Short circuit test of synchronous motor No. 674627.

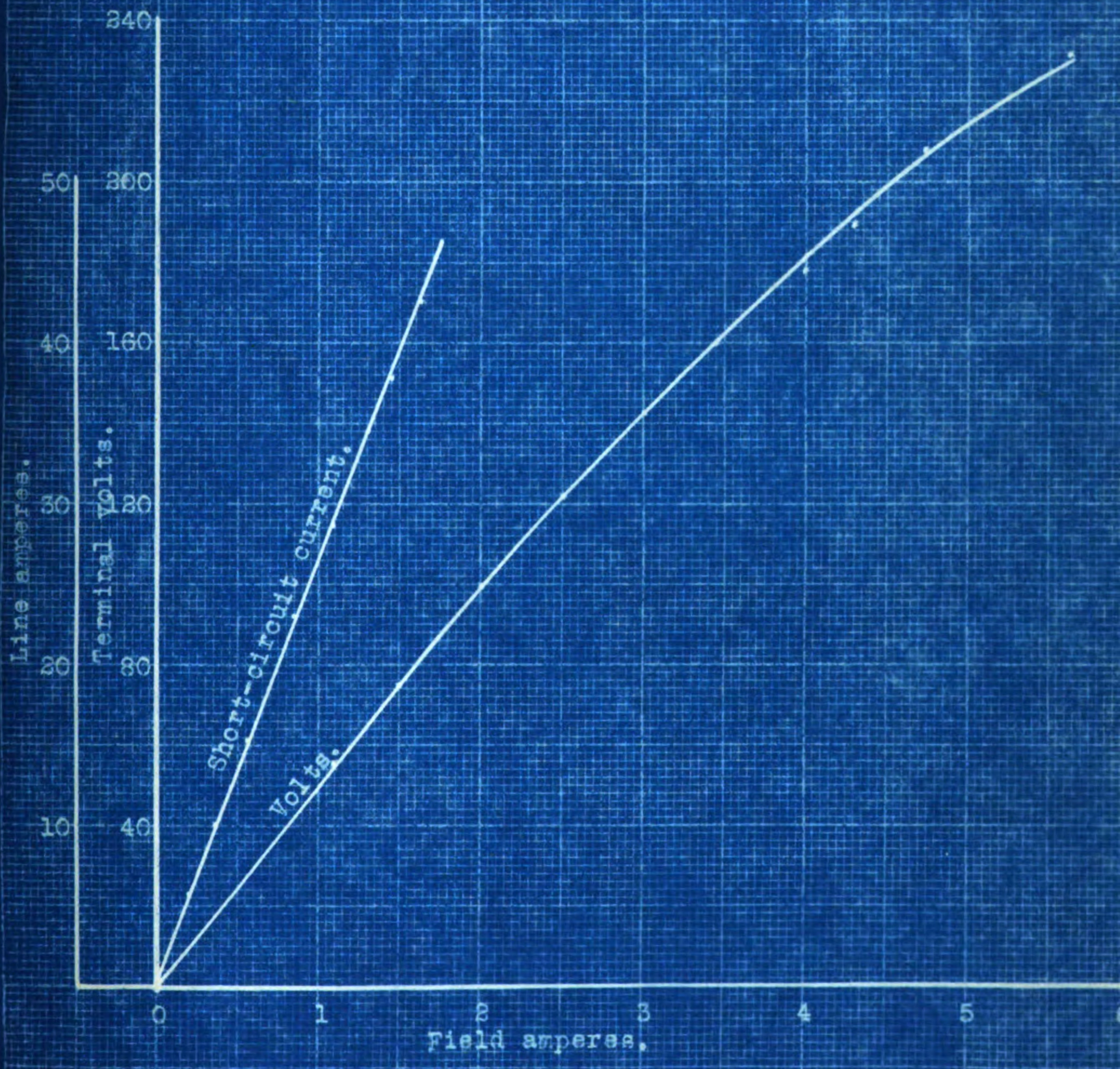
Line current.	Field current.
45.2	1.75
42.5	1.65
38.7	1.49
34.5	1.3
28.8	1.09
23.[illegible]	.85
15.4	.55
10.	.35
5.75	.2

No-load saturation

and

Short-circuit test.

Synchronous motor No. 684627



Load voltage test.

D. C. Generator No. 433850.

Series field shunted by entire shunt.

Terminal Volts.	Field Current.	Load Current.
122.5	1.63	22.2
123.5	1.64	20.
125.	1.645	19.
126.	1.65	18.
126.5	1.65	17.1
127.	1.66	16.
129.	1.68	14.
130.	1.69	13.2
130.05	1.7	11.9
131.	1.7	10.9
132.	1.71	9.5
133.	1.72	7.9
134.	1.73	5.3
134.5	1.74	2.9
134.5	1.74	1.6
134.5	1.74	0.00

Seri[illegible]

[illegible]

Pts.

122.

12[illegible]

127.

129.

131.

134.

137.

139

14[illegible]

1[illegible]

1[illegible]

Load voltage test.

D. C. Generator No. 433850.

Series field shunt tapped at center.

Terminal Volts.	Field Current.	Load Current.
122.	1.7	22.5
124.	1.725	20.75
127.	1.605	18.
129.	1.79	17.
131.5	1.815	15.
134.	1.85	13.2
137.	1.885	10.45
138.	1.91	7.95
142.	1.94	5.7
144.	1.96	3.
146.	2.00	0.00

Load voltage test.

D. C. Generator No. 433850.

Series field shunt removed.

Terminal Volts.	Field Current.	Load Current.
122.5	141	24.25
122.5	1.41	20.5
122.5	1.41	18.
122.5	1.41	16.1
122.	1.4	13.6
121.	1.39	11.6
118.	1.35	8.8
116.	1.32	6.8
109.	1.26	4.2
101.	1.18	2.
87.5	1.5	0.00

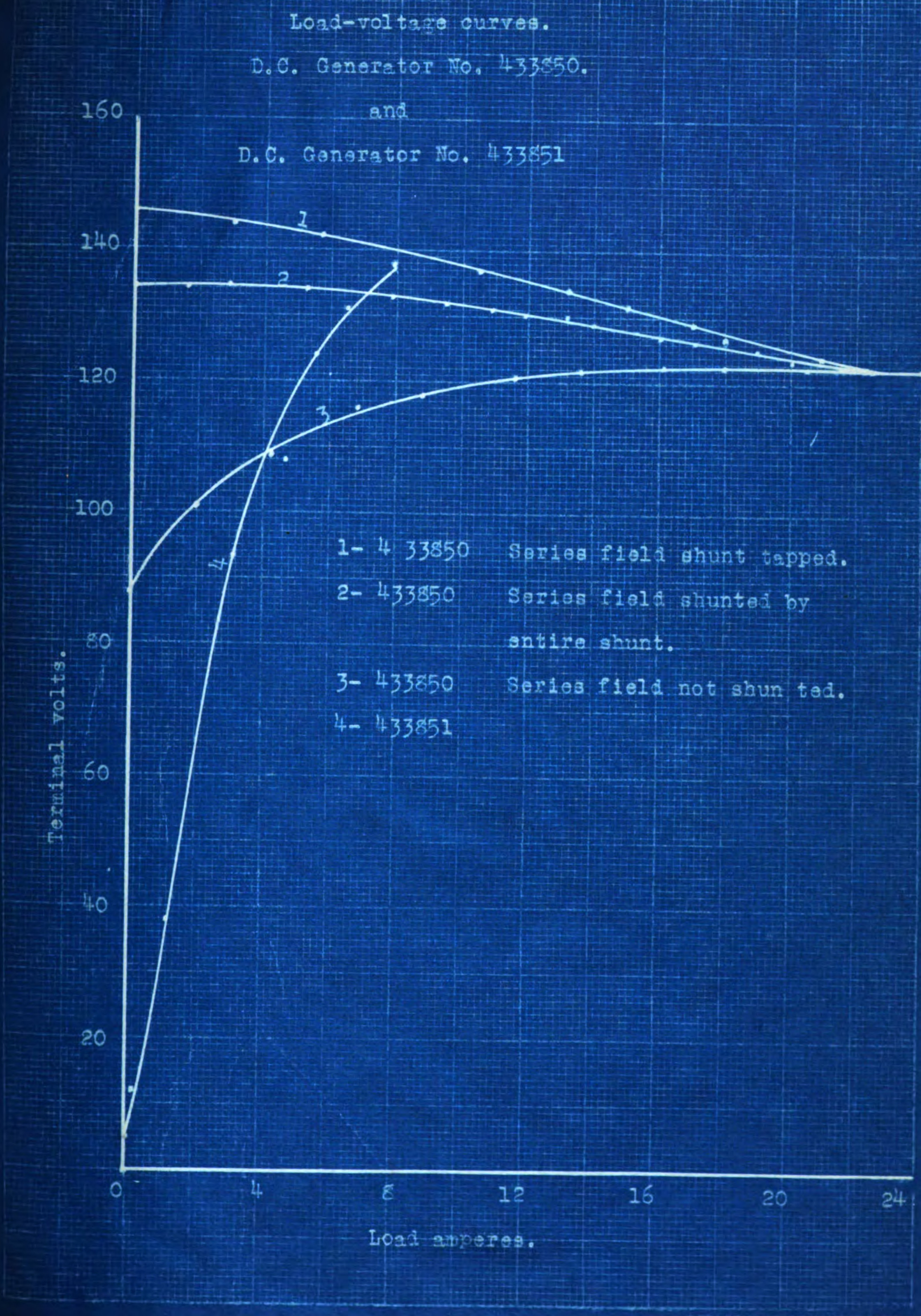
Load voltage tests.

D.C. Generator No. 434701.

Terminal Volts.	Load Current.
2380	7.1
2380	5.9
2440	4.95
2480	3.9 5
2520	2.95
2540	1.95
2500	1.5
2480	1.00
2460	.6
2320	0.00

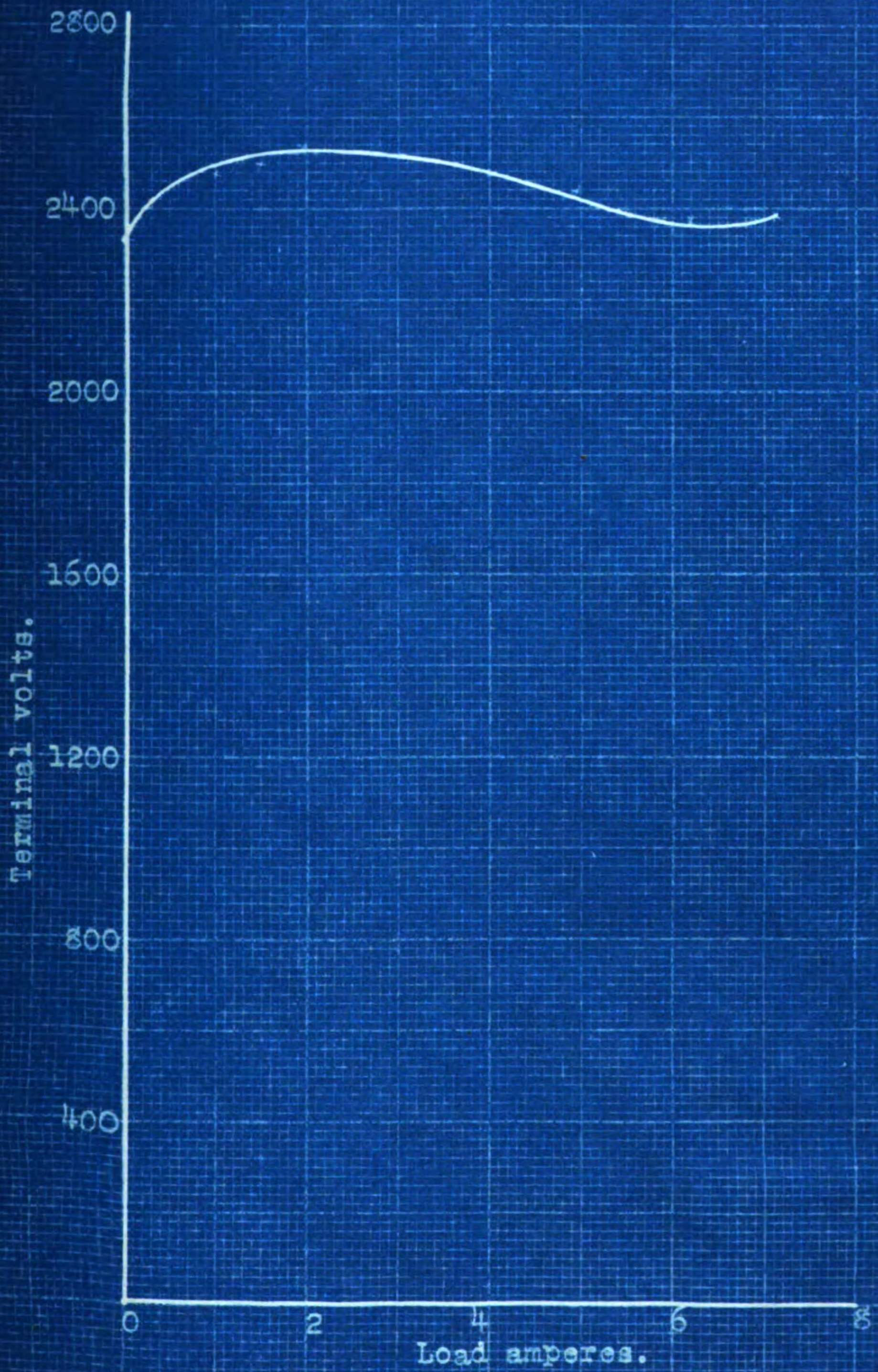
D.C. Generator No. 433851.

Terminal Volts.	Field Current.	Load Current
137	.22	7.95
131	.20	6.5
124	.19	5.6
108	.16	4.55
93	.14	3.15
38	.06	1.20
12	.01	.2
5	.005	0.00


Load-voltage curves.
D.C. Generator No. 433850.
and
D.C. Generator No. 433851
160
140
120
100
80
60
40
20
Terminal volts.
0
4
8
12
16
20
24
Load amperes.
1
2
3
4
1- 4 33850 Series field shunt tapped.
2- 433850 Series field shunted by entire shunt.
3- 433850 Series field not shun ted.
4- 433851

Load-voltage curve.

D.C. Generator No. 434701.



V-Curves for synchronous motor No. 654627.

Load No. 1.		Load No. 2.		Load No. 3.	
Line Current.	Field current.	Line current.	Field current.	Line current.	Field current.
47.	3.9	49.0	4.2	45.0	3.7
44.	4.0	43.0	5.0	42.5	3.8
42.0	4.1	41.0	6.2	31.0	4.4
38.0	4.3	44.0	6.8	6.0	5.7
30.0	4.9	47.0	7.4	13.5	6.5
25.0	6.4			22.0	7.1
30.0	7.0			38.0	8.0
39.0	7.5			43.0	8.4
44.0	7.9				

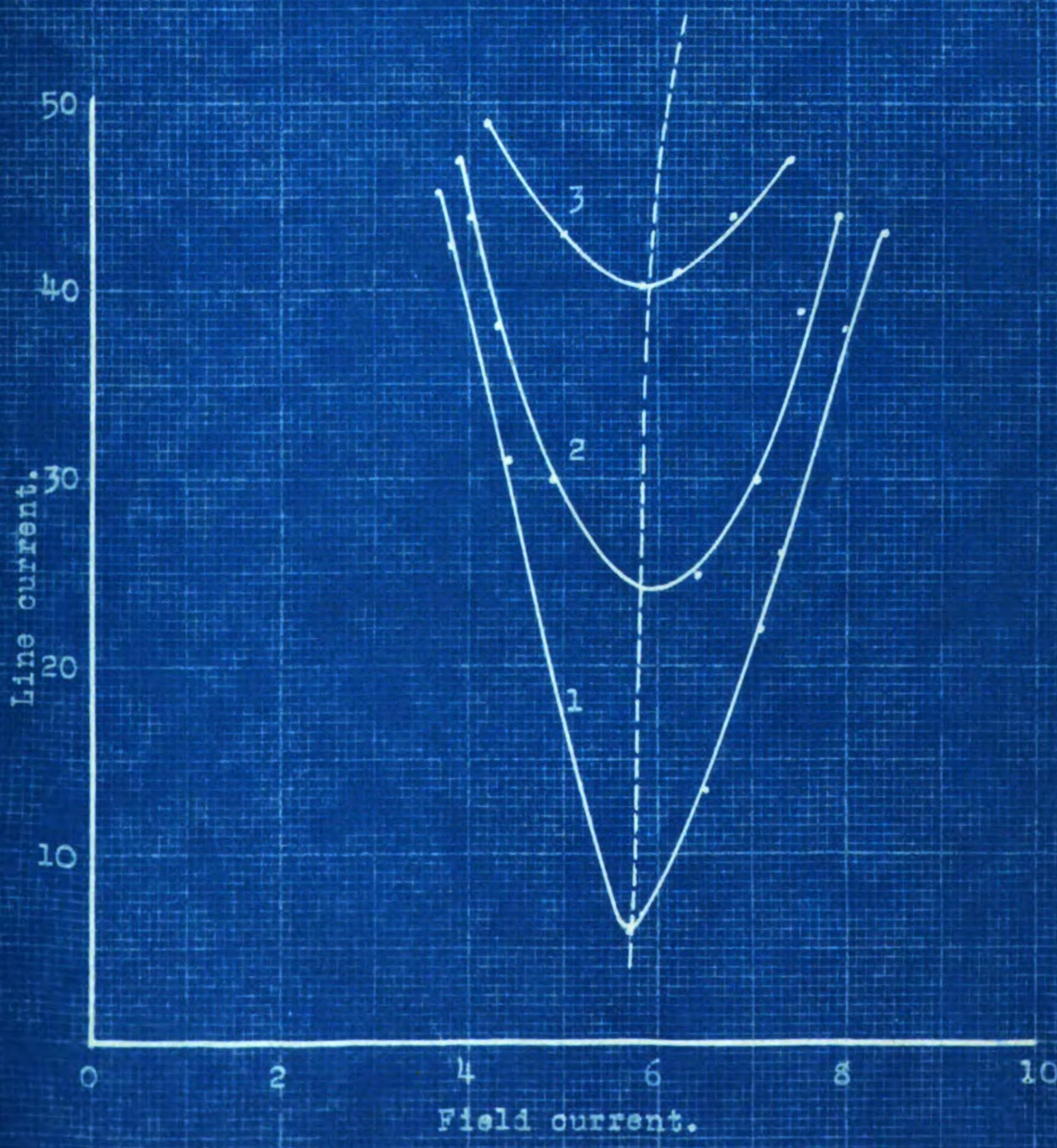
V-Curves.

Synchronous motor No. 684627.

1-No load

2-medium load.

3-overload.



[illegible]

D. C. [illegible]

	Field I=0 Brushes down Power = 625w R.P.M. = 820	Field I-0 Brushes up Power - 670w R.P.M. = 970	Field I - 1.7 Brushes down Power - 850w R.P.M. - 990
Time Sec.	R.P.M.	R. P. M.	R.P.M.
0	1260	1285	1365
5	1205	1240	1320
10	1160	1200	1270
15	1115	1155	1215
20	1070	1110	1165
25	1025	1070	1120
30	980	1030	1065
35	930	990	1020
40	890	955	970
45	840	915	925
50	800	880	880
55	760	845	840
60	720	810	790
65	680	775	750
70	645	740	710
75	610	705	680
80	575	680	640
85	540	645	605
90	505	620	565
95	470	590	530

Retardation on No. 433850. Cont.

Time Sec.	R. P. M.	R. P. M.	R. P. M.
100	440	560	495
105	410	535	460
110	375	510	425
115	350	480	395
120	315	455	365
125	290	430	335
130	260	400	305
135	230	375	275
140	205	350	245
145	180	325	215
150	150	305	190
155	125	280	160
160	100	255	130
165	75	235	100
170		215	70
175		195	
180		175	
185		150	
190		130	
195		110	
200		90	

Retardation on No. 433850. Cont.

Time Sec.	Field I-1.5 Brushes down. Power-860w R.P.M.-1010 R.P.M.	Field I-1.3 Brushes down. Power -900w R.P.M.- R.P.M.	Field I-1.1 Brushes down. Power -690w R.P.M.-900 R.P.M.	Field I-.9 Brushes down. Power -820w R.P.M.-962 R.P.M.
0	1300	1275	1330	1285
5	1245	1220	1280	1235
10	1200	1170	1230	1185
15	1150	1125	1180	1140
20	1100	1080	1135	1095
25	1050	1035		1045
30	1005	990	1035	995
35	960	940	990	950
40	915	900	950	910
45	870	860	905	865
50	830	810	860	825
55	785	770	810	780
60	745	730	770	740
65	700	690	730	705
70	670	655	700	670
75	630	620	665	635
80	595	585	630	600
85	560	550	590	560
90	525	510	550	530
95	490	480	515	495
100	450	445	480	460
105	420	410	450	430
110	390	380	420	400

Retardation of No. 433850. Cont.

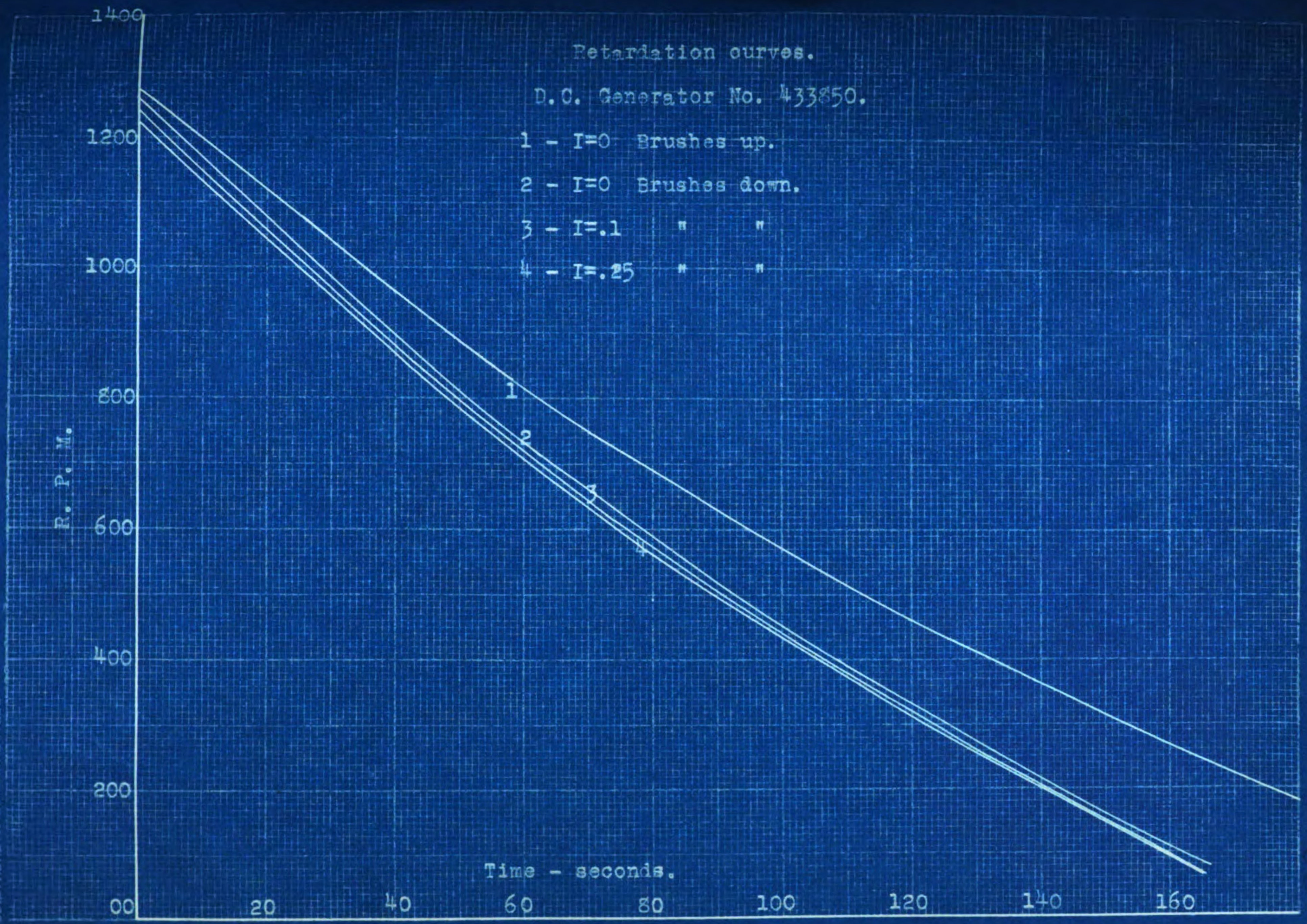
Time Sec.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
115	355	350	385	370
120	320	320	355	340
125	300	290	325	310
130	265	255	300	280
135	235	230	270	250
140	210	205	240	220
145		175	210	195
150	155	150	185	165
155	130	125	160	140
160	100	95	130	110
165	75		105	85
170			80	50
175				
180				
185				
190				

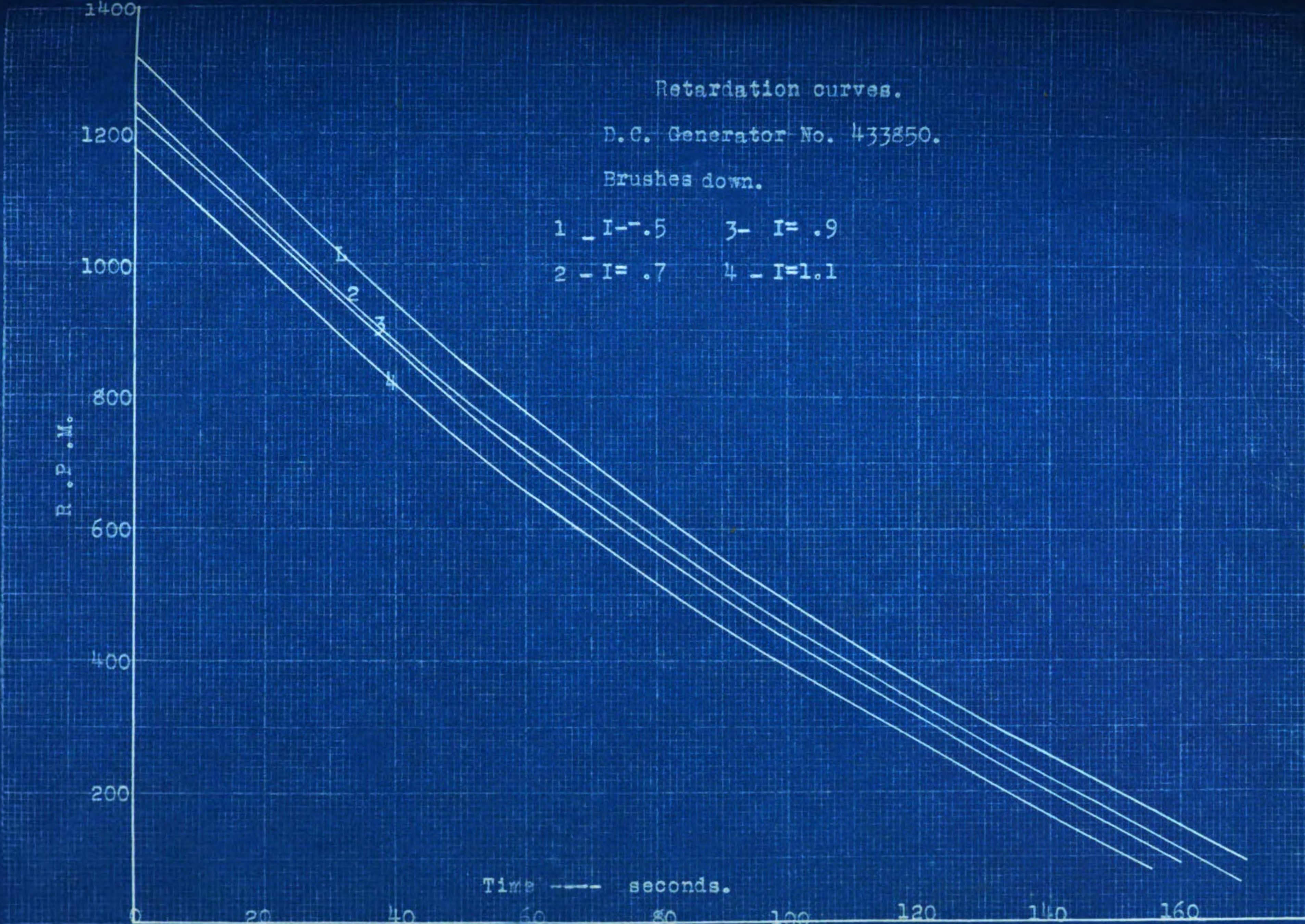
Retardation on No. 433850. Cont.

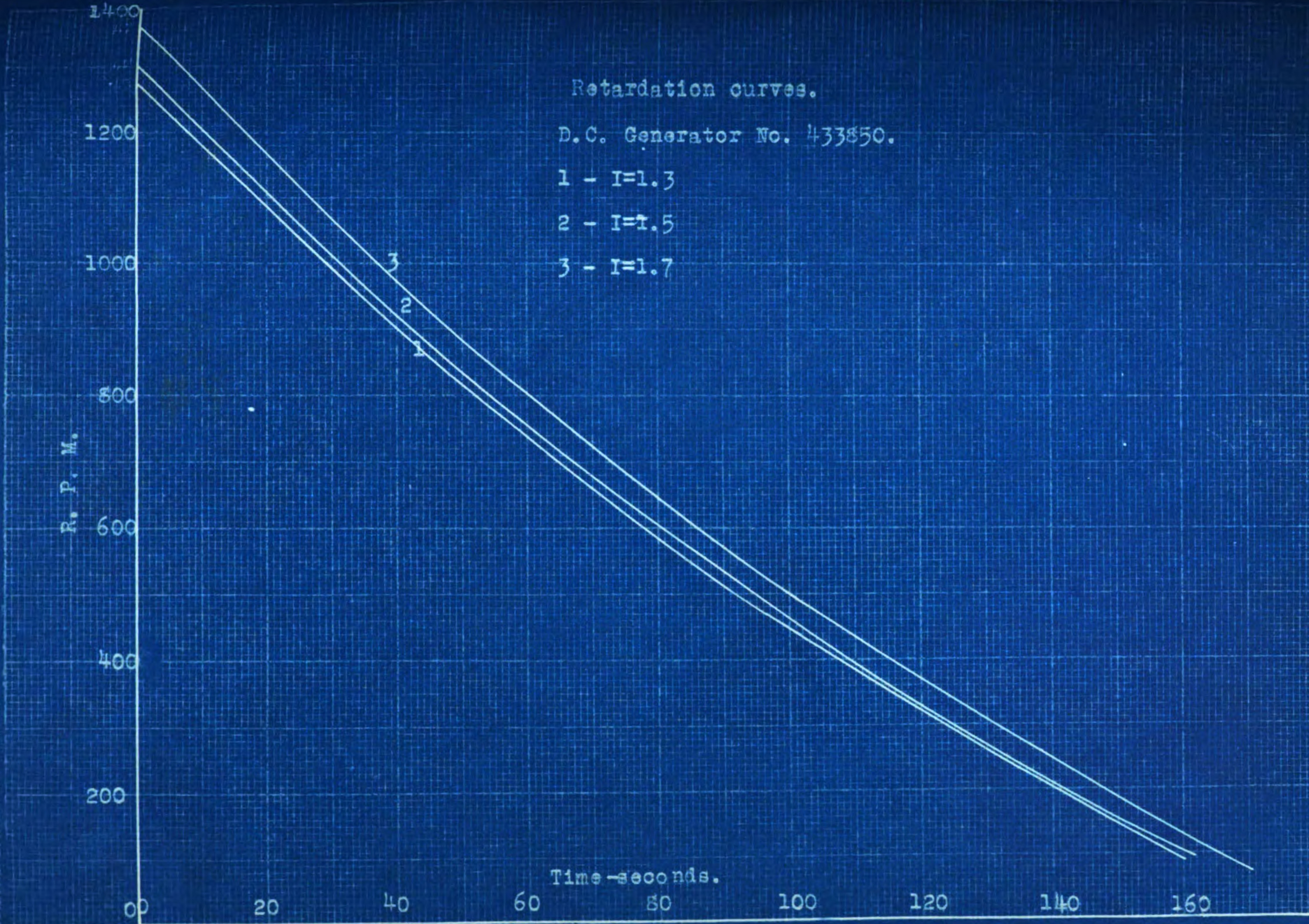
Time Sec.	Field I-.7 Brushes down. Power -810w R.P.M.- 990 R.P.M.	Field I -.5 Brushes down. Power -865w R.P.M. -840 R.P.M.	Field I-.25 Brushes down. Power - 785w. R.P.M.-880 R.P.M.	Field I-.1 Brushes down. Power - 590w. R.P.M.- 815 R.P.M.
0	1250	1320	1275	1250
5	1200	1270	1225	1205
10	1150	1225	1180	1160
15	1110	1180	1135	1115
20	1060	1130	1090	1070
25	1015	1085	1040	1020
30	970	1030	995	975
35	925	985	950	930
40	880	940	905	890
45	840	895	865	835
50	800	850	825	795
55	765	815	780	760
60	725	770	740	715
65	690	735	700	675
70	655	695	665	640
75	620	655	630	600
80	585	625	600	570
85	550	590	560	530
90	515	550	525	500
95	485	520	490	465
100	450	480	460	430

Retardation on No. 433850. Cont.

Time Sec.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
105	420	450	430	400
110	390	420	400	370
115	360	395	370	340
120	330	365	340	310
125	300	335	310	280
130	270	305	280	250
135	245	275	250	220
140	215	245	230	200
145	190	220	200	170
150	160	190	175	140
155	135	165	150	120
160	100	140	120	90
165	80	115	95	65
170		90		

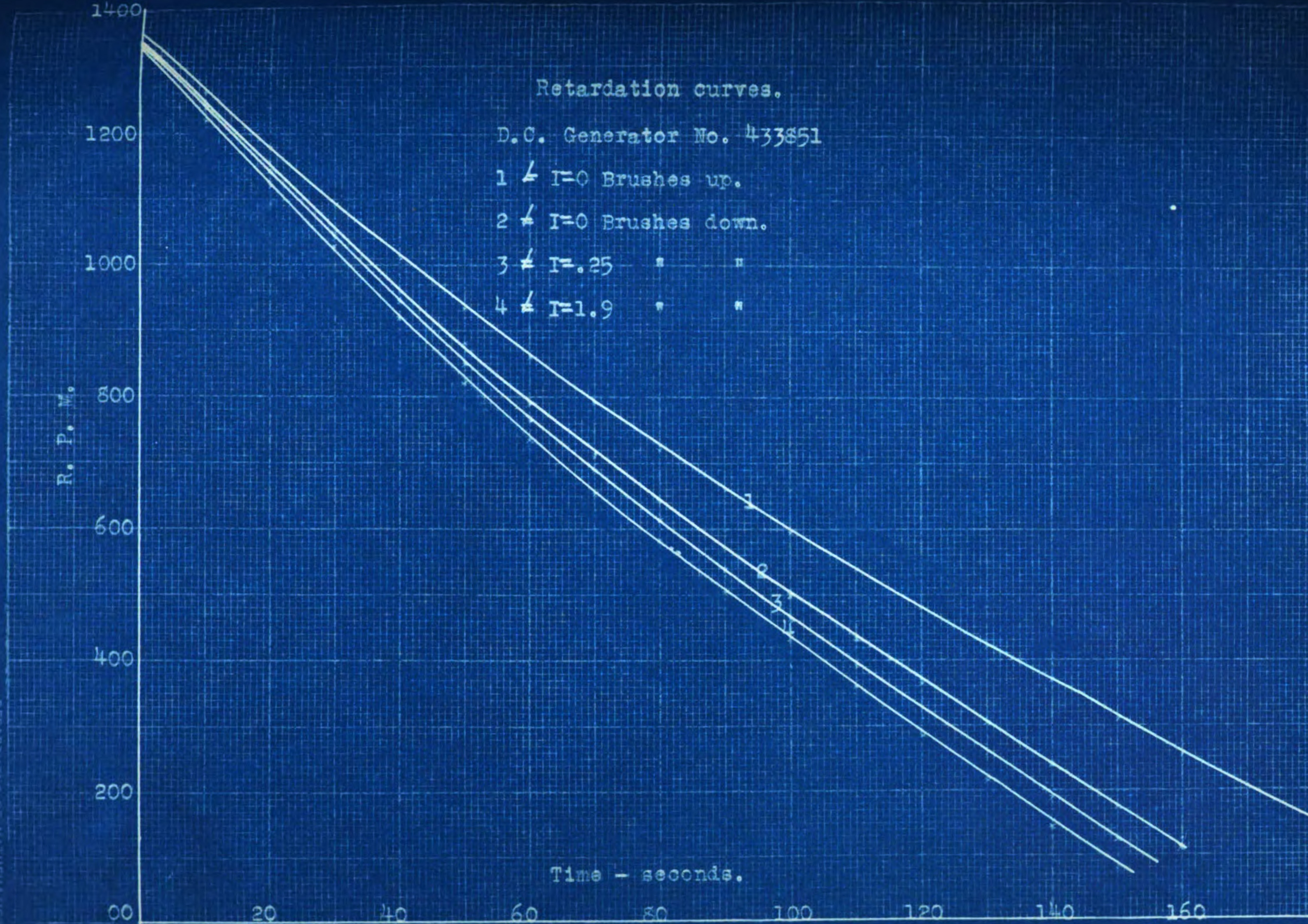

Retardation curves.
D.C. Generator No. 433850.
1 - I=0 Brushes up.
2 - I=0 Brushes down.
3 - I=.1 " "
4 - I=.25 " "
R. P. M.
1400
1200
1000
800
600
400
200
00
20
40
60
80
100
120
140
160
Time - seconds.
1
2
3
4


Retardation curves.
D.C. Generator No. 433850.
Brushes down.
1 _ I-‾.5   3- I= .9
2 - I= .7   4 _ I=1.1
1
2
3
4
R.P.M.
1400
1200
1000
800
600
400
200
Time ---- seconds.
0
20
40
60
80
100
120
140
160


Retardation curves.
D.C. Generator No. 433850.
1 - I=1.3
2 - I=1.5
3 - I=1.7
R. P. M.
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
Time-seconds.
3
2
1

Retardation test on No. 433851.

Time Sec.	Field I-0 Brushes up. Power-610w. R.P.M.-1000 R.P.M.	Field I-0 Brushes down. Power -702.5w. R.P.M.-9[illegible]0 R.P.M.	Field I-.25 Brushes down. Power-7[illegible]w. R.P.M.-1030 R.P.M.	Field I-1.9 Brushes down. Power -7[illegible]w. R.P.M.-1025 R.P.M.
0	1355	1340	1290	1275
10	1265	1240	1190	1175
20	1180	1145	1095	1065
30	1095	1050	990	970
40	1010	960	900	870
50	935	880	805	720
60	860	790	730	690
70	790	715	650	620
80	720	645	575	545
90	650	570	495	465
100	595	500	430	390
110	540	430	355	320
120	480	365	290	250
130	420	305	220	180
140	370	240	155	100
150	310	175	80	
160	255	110		
170	205			
180	155			
190	105			


Retardation curves.
D.C. Generator No. 433851
1 ∠ I=0 Brushes up.
2 ∠ I=0 Brushes down.
3 ∠ I=.25 " "
4 ∠ I=1.9 " "
R. P. M.
1400
1200
1000
800
600
400
200
00
20
40
60
80
100
120
140
160
Time - seconds.
1
2
3
4

Retardation on No. 434701.

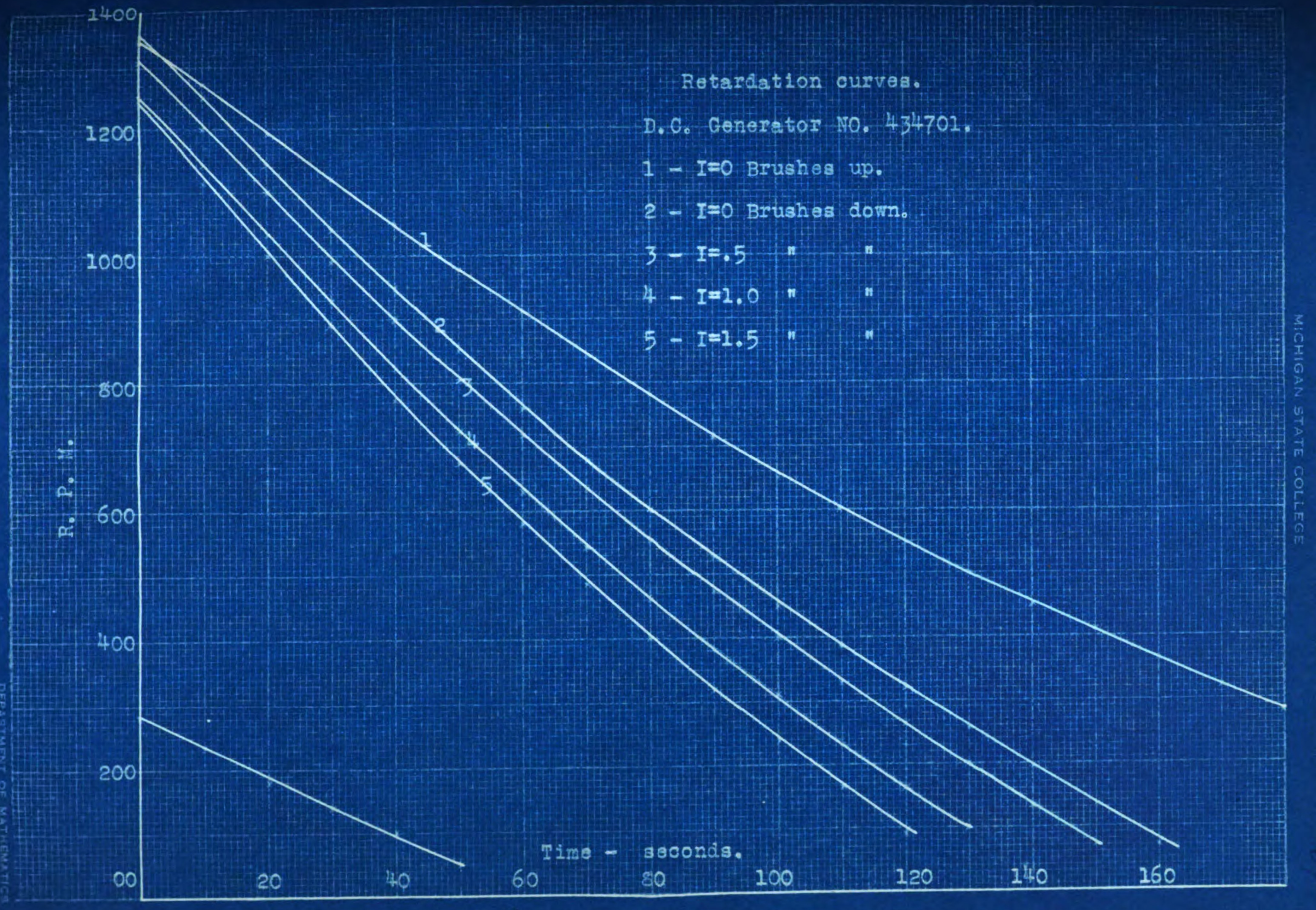
Time Sec.	Field I-0 Brushes up. Power-453w. R.P.M.-1005 R.P.M.	Field I-0 Brushes down. Power-670w. R.P.M.-965 R.P.M.	Field I-.5 Brushes down. Power-855w. R.P.M.-1060. R.P.M.	Field I-1 Brushes down. Power-904w. R.P.M.-1028. R.P.M.
0	1345	1355	1310	1250
10	1270	1250	1200	1145
20	1190	1145	1100	1035
30	1120	1040	990	930
40	1050	950	900	825
50	980	850	805	725
60	910	760	720	630
70	845	680	635	545
80	780	600	555	460
90	715	525	475	385
100	650	450	400	310
110	600	385	330	235
120	550	320	265	165
130	500	255	200	100
140	450	195	135	
150	410	135	70	
160	365	70		
170	320			
180	280			
190	235			
200	180			
210	140			
220	100			

Retardation on No. 434701. Cont.

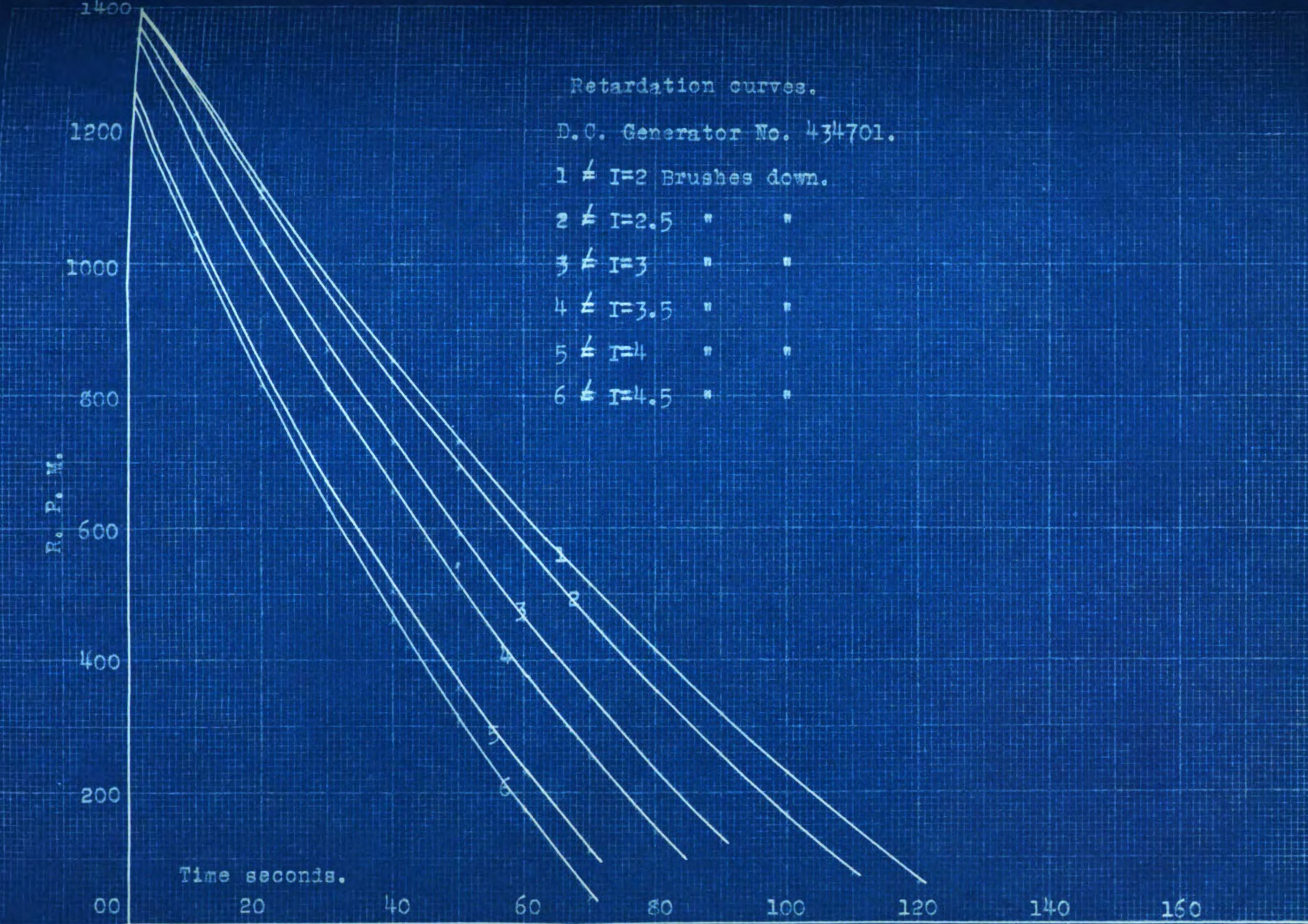
Time Sec.	Field I-1.5 Brushes down. Power-1000w. R.P.M.-1012 R.P.M.	Field I-2 Brushes down. Power-1215w. R.P.M.-1025 R.P.M.	Field I-2.5 Brushes down. Power-1265w. R.P.M. 992 R.P.M.	Field I-3 Brushes down. Power-1[illegible]85w. R.P.M.-9[illegible]5. R.P.M.
0	1240	1400	1390	1360
10	1115	1250	1250	1200
20	1000	1110	1100	1030
30	890	980	960	870
40	775	855	820	730
50	675	730	690	590
60	580	625	575	465
70	485	515	460	345
80	400	415	355	235
90	320	320	260	130
100	240	230	170	
110	165	150	75	
120	90	65		
130				

Retardation on No. 434701. cont.

Time Sec.	Field I-3.5 Brushes down. Power-1630w. R.P.M. 985 R.P.M.	Field I-4 Brushes down. Power-1890w. R.P.M.-1010 R.P.M.	Field I-4.5 Brushes down. Power-2070w. R.P.M.-1020 R.P.M.
0	1340	1250	1240
10	1160	1045	1020
20	980	850	815
30	810	670	630
40	655	505	460
50	510	306	310
60	380	230	175
70	255	110	40
80	140		



Retardation curves.
D.C. Generator NO. 434701.
1 - I=0 Brushes up.
2 - I=0 Brushes down.
3 - I=.5 " "
4 - I=1.0 " "
5 - I=1.5 " "
1
2
3
4
5
R. P. M.
1400
1200
1000
800
600
400
200
00
20
40
60
80
100
120
140
160
Time - seconds.
MICHIGAN STATE COLLEGE
DEPARTMENT OF MATHEMATICS


Retardation curves.
D.C. Generator No. 434701.
1 ≠ I=2 Brushes down.
2 ≠ I=2.5 " "
3 ≠ I=3 " "
4 ≠ I=3.5 " "
5 ≠ I=4 " "
6 ≠ I=4.5 " "
R. P. M.
1400
1200
1000
800
600
400
200
00
Time seconds.
20
40
60
80
100
120
140
160
1
2
3
4
5
6

Retardation test on No. 584627.

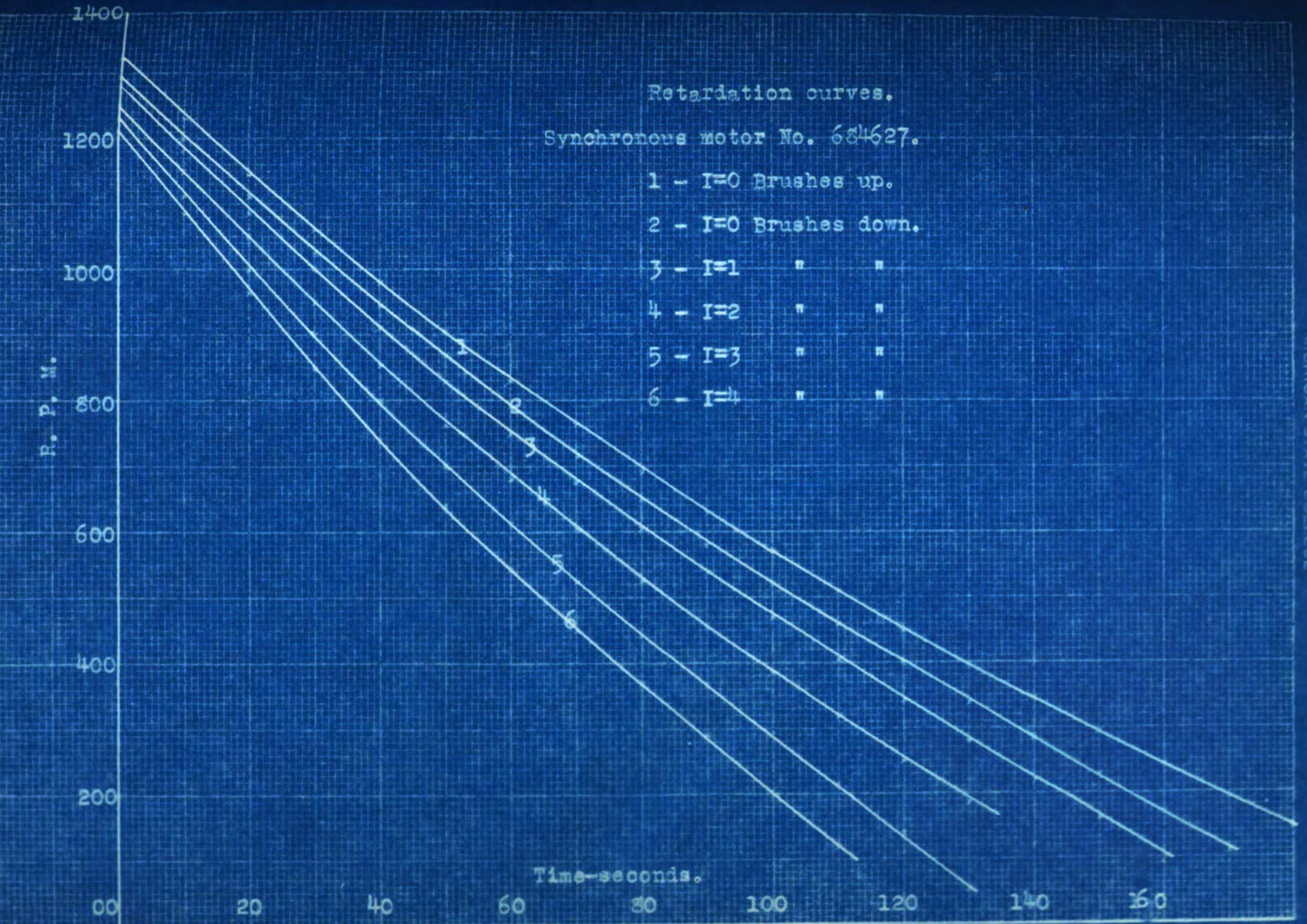
Time Sec.	Field I-0 Brushes up. Power-533w. R.P.M.-920	Field I-0 Brushes down. Power-465w. R.P.M.890	Field I-1 Brushes down. Power-675w. R.P.M.-950	Field I-2 Brushed down. Power-652w. R.P.M.-910
	R.P.M.	R.P.M.	R.P.M.	R.P.M.
0	1325	1295	1280	1250
10	1230	1200	1180	1150
20	1145	1110	1085	1050
30	1060	1025	1000	950
40	980	945	910	855
50	905	870	830	765
60	830	790	750	680
70	765	715	675	605
80	690	650	605	525
90	630	580	540	455
100	570	520	470	385
110	510	460	405	320
120	450	400	345	250
130	400	340	280	185
140	345	285	220	120
150	295	230	160	
160	245	170	95	
170	190	110		
180	145			
190	95			

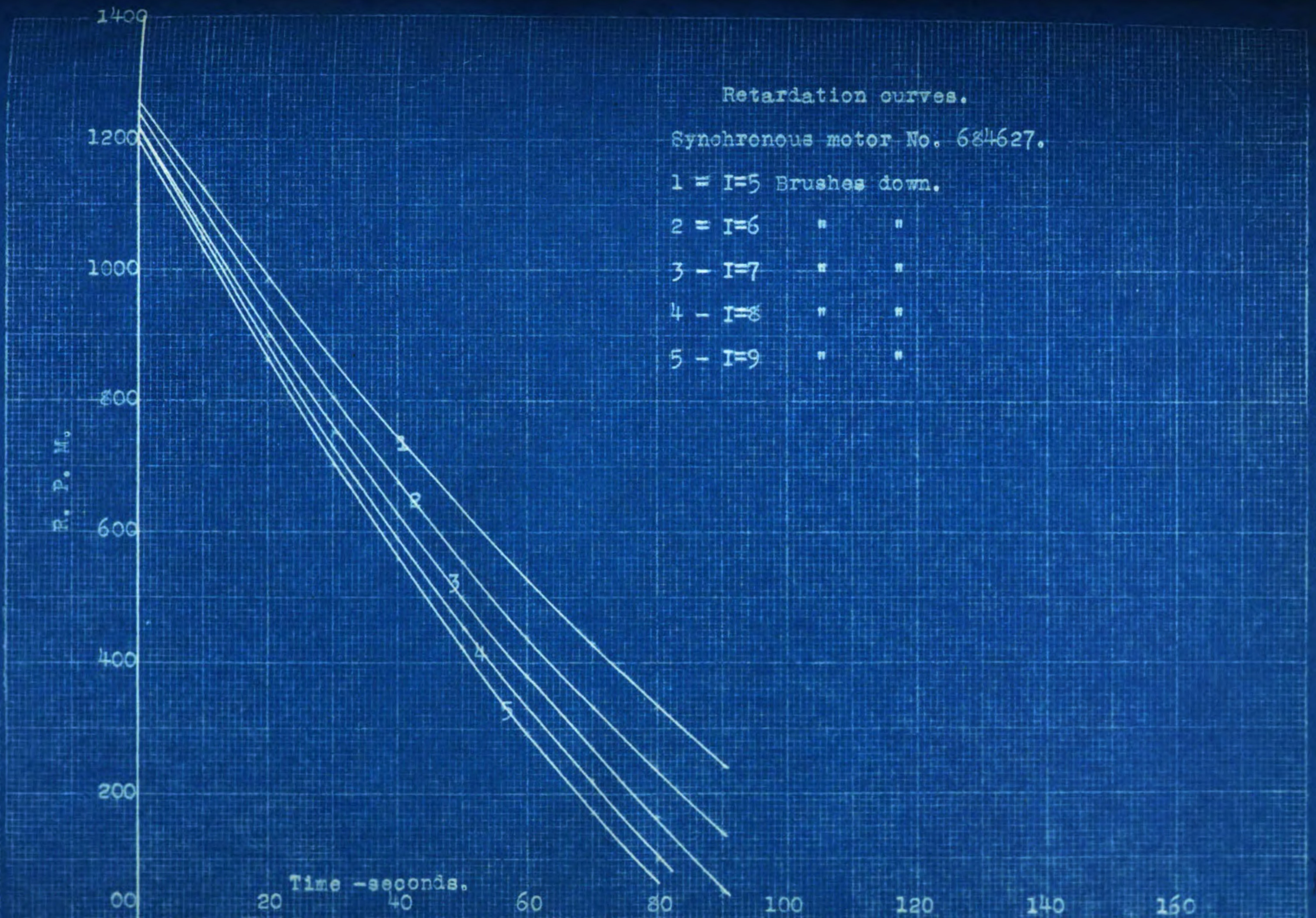
Retardation test on No. 684627. Cont.

Time Sec.	Field I-3 Brushes down. Power-914w. R.P.M.-1000 R.P.M.	Field I-4 Brushes down. Power-995w. R.P.M.-960 R.P.M.	Field I-5 Brushes down. Power-1305w. R.P.M.-1015 R.P.M.	Field I-6 Brushes down. Power-1190w. R.P.M.-935 R.P.M.
0	1230	1210	1260	1240
10	1110	1085	1125	1090
20	1000	965	985	945
30	900	850	860	805
40	800	740	740	675
50	700	640	630	555
60	615	545	525	440
70	525	450	430	335
80	445	370	335	240
90	365	290	240	140
100	290	200	150	
110	215	120		
120	140			
130	55			

Retardation test on No. 634627. Cont.

Time Sec.	Field I-7 Brushes down. Power-1415w. R.P.M.-930 R.P.M.	Field I-8 Brushes down. Power-1360w. R.P.M.-905 R.P.M.	Field I-9 Brushes down. Power-1[illegible]15w. R.P.M.-1015 R.P.M.
0	1220	1220	1200
10	1050	1050	1030
20	900	890	865
30	755	730	705
40	625	590	560
50	500	455	425
60	380	335	295
70	270	2[illegible]0	175
80	165	100	
90	50		
100			


Retardation curves.
Synchronous motor No. 684627.
1 - I=0 Brushes up.
2 - I=0 Brushes down.
3 - I=1 " "
4 - I=2 " "
5 - I=3 " "
6 - I=4 " "
R. P. M.
1400
1200
1000
800
600
400
200
00
20
40
60
80
100
120
140
160
Time-seconds.
1
2
3
4
5
6


Retardation curves.
Synchronous motor No. 684627.
1 = I=5 Brushes down.
2 = I=6 " "
3 - I=7 " "
4 - I=8 " "
5 - I=9 " "
R. P. M.
Time -seconds.
1400
1200
1000
800
600
400
200
00
20
40
60
80
100
120
140
160
1
2
3
4
5

TABULATED RESULTS.

PERCENT VOLTAGE REGULATION.

On D. C. Generator No. 434701.

Full Load (7.4) = -3.3

$\frac{3}{4}$ Load = -3.93

$\frac{1}{2}$ Load = -7.3

On D. C. Exciter No. 433851.

Full Load (8 amps) = -96.4

$\frac{3}{4}$ Load = -98.2

$\frac{1}{2}$ Load = -95.5

On D. C. Exciter No. 433850.

1. With compounding shunt disconnected.

Full Load (13 amps) = -38.3

$\frac{3}{4}$ Load = -38.3

$\frac{1}{2}$ Load = -35.9

2. With compounding shunt tapped at midpoint.

Full Load = 10.65

$\frac{3}{4}$ Load = 8.95

$\frac{1}{2}$ Load = 5.04

3. With compounding shunt

Full Load = 9.84

$\frac{3}{4}$ Load = 3.[illegible]8

$\frac{1}{2}$ Load = 1.49

CALCULATION OF SYNCHRONOUS REACTANCE

From the curve sheet showing the no-load saturation curve and the short circuit curve of the synchronous motor, take the short circuit current and the open circuit voltage corresponding to the largest field excitation used on short circuit.

Since this is a Y connected machine the phase voltage equals the terminal voltage divided by $\sqrt{3}$. The largest field excitation used is 1.75. With this excitation the short circuit current is 46.5 and the phase voltage is $\frac{87}{\sqrt{3}} = 50.4$. Then Z_s or synchronous reactance

$$= \frac{50.4}{46.5} = 1.085 \text{ per phase.}$$

$$r_e = .063$$

$$\text{Since } X_s = \sqrt{Z_s^2 - r_e^2}$$

$$\text{Then } X_s = \sqrt{(1.085)^2 - (.063)^2}$$

$$= 1.084$$

Losses of D.C. Generator No. 433850.

Series field shunt tapped.

I_1=	18	13.5	9
I_f-	1.58	1.72	1.86
E_t-	127	133	139
	Watts	Watts	Watts
Series field	39.2	22.2	9.8
Armature	167.5	95.3	42.
Windage & bearing	90.	90.	90.
Brush	140.	140.	140.
Shunt field	114	135	158
Core loss	240	290	320
Total	790.7	772.5	759.8

Series field shunted by entire shunt.

I_1	18	13.5	9
I_f	1.54	1.62	1.68
E_t	125.5	129	132
	Watts	Watts	Watts
Series field	39.2	22.2	9.8
Armature	167.5	95.3	42
Windage & bearing	140	140	140
Brush	90	90	90
Shunt field	108.5	120	129
Core loss	230	260	280
Total	774.2	727.5	690.8

Losses of D. C. Generator No. 433850.

Series field not shunted.

I_1	18	13.5	9
I_f	1.5	1.48	1.42
E_t	125.5	129	132
	Watts	Watts	Watts
Shunt field	102	100	92.2
Series field	39.2	22.2	9.8
Armature	167.5	95.3	42
Windage & bear	90	90	90
Brushes	140	140	140
Core loss	220	210	200
Total	758.7	657.5	574.0

Losses of D. C. Generator No. 433851.

Series field not shunted.

I_1	8	6	4
I_f	1.8	1.58	1.2
E_t	137.	127	108
	Watts	Watts	Watts
Shunt field	264	205	119
Series field	17	9.55	4.24
Armature	50.	18.7	8.32
Windage & Bear	90	90	90
Brushes	130	130	130
Core Loss	390	300	180
Total	941.	633.25	531.56

Losses of D. C. Generator No. 434701.

I_1	7.4	5.55	3.7
I_f	4.1	4	4.35
E_t	2400	2380	2475
	Watts	Watts	Watts
Shunt field	555	470	494
Series field	1087	2440	4340
Armature	103.5	233	414
Windage & bearing	210	210	210
Brush	675	675	675
Core loss	3100	3600	3700
Total	5730.5	7628	9833

Losses on Synchronous Motor No. 684627.

E_t	220	220	220
I_1	35	26.2	17.5
I_f	5.65	5.8	5.75
	Watts	Watts	Watts
Field /3	142	134	133
Armature /ϕ	77	44	19.2
Windage /3	70	70	70
Brush /3	27	27	27
Core loss /3	450	433	425
Total/ϕ	766	708	674

Percent efficiencies.

Generator No. 433850. Series field not shunted.

Efficiency at full load------------- 74.6

Efficiency at $\frac{3}{4}$ load-------------71.4

Efficiency at $\frac{1}{2}$ load------------- 64.8

Series field tapped at center.

Efficiency at full load------------- 74.5

Efficiency at $\frac{3}{4}$ load------------- 70.5

Efficiency at $\frac{1}{2}$ load------------- 63.2

Series field shunted by entire shunt.

Efficiency at full load------------- 74.5

Efficiency at $\frac{3}{4}$ load------------- 70.0

Efficiency at $\frac{1}{2}$ load------------- 59.6

Generator No. 433851.

Efficiency at full load------------- 53.8

Efficiency at $\frac{3}{4}$ load------------- 54.5

Efficiency at $\frac{1}{2}$ load------------- 45.0

Generator No. 434701.

Efficiency at full load------------- 64.4

Efficiency at $\frac{3}{4}$ load-------------63.2

Efficiency at $\frac{1}{2}$ load------------- 61.5

Synchronous motor No. 684627.

Efficiency at full load------------- 83.0

Efficiency at $\frac{3}{4}$ load------------- 78.8

Efficiency at $\frac{1}{2}$ load------------- 69.6

SAMPLE

COMPUTATIONS.

SAMPLE COMPUTATION FOR PER CENT VOLTAGE REGULATION

Per cent voltage regulation $= 100 \frac{V_o - V}{V}$ where V is the voltage of the load at which the regulation is desired while V_o is the terminal volts at no load.

In computing the per cent voltage regulation for each machine the load voltage curve for that respective machine is referred to. For example take the per cent regulation for the D. C. Generator No. 434701. From the load voltage curve the voltage at no load is 2320. At full load it is 2400.

Therefore % Reg. $= \frac{2320 - 2400}{2400} \times 100 = -3.3$

SAMPLE COMPUTATION FOR EFFICIENCY

Generator No. 433851.

From the load voltage curve for this machine find the voltage (137 volts) at full load (8 amps.). Refer to the no-load saturation curve and find the field current necessary to give this voltage (1.8 amps.). Refer to the loss-field current curve and determine the core loss, brush loss, windage and bearing loss, as follows:

Distance A is core loss of machine as stated on curve.

Distance B is the brush loss of machine as stated on curve.

Distance C is the sum of the brush losses on the other three machines.

Distance D. is the windage and bearing friction on the entire set.

Since it was impossible to separate these machines mechanically and determine the losses it will be assumed that the windage and bearing loss on No.s 433851 and 433850 is each 15% of the total, and that the windage and bearing loss on No.s 434701 and 684627 is each 35% of the total. Refer to the sheet of tabulated losses on machine No. 433851.

Shunt field loss $= I_f^2 R_f = 1.8^2 \times 81.5 = 264$ watts.

Series field loss $= I_s^2 R_s = 8^2 \times .265 = 17$ watts.

$I =$ line current + shunt field current $= I_s + I_f$.

$I_A = 8 + 1.8 = 9.8$

Armature loss $= I_A R_A = 9.8 \times .52 = 50$ watts.

Brush friction loss, from curve sheet = 130 watts.

Windage on entire set as described above is 600 watts.

Therefore windage loss on 43[illegible]51 as assumed above equals .15 x 600 = 90 watts.

Core loss from curve sheet = 390 watts.

Total loss is the sum of the above or 941 watts.

$$\%\ \text{efficiency} = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

$$= \frac{137 \times 8 \times 100}{137 \times 8 + 941} = \frac{1096}{2037} \times 100 -$$

$$= 53.8\%$$

SAMPLE COMPUTATION FOR EFFICIENCY

Synchronous Motor No. 6[illegible]4627.

From V- curves for synchronous motor determine the field current for full load at unity power factor.

Proceed as for the D. C. machine described above and determine the losses. Determine all losses per phase by dividing the curve reading by three.

$$\text{Then } \%\ \text{efficiency} = \frac{\text{input} - \text{losses}}{\text{input}} \times 100$$

$$= \frac{\frac{220 \times 35}{\sqrt{3}} - 766}{\frac{220}{\sqrt{3}} \times 35} \times 100$$

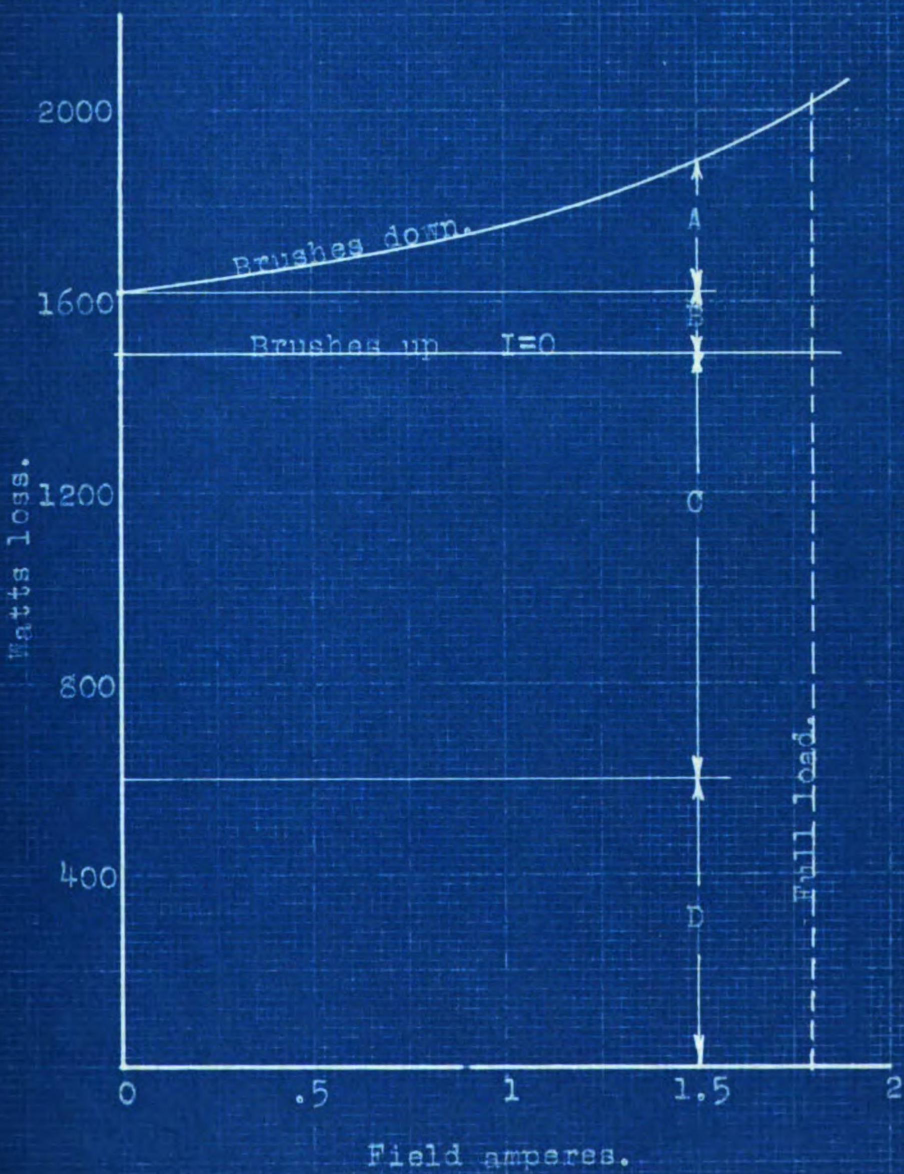
$$= 83\%$$

Loss--field current curves.

Generator No. 433251.

at

1200 r.p.m.

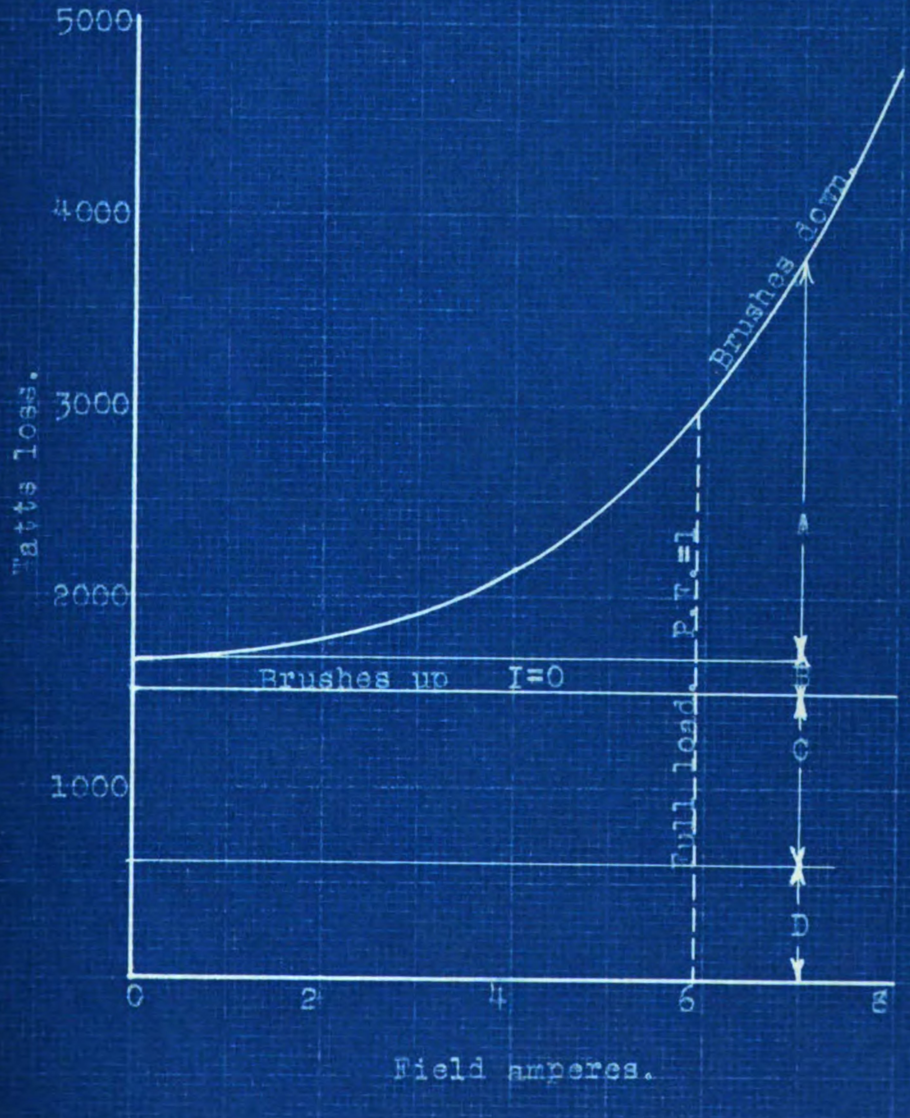


Loss--field current curves.

Synchronous motor No. 684627.

at

1200 r.p.m.



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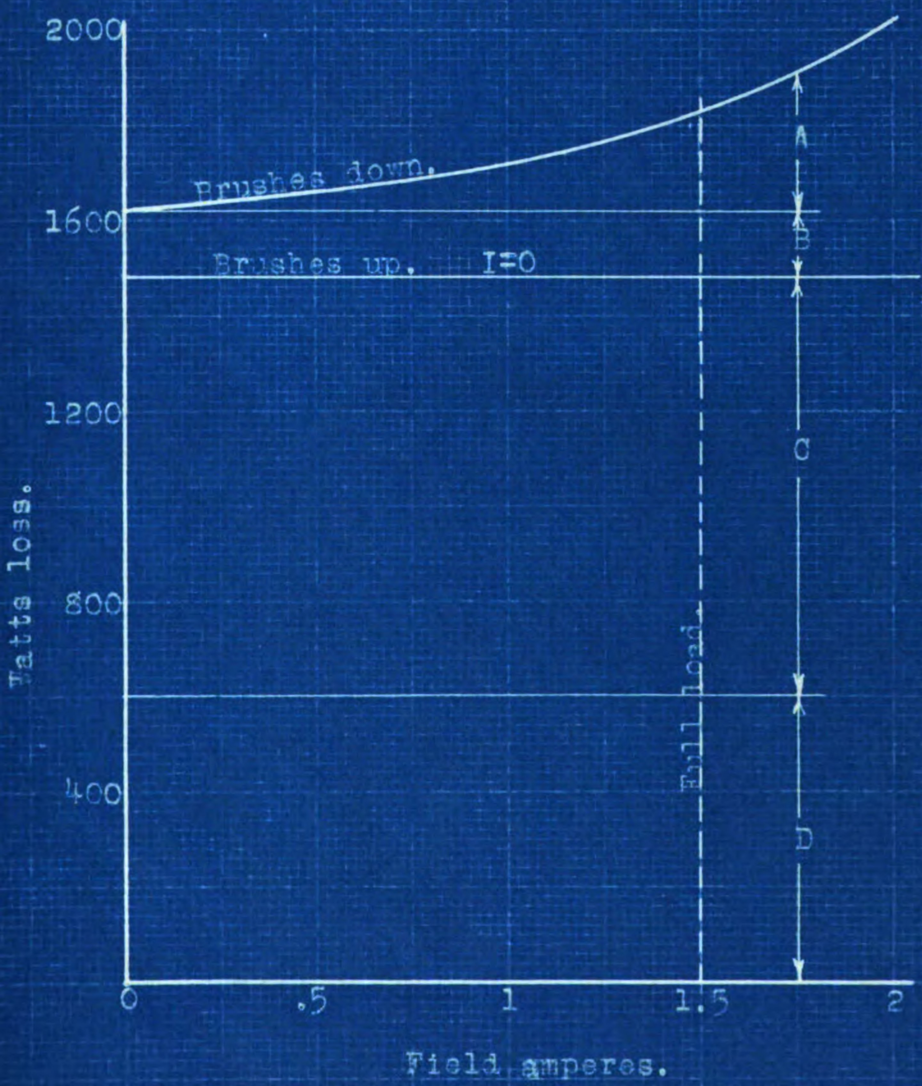
Loss curves.
Generator No. 433850.
at
1200 r.p.m.

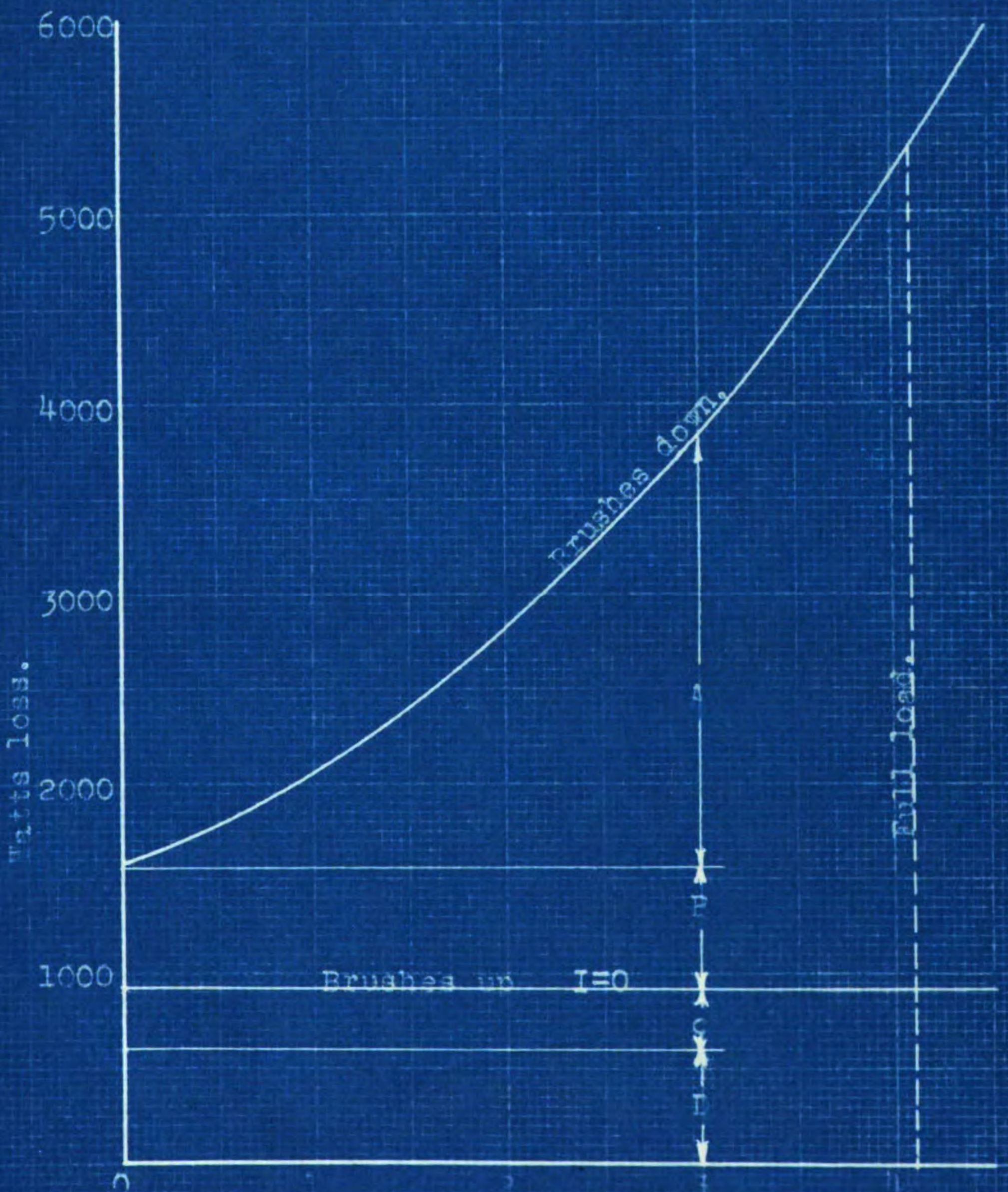


Loss--Field current curve.

Generator No. 434701.

at

1200 r.p.m.



CONCLUSION

One of the objects of this test was to determine the feasibility of accepting it if this same machine were being delivered to an industrial plant. Before making any conclusions or recommendations, the fact that the machine is not being operated in the way for which it was designed, must be considered. As mentioned before, the large D. C. motor is now being operated as a generator while the alternator is being operated as a synchronous motor.

From the tests run and the data taken the authors are of the opinion that this machine does not pass a satisfactory acceptance test. This conclusion is based on the following facts:

1. The efficiency of the individual machines are exceedingly low.

2. The synchronous motor has decided hunting characteristics.

3. The current rating of the 2400 volt D. C. Generator is excessive.

4. The current rating of the D. C. Exciter No. 433851 is excessive.

5. Exciter No. 433851 does not fulfil standards of the General Electric Co.

6. The synchronous motor does not have suitable characteristics for starting the set.

A more complete discussion of each of the above facts will aid in the understanding of them.

From an examination of the efficiencies obtained from the calculation it is seen that they are unusually low. The synchronous motor is the best machine in this respect, having maximum efficiency of 83% at full load. However, the other machines have efficiencies which are lower. For example, the 2400 volt D. C. Generator has a maximum efficiency of 64.4%. The D. C. Exciter No. 433350 has an efficiency of 74.6% at full load with the compounding shunt on the series field disconnected and has an efficiency of 74.8% at full load with the shunt connected, and with the shunt tapped at the mid point. Exciter No. 433351 has the lowest efficiency of any other machine of the set. Its maximum efficiency if 54.5% at $\frac{3}{4}$ load. This is partly due to the machine being of very small capacity and it would inherently have a lower efficiency.

During the tests the synchronous motor was found to have an exceedingly bad hunting characteristic. At times when the machine was heavily loaded, this characteristic was so pronounced that it greatly effected the obtaining of accurate readings on other parts of the test.

As the set is now being operated the current rating of 7.4 amperes on the 2400 D. C. Generator is excessive and causes the machine to operate at a temperature which would prove harmful in a very short time. If 7.4 amperes is carried by the series filed of the machine it will over heat to the extent that the impregnating compound will boil out of the insulation. This current does not effect the interpole winding or the armature but does have a decided effect on the field circuit as mentioned.

The present rating of the D. C. exciter No. 433851 causes a rise in temperature which would be detrimental to the insulation if the full load current of 18 amperes were carried for more than 4 minutes. Evidently this machine has been rewound, to a certain extent, and the original name plate has never been changed.

However, the excitation for the 2400 volt D. C. generator is of such a value that the output of the D. C. exciter No. 433851 need be only a small per cent of its present full load rating. Luckily this output is of such a value that the temperature rise of the exciter is normal and the machine would be satisfactory, as far as rating is concerned, if the name plate rated current was changed from 18 to 8 amperes.

One of the General Electric standards for exciters is that all 125 volt exciters should deliver 165 volts at normal field current at no-load. From an examination of the no-load saturation curve on the D. C. exciter No. 433851, it is seen at normal field current (1.535) that only 123 volts are generated. From an examination of the no-load saturation curve for exciter No. 433850 it might be concluded that the voltage would be very near 135 volts at a normal field current of 2.76 amperes. An accurate conclusion cannot be made since the field current was not carried to normal conditions in the no-load test.

Possibly one of the greatest difficulties connected with the operation of this machine is to bring the set up to synchronous speed so that the synchronous motor may pick up the load. Ordinarily a set of this type should be started by using the synchronous motor as an induction motor. Since this motor has no damping winding it has practically zero starting torque and will run at 600 R.P.M. as a maximum speed and draw a current of 300 amperes. Therefore it appears to be impossible to start the synchronous motor as an induction motor.

R E C O M M E N D A T I O N S

After running tests on the motor generator set there are certain changes in the rating of some of the units of the set which should be made before the set may be operated at the actual name plate rating of each unit. In the cases of the D. C. exciter No. 433851 and the 2400 volt D. C. Generator the current ratings were found to be too large. Due to the fact that time was limited, a heat run was not taken of any unit of the set; therefore, an accurate calculation of the correct rated current for a standard temperature rise cannot be made. However, the rapidity of the temperature rise with the present name plate rating and the nature of the circuit factors of each machine makes it seem probable that the following ratings would be satisfactory.

Machine No.	Current rating.
434701	6.00
433851	8.00

There are many other tests which may be run on the set and the authors are of the opinion that there is an ample field for more extended tests which might be incorporated in other theses similar to this. Tests which should prove very interesting would be the investigation of the effect of a damping winding on the starting characteristics of the synchronous motor. The addition of a damping winding would correct the hunting characteristic to some extent; however, it would be of interest to determine the effect of putting reactance coils in the line and investigating their effect on the hunting characteristic. Probably the most important test yet to be taken is a heat run of each unit of the set. With a complete heat run, the ratings of each machine could be accurately determined.

As a bit of advice to those who may have occasion to run similar tests on other machines in regards to determining the losses of the machine, it is concluded that other methods rather than the retardation method, might be more desirable for finding and separating the losses. In text books, one is warned that the retardation method should not be used on machines of small inertia; but one should not use it on any machine whose losses are small. There is a great chance for error in an accurate determination of the instantaneous speeds, but we were not handicapped in this way since the inertia of

the set was sufficient to keep the small machines running long enough so that reliable speeds could be taken.

The greatest trouble encountered in this particular test was to note the change in the core loss of the exciters when the field current was changed slightly. It was found, upon working up the data, that some curves were of no value after considerable time had been spent making the test. As a check it would be of interest to determine the efficiency of the exciters by some other independant method.

BIBLIOGRAPHY.

Standard Rules and Practice ——————————Westinghouse.

Expermental Electrical Engineering. Vol. 1-2.-Karapetoff.

Direct Current Machinery.——————————— Pender.

Principles of A.C. Machinery.—————————Lawrence.

Handbook For Electrical Engineers.——————Pender.

General Electric Test Book.—————General Electric CO.

Synchronous Motors and Converters.—————Blondell.

Manual of Electrical Testing.————————Wagner Electric CO.

Electrical Measurements——————————————Smith.