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Cosmic, Inc. Report No. 84

EXPERIMENTAL EVALUATION OF ELECTROSTATIC GENERATOR CONFIGURATIONS

by

D. Gignoux and H. F. Anton

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS3-6462

COSMIC, INC.
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FINAL REPORT

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March 1965

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FOREWORD

The work reported herein was accomplished under contract NAS3-6462 to the National Aeronautics and Space Administration. Mr. Larry Scudder of the Lewis Research Center was the Technical Monitor, and we thank him for his assistance. We also express our gratitude to Mr. Charles Corcoran, Dr. Robert English, and Dr. Bernard Lubarsky of the Lewis Research Center whose continued interest made this project possible.

1. Introduction

The purpose of this report is to relate certain tests accomplished with various designs of electrostatic generators. To place this work in its proper context and enable the reader to assess its significance, we shall examine briefly electrostatic generators as they relate to space power systems. High efficiency, high power-to-weight ratio, and long life are the most important requirements of a converter of mechanical into electrical energy for use in space. The comparison of the electrostatic generator on one hand and of the electromagnetic generator with or without substantial power conditioning equipment has not yet been accomplished and this comparison will not be attempted in this report. For our purposes, it will suffice to say that for applications such as ion engines, electrostatic generators appear to be interesting but that their interest is even more certain for applications which inherently require a very high voltage such as heavy particle or colloid propulsion. The development of electrostatic generators is not as advanced as that of electromagnetic generators but this truism should be interpreted to mean that there are still design decisions to be made before engineering development and construction of an electrostatic generator for space can be undertaken.

In the past two years, two different designs of electrostatic generators have been under consideration: the single capacitor generator and the constant oblique field generator. No tests of these two designs had ever been performed on the basis of which a comparison would be possible, i.e., with generators of the same size operating under the same conditions at the same rotating speed in the same insulating medium. Ideally, such comparative tests should be undertaken in a vacuum, at 24,000 rpm, and with the maximum diameter compatible with the materials used. Whereas such elaborate tests might be necessary in order to decide on the final version of a given design of generator, it is possible to make a valid basic design decision by accomplishing some comparative tests with small generators at low velocity, using air as the insulating medium. The tests related in this report have been accomplished with several versions of a single capacitor generator and of a constant oblique field generator. They were accomplished in air at atmospheric pressure at 3600 rpm.

To make this report self-contained, we shall first describe the generators and their principle of operation. Then present the data obtained during the tests, and finally, formulate conclusions.

2. Principles of Operation of Electrostatic Generators

When an electric field E exists at the surface of a conducting material, the force acting upon an element of surface dS is perpendicular to the surface. It is a pressure called

electrostatic pressure, $P = \epsilon/_2 E^2$. As is the case with a turbine blade, the movement of a surface submitted to a pressure causes the transfer of energy. In our particular case here, the power produced per unit area of rotor is equal to the product of the two vectors representing the velocity and the pressure.

$$W/_A = \vec{P} \cdot \vec{v}$$

Two methods can be used to explain the operation of electrostatic machines or to calculate their power: 1) the method of field theoretic analysis, or 2) the method of capacitance analysis. The first method consists in applying the formula

$$W = \int_A \vec{P} \cdot \vec{v}$$

to the total surface of the machine. This would give the exact amount of energy being converted at any given time; however, this power may vary during one cycle of the machine so that the average has to be calculated. Such analysis may lead to extreme complications and it is usually more convenient to use the method of capacitance analysis. In an electrostatic machine using conducting charge carriers, the problem is greatly simplified by the fact that the potential is the same everywhere on a charge carrier. One can therefore use the concept of potential energy of each charge carrier and describe its variation in terms of the variations of the capacitance of the charge carrier with respect to the stator members. In this type of analysis no integration is required since the energy conversion per cycle may be properly defined by the minimum and maximum capacitance of the charge carrier with respect to the stator.

It is understood that the charge carriers are conducting elements and that we exclude from this discussion the Felici or Van de Graaff generators in which the charges are deposited on insulating rotors or moving belts.

The operating principle of a generator is shown in Figure 1, top left. A rotor element is charged by influence in the input position in which it is in contact with the ground. The charge carrier then moves to a position where it is in contact with an output terminal.

The operation of this generator can be explained from the variations of the capacitance C between the rotor and the stator. One can then see that the rotor member is charged by influence while in the position of maximum capacitance, is moved while C decreases, and is connected to the output terminal when C is at its minimum. Consideration of the formula $Q = CV$ shows clearly that during the cycle where there is no transfer of charges V increases as C decreases so that charges are being removed at the output position at an elevated potential.

The same machine may be operated with a slip ring instead of a commutator. In this case the output of the generator is AC instead of DC. Generators of this type, coupled with rectifiers were built by Trump in the early thirties, Felici (Reference 1) in 1950 and Trump (Reference 2) in 1960-64.

In such machines, there may be several charge carriers connected in parallel. However, the operation may be derived entirely from the variation of the capacitance of the rotor with the stator and ground. Consequently, such machines are called single-capacitor machines.

One construction consists in using a second stator member which is placed in close relation to the rotor while in the output position (Figure 1A). In this case, the machine may be called a three-element machine, since its operation involves an input inductor, an output inductor, and a charge carrier. A machine consisting only of an input inductor and a charge carrier is called a two-element machine.

The conducting-carrier, multiple-capacitor machine is shown in Figure 1C. It consists of several rotor members or charge carriers, insulated from one another, which transfer charges from an input to an output pole. In such a machine, the capacitance of each carrier varies with respect to the stator elements (input and output inductors) during a cycle in the same manner as in a single-capacitor machine.

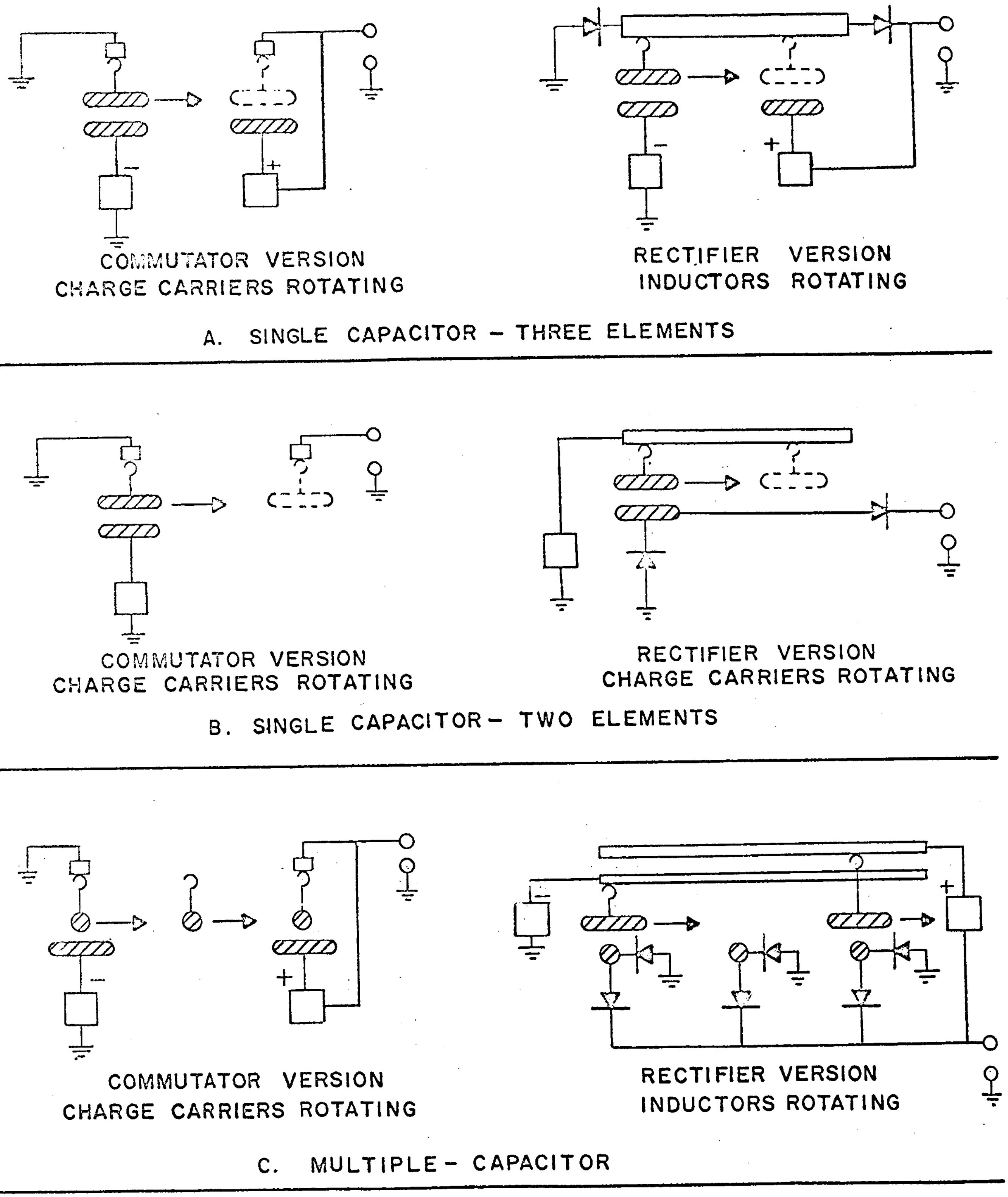


Figure 1. Classification of Conducting-Carrier Electrostatic Generators

Multiple-capacitor generators are more complex than the single-capacitor type but are capable of higher powers.

3. The Single-Capacitor Generator

The theory of the single-capacitor generator has been analyzed by Trump (Reference 2) and further by Denholm, et al (Reference 3). The calculations are simplified by the fact that only the mutual capacitance of the two elements (the stator and rotor) and their capacitance with respect to ground need be considered. Furthermore, only the extreme values of these capacitances come into play. Trump (Reference 1) gives the following expression for an AC machine using rectifiers, in which the rotor is connected to the excitation voltage, the stator connected to ground, and the high-voltage terminal connected to the load by rectifiers.

The charge transferred per cycle is

$$Q = C_m V - C_o (V + E) - C_g E$$

where V is the excitation voltage, E the output voltage, C_m, the maximum rotor-stator capacitance, C_o, the minimum rotor-stator capacitance, and C_g the capacitance of the stator to ground in the position of minimum capacitance. The above formula means that the charge transferred is the charge induced in the position of maximum capacitance minus the charge which the parasitic capacitances C_o and C_g cause to remain on the stator in the position of minimum capacitance.

The output power of a generator is then

$$W = \nu K C_m V E$$

where ν is the number of cycles of the generator (i.e., number of poles times rps) and where

$$k = 1 - \frac{C_o (V + E) + C_g E}{C_m V}$$

According to Trump, the value of k may lie in the range of 0.3 to 0.7. This formula still contains E, the output voltage. It is possible to calculate E itself and obtain a formula for the power based on capacitances and assumed maximum gap voltage breakdown. This type of generator is used in Test 1 through 3.

4. The Oblique Field Generator

This section will summarize how the evolution of the electrostatic machine has resulted in the oblique field concept.

As we have seen before, capacitance analysis is a convenient method of calculating the performance of an electrostatic generator. However, capacitance calculations do not show the quantities which, in effect, limit the power of the electrostatic generator. Such quantities are determined generally by the ability of the vacuum to withstand dielectric stresses. On the other hand, field-theoretic analysis keeps in focus the electric field on the surface of the electrodes and, therefore, is useful in the the determination of the best design. As a result of field-theoretic analysis, the sharp edges of the foil used in the Wimshurst machine were replaced by thick segments. The same thinking led to generators with many charge carriers (Reference 4) and then to the constant oblique field generator.

Let us now examine the evolution from the single-capacitor generator to the constant oblique field generator from the standpoint of the field-theoretic method.

Figure 2a shows a conducting-carrier generator and the lines of force in the vicinity of a charge carrier. In the following discussion we shal analyze the forces which are being created by the charges and the electric field and determine which part of the rotor is the subject of the active forces. The electrostatic pressure $\vec{P}$ is tangent to the lines of force. Therefore, it can be seen that on most of the surface of the rotor blade the produce $\vec{P} \cdot \vec{v}$, which is the power per unit area of charge carrier, is very small or nil; only the edges of the rotor blades contribute to energy conversion. It appears, then, that the conducting-carrier generators which we have seen so far utilize only a small percentage of the rotor surface.

The first improvement which stems from the above considerations is that of utilizing a multiple-capacitor design and replacing the blades of the rotor by rods in the manner shown in Figure 2b. One method for transforming the discontinuous forces in the gap into continuous ones consists in embedding the rods in an insulating material as shown in Figure 1c and in Figure 2b. If the rods are in sufficient number, the field in the rotor-stator gap approaches a uniform field. The main limitation of electrostatic machines is the breakdown in the rotor-stator gap. If one considers only the gap, it appears that the

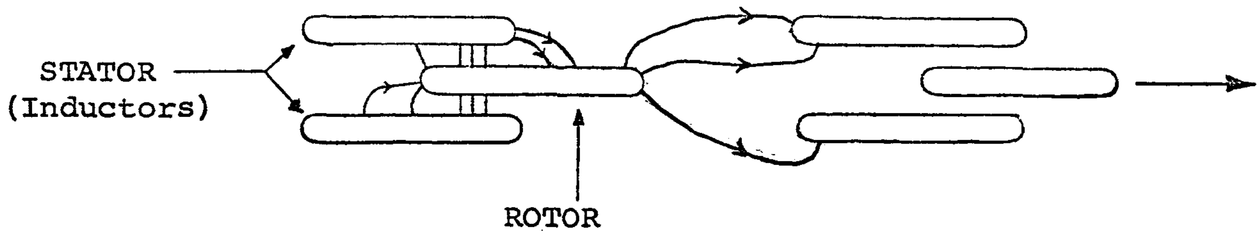


Figure 2a. Single Capacitor, Two-Element Machine with Lines of Force of the Electric Field

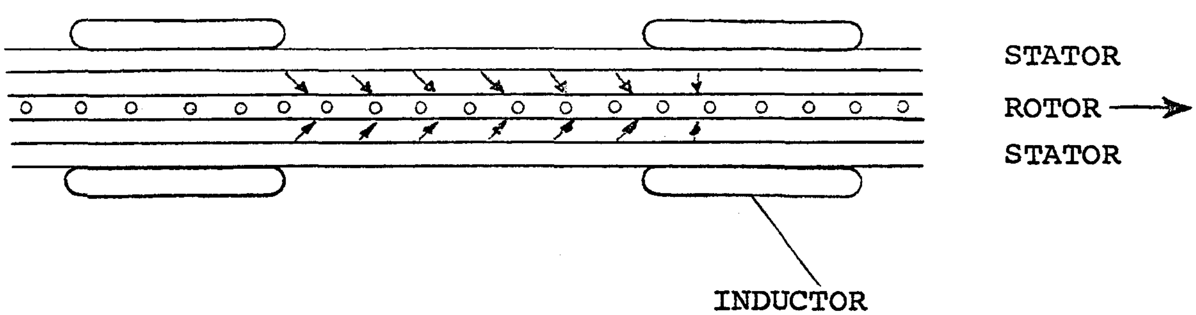


Figure 2b. Constant Oblique Field Machine Lines of Force of the Electric Field

generator with embedded rods may be treated in a fashion similar to that of an insulating-carrier machine. For example, let σ be the average charge density per rotor area (this charge is, in fact, located on the rods) and N and T, the normal and tangential components of the field at a point just off the rotor surface (see Figure 2b). In the rotor-stator gap we then have

$$\sigma = 2 \epsilon N,$$

and the power per unit area becomes

$$\frac{W}{A} = 2 \epsilon N T v,$$

with a force per unit area having a tangential component

$$\frac{F}{A} = 2 \epsilon N T$$

where A is the rotor area, not the charge-carrier area.

To make the field in the gap more uniform, the stator is built of a semiconducting dielectric material, which acts as a voltage divider between the input and the output inductor. It is important to obtain a constant oblique field, for the obliqueness means that there is a component of the force in the direction of movement at all points of the rotor. This advantage becomes obvious when one considers that the power of an electrostatic generator is limited by the electric field due to breakdown. It is of interest, therefore, to have a constant field which is close to the maximum field permitted by breakdown phenomena so as to maximize the force at all points of the rotor. A construction which approaches this ideal case is the one utilized for tests 4 and 5 and 8 through 13. The generator used in tests 6 and 7 has a stator with bare inductors.

5. Scaling Laws

It is of interest to be able to compare generators of different size and operating under different conditions. The scaling laws which have been established state that the power of a disk shaped electrostatic generator of any type, in a given environment is proportional to the rotating speed and to the cube of the radius. A justification of this scaling law is found in Reference 6 and in Reference 3, Page 61.

In Reference 7 an expression is given for the power of an electrostatic generator as follows:

$$\text{Power} = 0.192 \times \text{Normalized power} \times \text{rpm} \times (\text{radius})^3$$

Expressed in this manner the scaling law sets forth the normalized power which can be expressed in Pascals or Newtons/meter^2 and which is precisely the average tangential force per unit rotor area. The normalized power can be used as a figure of merit to compare electrostatic generators of different sizes and rpm operated in the same insulating medium.

6. Description of Tests

Under NAS3-3859, Cosmic, Inc. built two motor generator sets for Lewis Research Center, to be used to test and evaluate the single and multiple capacitor types of conducting carrier electrostatic generators. These generator sets are the ones used in this program. The generators were designed for maximum flexibility of assembly to allow several types of stators to be used and to allow the rotor-stator gap to be varied considerably.

The single capacitor generator set is shown in Figures 3 and 4 and the multiple capacitor generator set is shown in Figures 5 and 6. The rotor of the single capacitor generator is a completely conducting member, aluminum in this case, requiring an insulating shaft. The rotor of the multiple capacitor generator, fabricated of an insulating material, in this case an epoxy resin with embedded charge carriers, does not require an insulated shaft. Both rotors are 5 inches in diameter. The stators of both machines are mechanically interchangeable and if electrically compatible work equally well in either machine. The multiple capacitor generator requires a commutator and the single capacitor generator a slip ring. The versions of each generator differ therefore only by the stators in which either bare or embedded inductors are used. In the case of the constant oblique field generator, it is possible to utilize several input and output inductors, resulting in a multipole machine equivalent to several generators operating in parallel with the same rotor. Thus 4- and 8-pole machines are tested. It is also possible to arrange two machines with the same rotor so that they excite one another and such a "self-exciting" generator is also tested. The various stators are seen and described in Figures 4 and 6. In addition a constant oblique field generator using two rotors and three stators was tested to demonstrate the possibility of multiple stage machines. To determine the

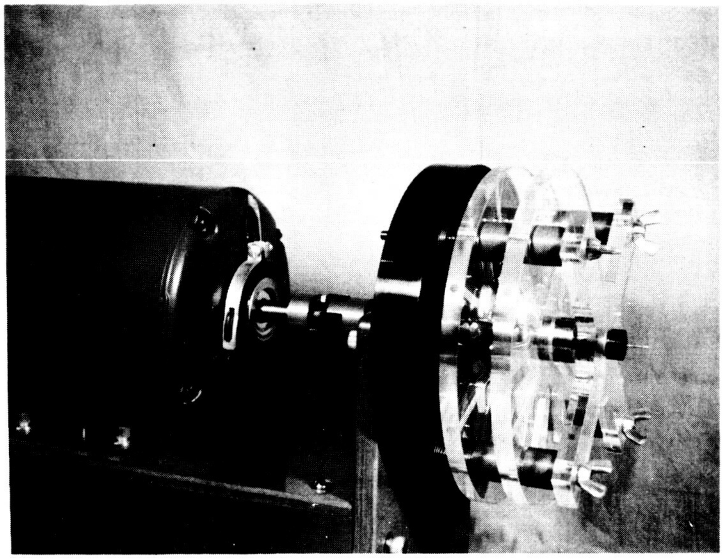


Figure 3. Single Capacitor Generator on Test Stand

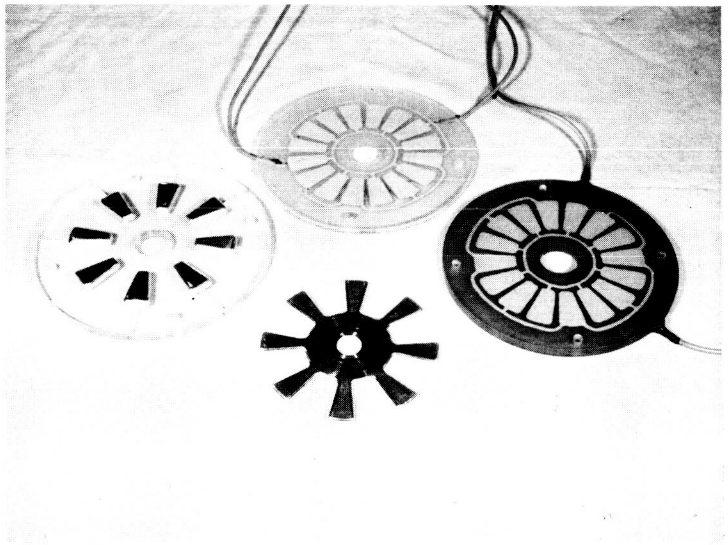


Figure 4. Single Capacitor Generator Showing Rotor and Three Stator Variations.

Bottom Center: Rotor.

Left: Stator with bare inductors for 2-element machine.

Top Center: Stator with glass imbedded inductors for 3-element machine.

Right: Stator with epoxy imbedded inductors for 3-element machine.

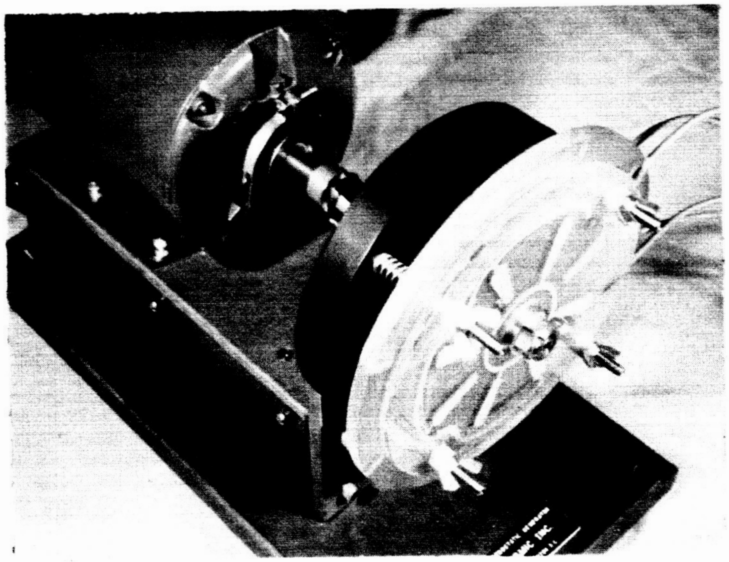


Figure 5. Constant Oblique Field (C. O. F.) Generator
on Test Stand

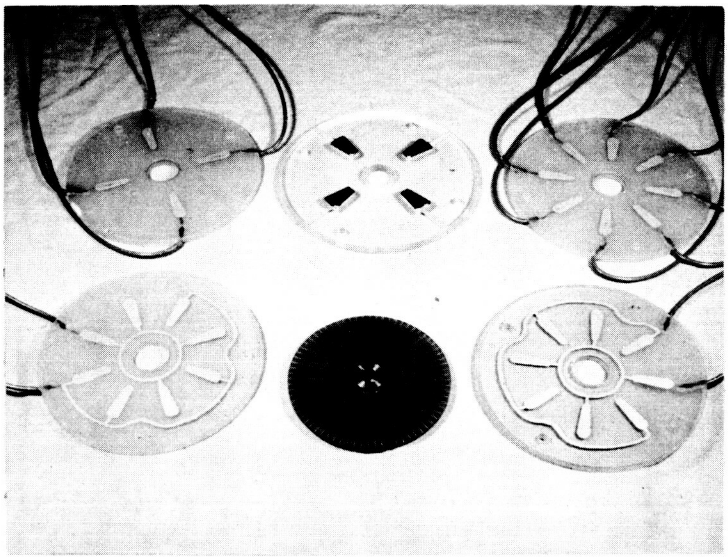


Figure 6. C.O.F. Generator Components

Top Left:	4-pole stator with imbedded inductors.
Top Center:	4-pole stator with bare inductors.
Top Right:	8-pole stator with imbedded inductors, separately connected.
Bottom Left:	stator with imbedded inductors for a self-excited machine.
Bottom Center:	72-charge carrier rotor.
Bottom Right:	8-pole stator with imbedded inductor, internally connected.

effect of rotor thickness, two tests were run with machines in which the rotor thickness was varied.

All the tests were performed in air at atmospheric pressure at 3,550 rpm utilizing the circuits shown in Figures 7 and 8 which are self-explanatory. Thirteen different tests were run representing different configurations and described below as No. 1 to 13. Each test consisted of measuring the excitation voltage (V_{ex}) from zero to breakdown and plotting the corresponding short circuit current (I_{sc}) (Test A). From this test the value of the excitation voltage which gives the maximum short circuit current was determined and called "optimum". Then tests were run for three constant values of the excitation voltage: optimum, below optimum and above optimum (Test B). While the load varied, the values of the output current (I_{out}) and voltage (V_{out}) are plotted. The tests are described below, followed by a series of curves, each referring to the test number followed by the letter "A" or "B". For clarity figure numbers have been omitted.

Test #1: Single Capacitor, 2 Elements, Bare Inductors

Attempts were made to adjust the rotor-stator gap as closely as possible starting with the spacing of .010 inch but breakdown between the rotor and stator with this spacing occured with relatively little short circuit current. It was found that a gap approximately .040 to .050 of an inch tended to give the optimum output. Breakdown occured with an excitation voltage of 4.4 KV and a short circuit current of 76 microamps. Two different types of rectifiers were used in running these tests. First, a pair of 18 KV peak-to-peak selinium rectifiers were used to determine the breakdown voltage point. After this point had been determined, a pair of 1.5 KV silicon rectifiers were used to obtain the performance data. The generator used for this test is similar to the one developed for space and which has been tested in a vacuum chamber (Reference 3).

Test #2: Single Capacitor, 3 Elements, Inductors Embedded in a Semi-Conducting Stator having a Resistivity of About 10^{12} ohms-cm

This particular configuration had never been tested before.

Test #3: Single Capacitor, 3 Elements, Inductors Embedded in Insulating Material Having a Resistivity Greater than 10^{14} ohms-cm

To understand this test, one must follow the sequence in which the data was obtained. First a I_{sc} versus V_{ex} was obtained (Run #1 in

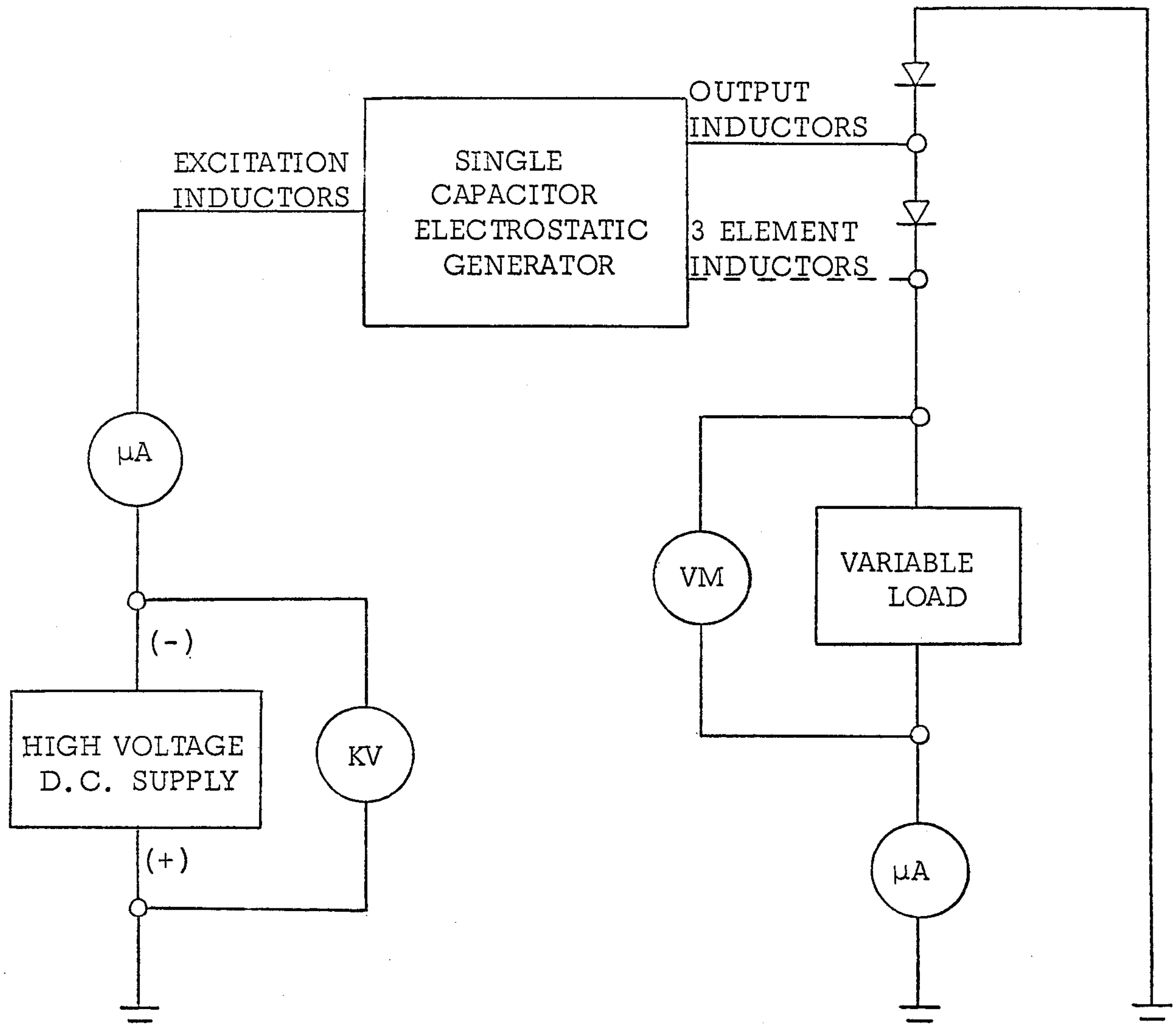


Figure 7. Schematic of Single Capacitor Electrostatic Generator Instrumentation

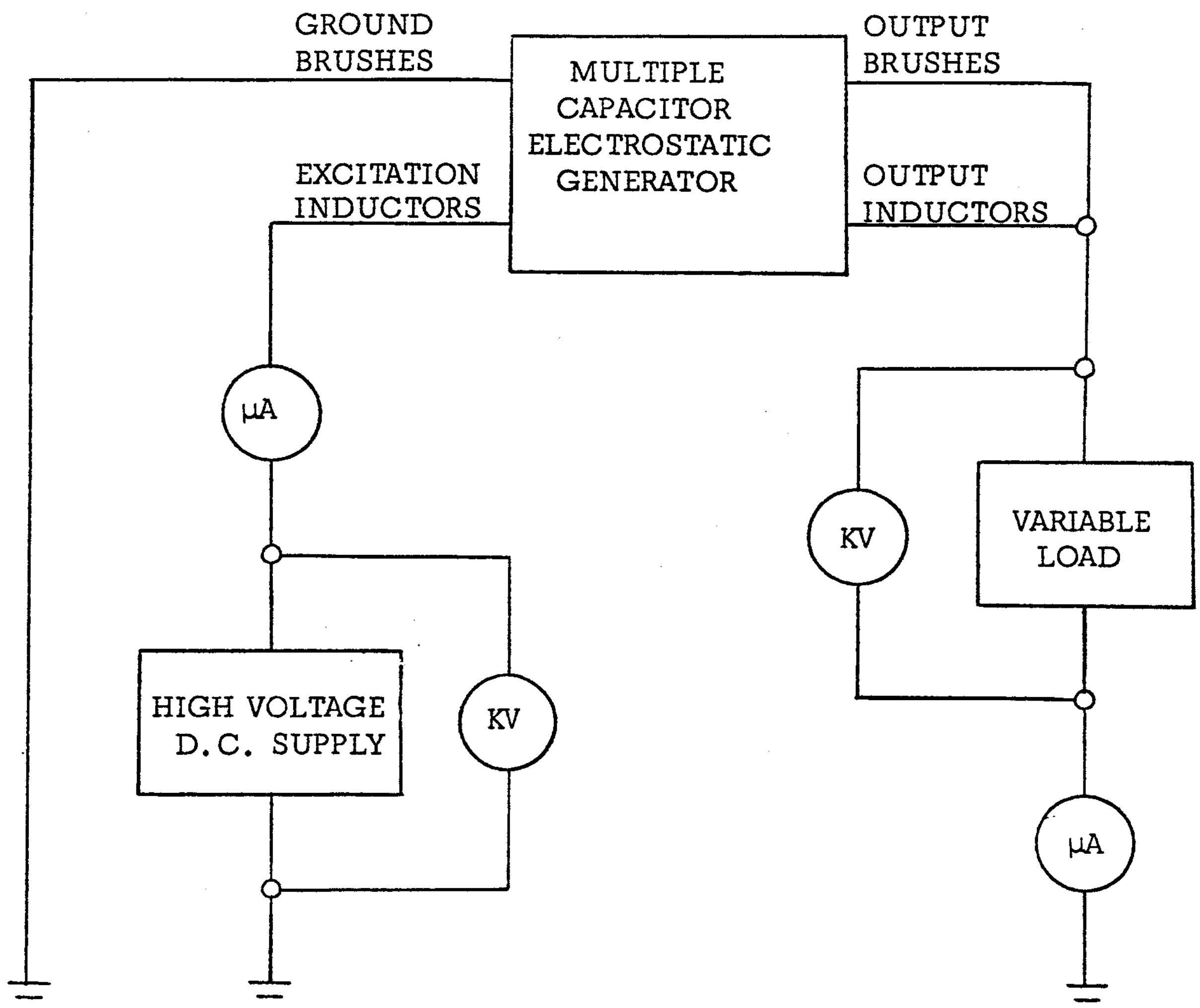


Figure 8. Schematic of Multiple Capacitor Electrostatic Generator Instrumentation

Test 3A). Then, a V_{out} versus I_{out} for V_{ex} = 8 KV (Test 3B). At this time an ion layer of a sign opposite that of the inductor had built up on the face of the stator adjacent to each inductor. When a second short circuit test was run (Run #2), the ion layers were sufficient to excite the generator in the absence of an excitation voltage on the inductors and were then neutralized for V_{ex} = 3.3 KV.

The fact that the ions white exist naturally around the generator build up on insulating components faster than they can be discharged by leakage prevents optimum operation. This stator construction is not recommended.

Test #4: C.O.F., Various Rotor Thicknesses, Constant Gap, 4 Poles

The rotor thickness is varied from .375" to .187", the geometry remaining otherwise the same, in particular the gap being constant. The maximum of I_{sc} occurs for a value of V_{ex} which is a function of the thickness. The B tests were run, using the optimum excitation voltage corresponding to each thickness. It can be seen that under these conditions, the rotor thickness has a minor influence on the output power.

Test #5: C.O.F., Various Rotor Thicknesses, Constant Gap, 8 Poles

This is essentially the same as Test #4 and it leads to the same conclusions.

Test #6: Multiple Capacitor, 4 Poles, Bare Inductors

Starting with this test, rotors .187" thick were used for all tests. Curves for optimum excitation voltage and for one value below optimum are given. It was not possible to operate above the optimum because of discharges.

Test #7: Multiple Capacitor, 8 Poles, Bare Inductors

Test #8: C.O.F., 4 Poles

This test demonstrates the substantial increase in power due to the use of the semiconducting stator. The power obtained in this test is 4.5 times that obtained in Test #6. The optimum excitation voltage is 2.5 times greater.

Test #9: C.O.F., 8 Poles

Test #10: C.O.F., 8 Poles, (In Special Stator with All Connections Made Internally)

Test #11: C.O.F., 8 Poles, 2 Stages Mounted on the Same Shaft

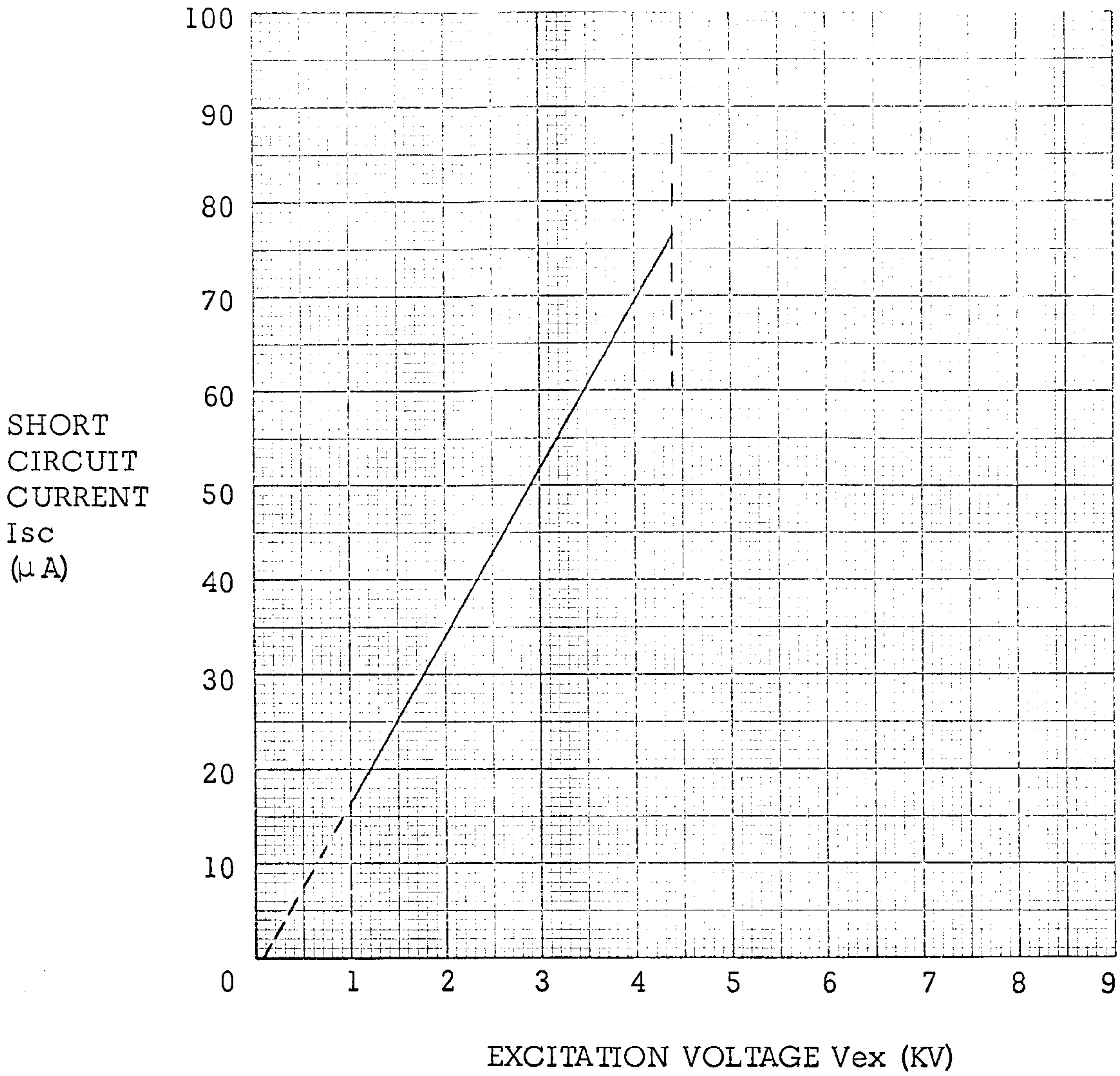
This test should have resulted in twice the power obtained in Test #9. The reason for the lower power may be found in gap settings.

Test #12: C.O.F., 8 Poles, but with only 6 Poles Connected

The power is 3/4 of that obtained in Test #9, so that the power corresponds exactly to the utilization of stator surfaces.

Test #13: C.O.F., Self Excited, 6 Poles Used as Main Generator, 2 Poles Used as Excitation Generator

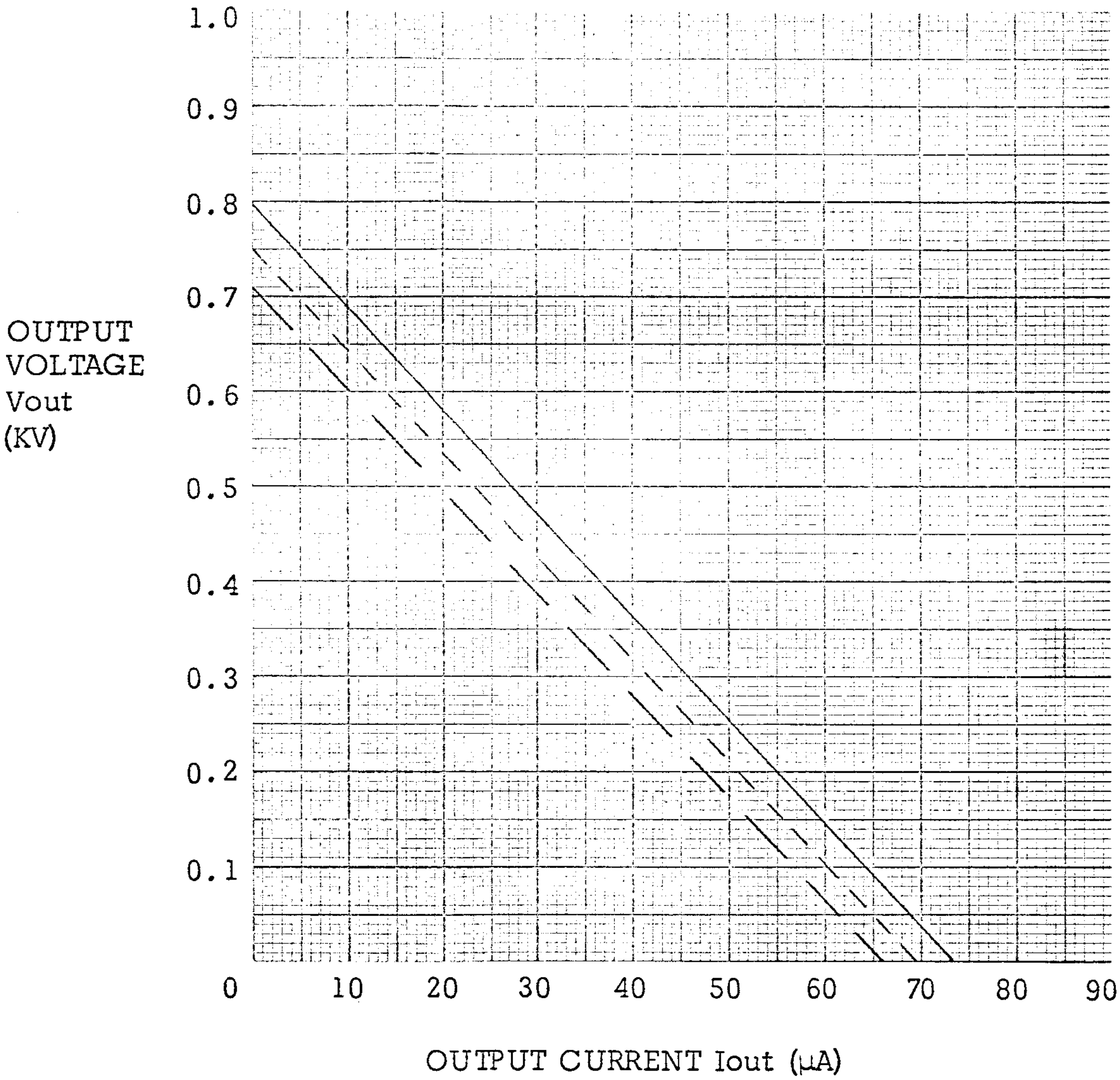
The power is slightly less than that obtained in Test #12, in which also 6 inductors out of 8 are used. This can be explained by the fact that in Test #12, the other 2 inductors are left floating whereas in Test #13, they are at fixed potentials and will therefore introduce parasitic capacitances.



3550 rpm
0.040" gap
8-blade bare inductor stator

4.4 KV breakdown

Test 1A. Short Circuit Current vs. Excitation Voltage for Single Capacitor Two-Element Electrostatic Generator



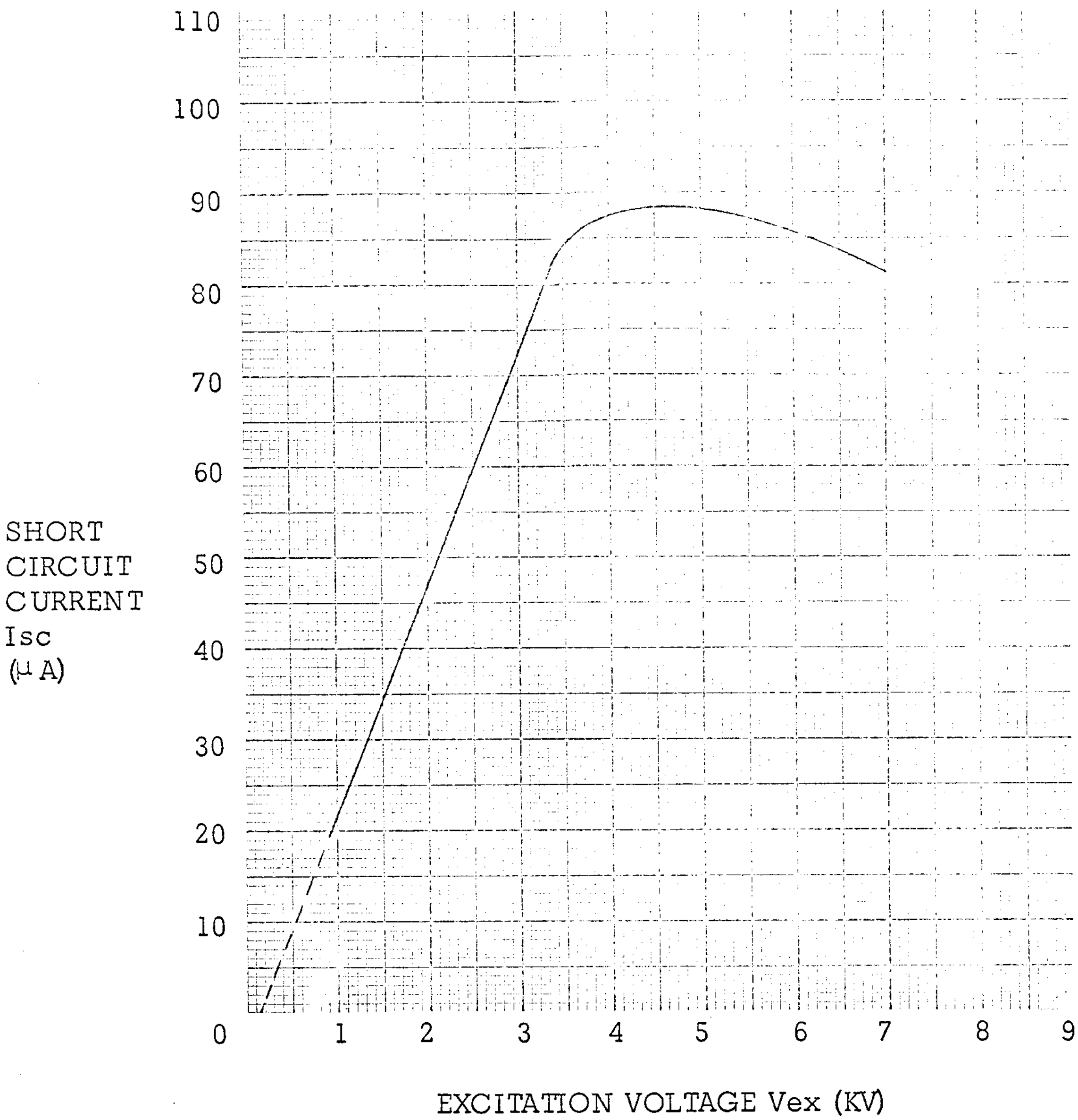
Excitation Voltages

——— 4.2 KV
- - - - - 4.0 KV
—— —— 3.8 KV

3550 rpm
0.040" gap
8-blade bare inductor stator

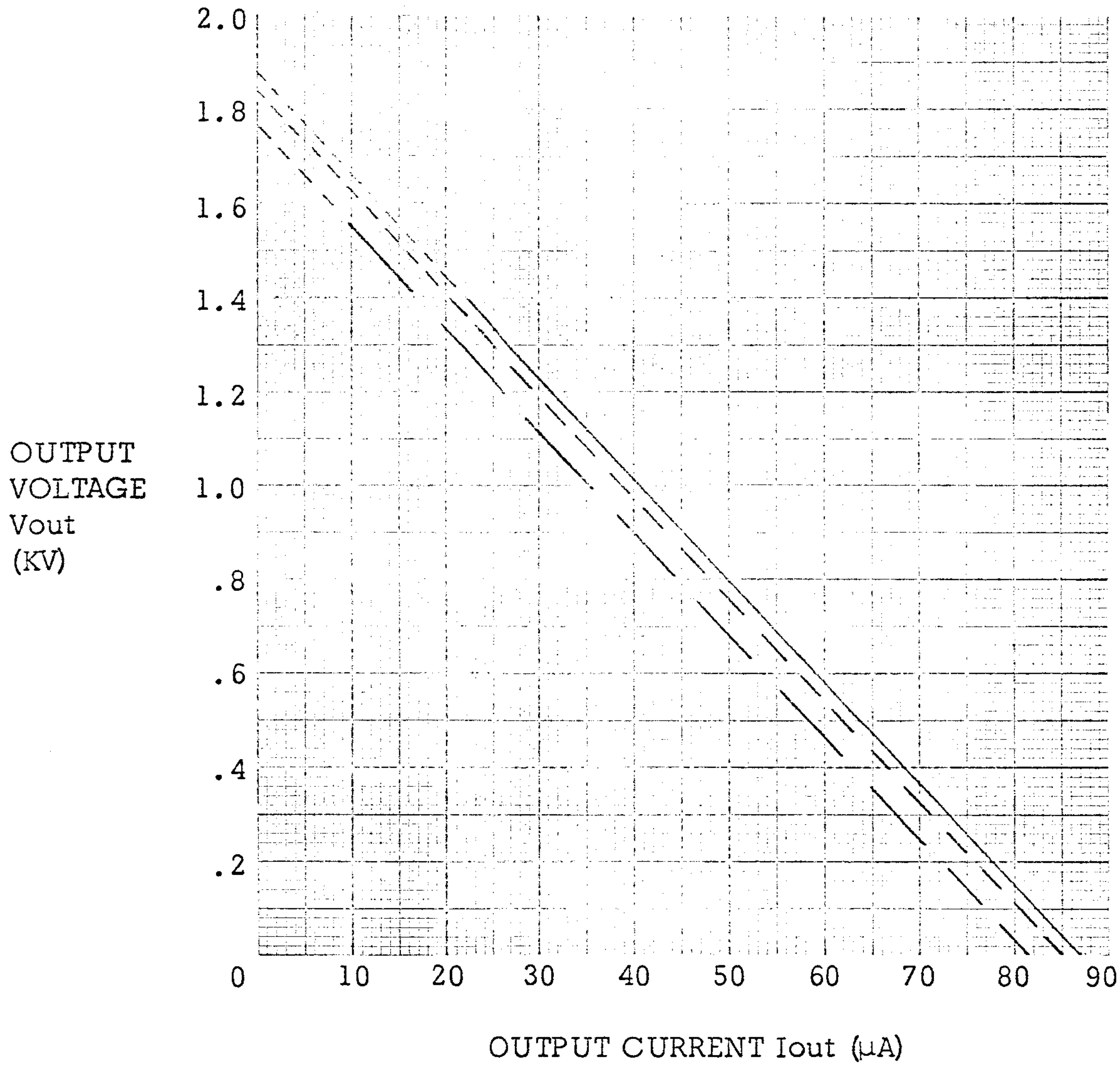
Maximum Power Output: 14.5 milliwatts

Test 1B. Output Voltage vs. Output Current for Single Capacitor Two-Element Electrostatic Generator



3550 rpm
0.020" gap
16-pole semiconducting stator

Test 2A. Short Circuit Current vs. Excitation Voltage for Single Capacitor Three-Element Electrostatic Generator

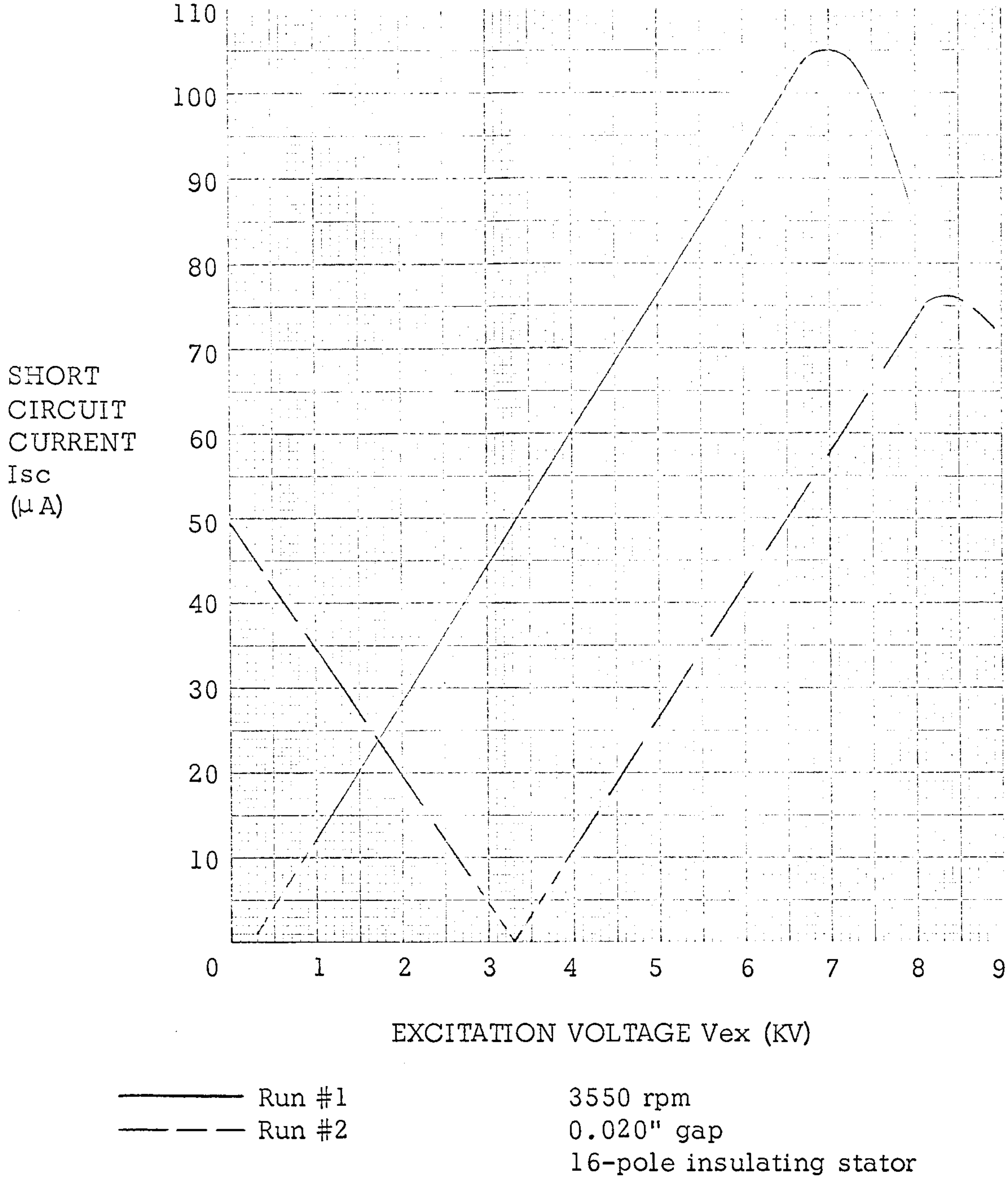


Excitation Voltages

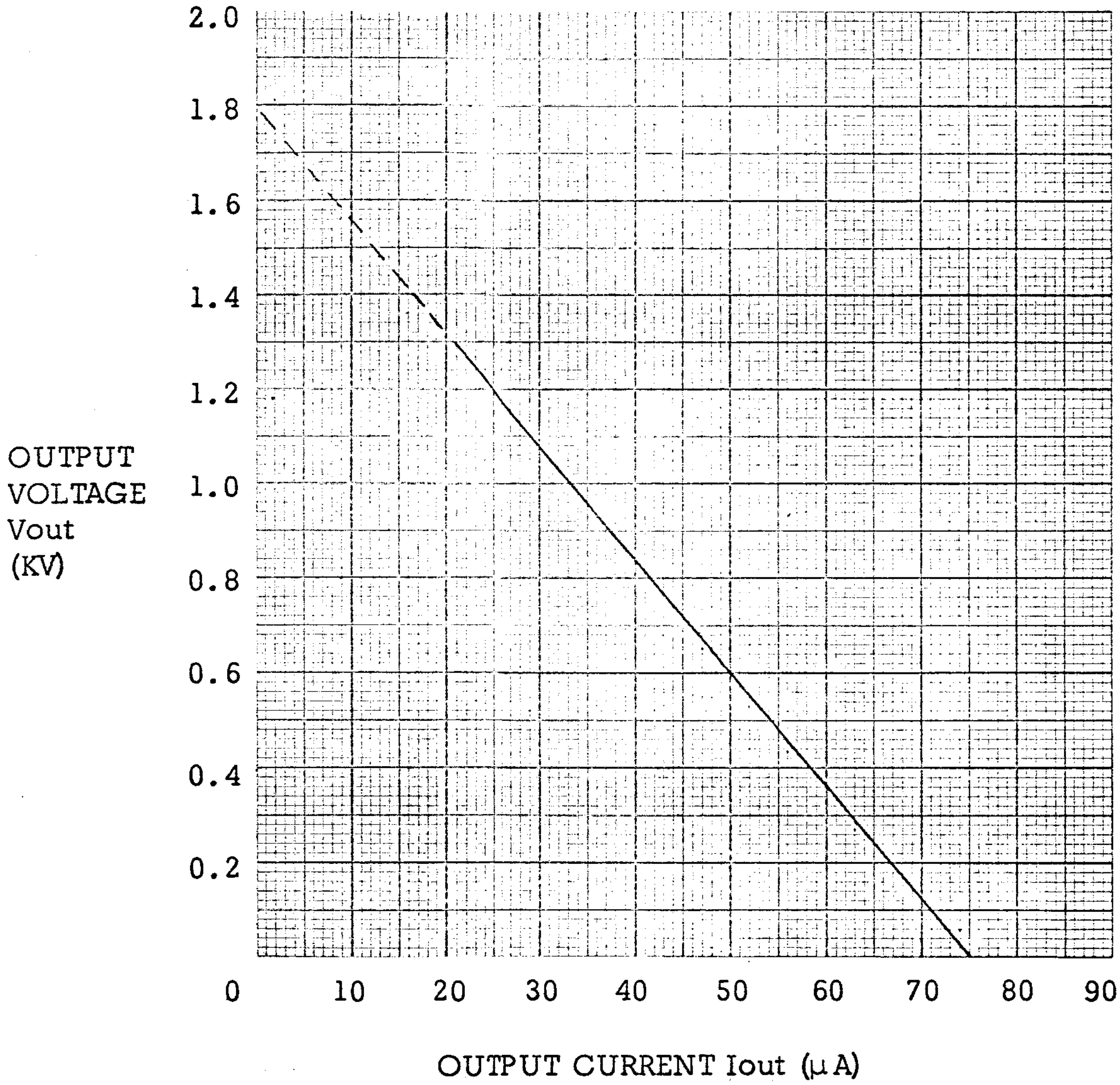
- - - - -	5.5 KV	3550 rpm
————	4.5 KV	0.020" gap
—— ——	3.5 KV	16-pole semiconducting stator

Maximum Power Output: 41 milliwatts

Test 2B. Output Voltage vs. Output Current for Single Capacitor Three-Element Electrostatic Generator



Test 3A. Short Circuit Current vs. Excitation Voltage for Single Capacitor Three Element Electrostatic Generator



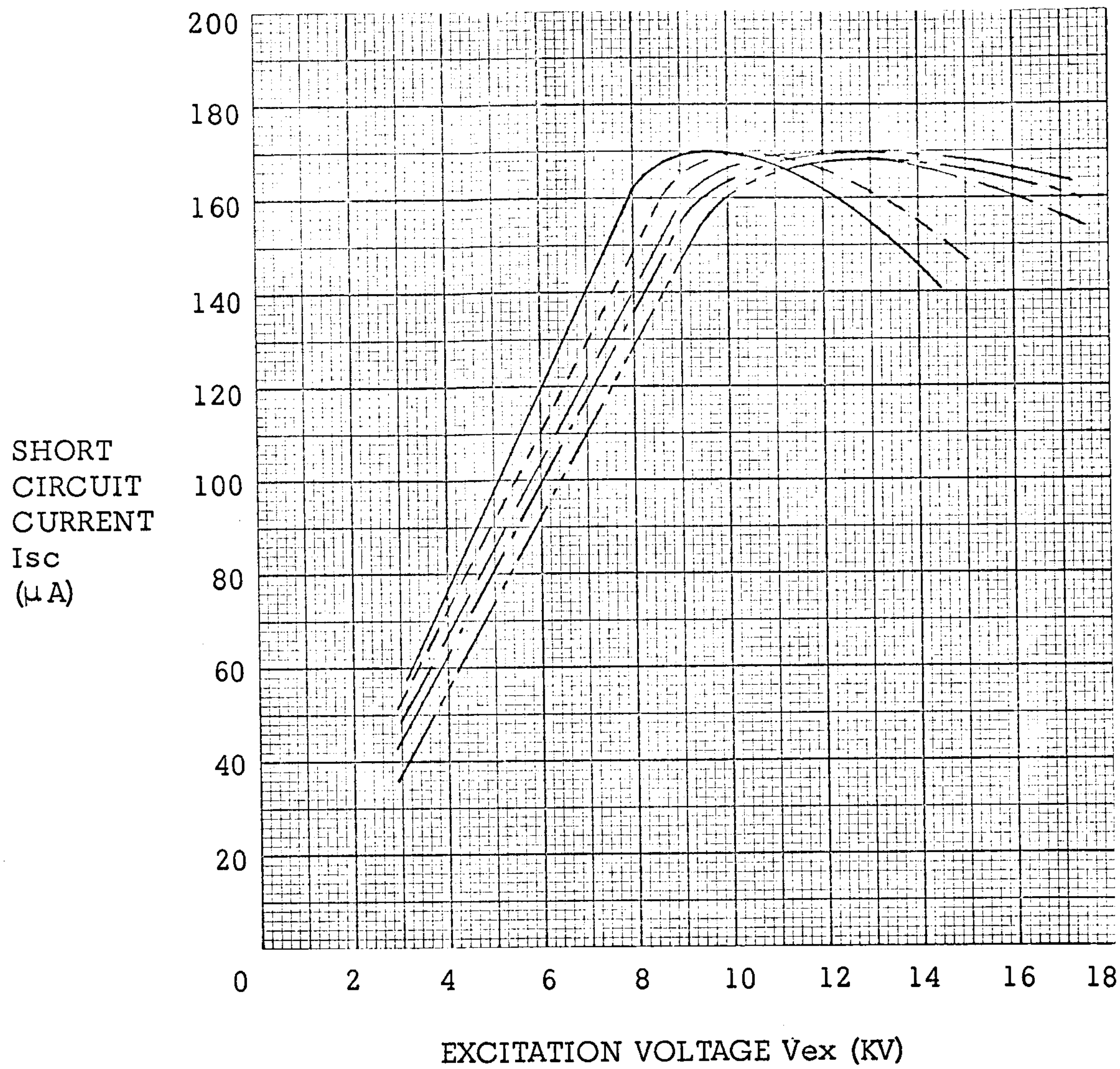
Excitation

8 KV

3550 rpm
0.020" gap
16-pole insulating stator

Maximum Power Output: 33 milliwatts

Test 3B. Output Voltage vs. Output Current for Single Capacitor Three-Element Electrostatic Generator

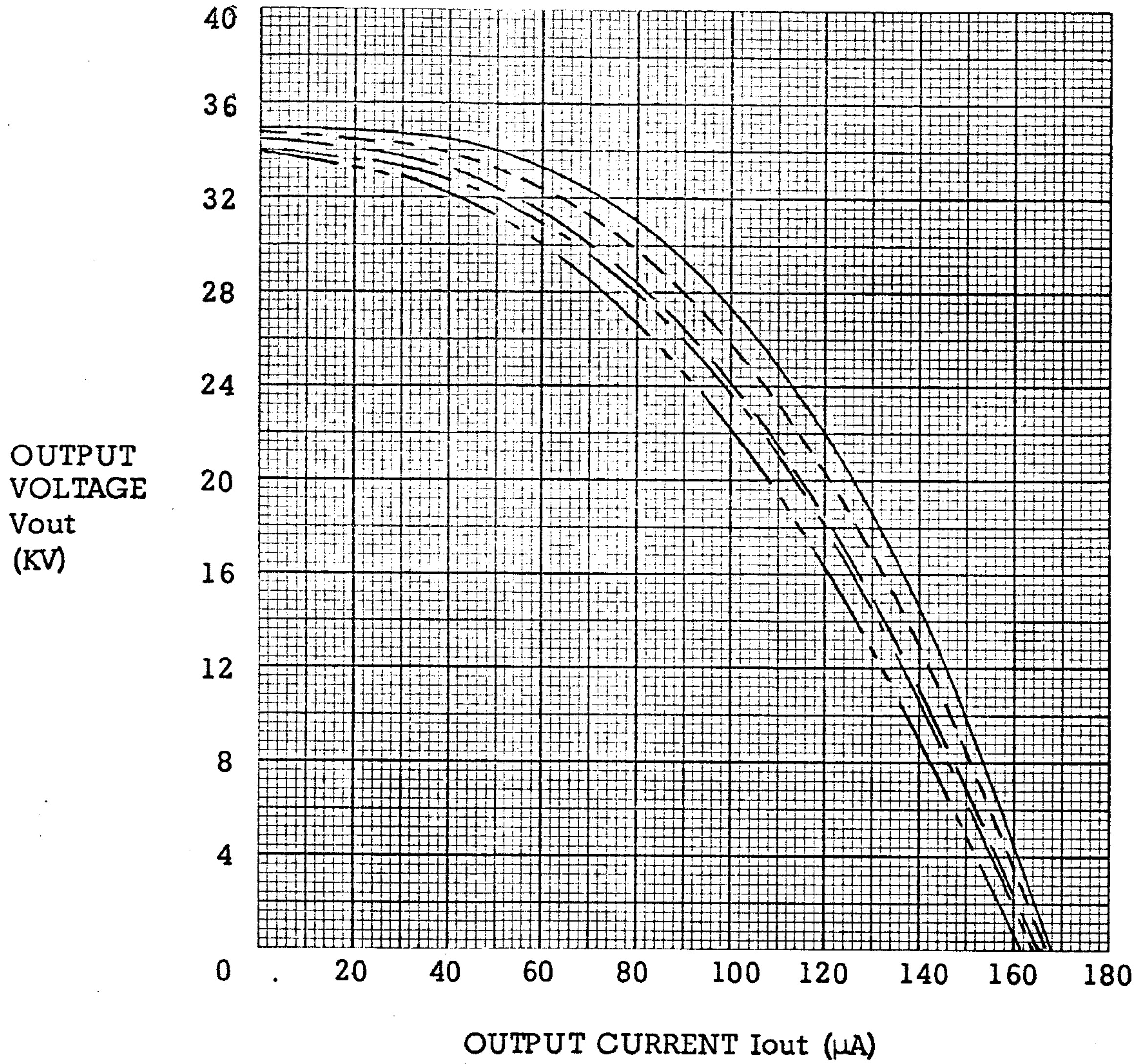


Rotor Thickness

———— 3/16 inch
- - - - - - 7/32 inch
— — — 1/4 inch
—— - —— 5/16 inch
—— - - —— 3/8 inch

3550 rpm
0.010" gap
4-pole semiconducting stator

Test 4A. Short Circuit Current vs. Excitation Voltage for Constant Oblique Field Electrostatic Generators with Various Rotor Thicknesses

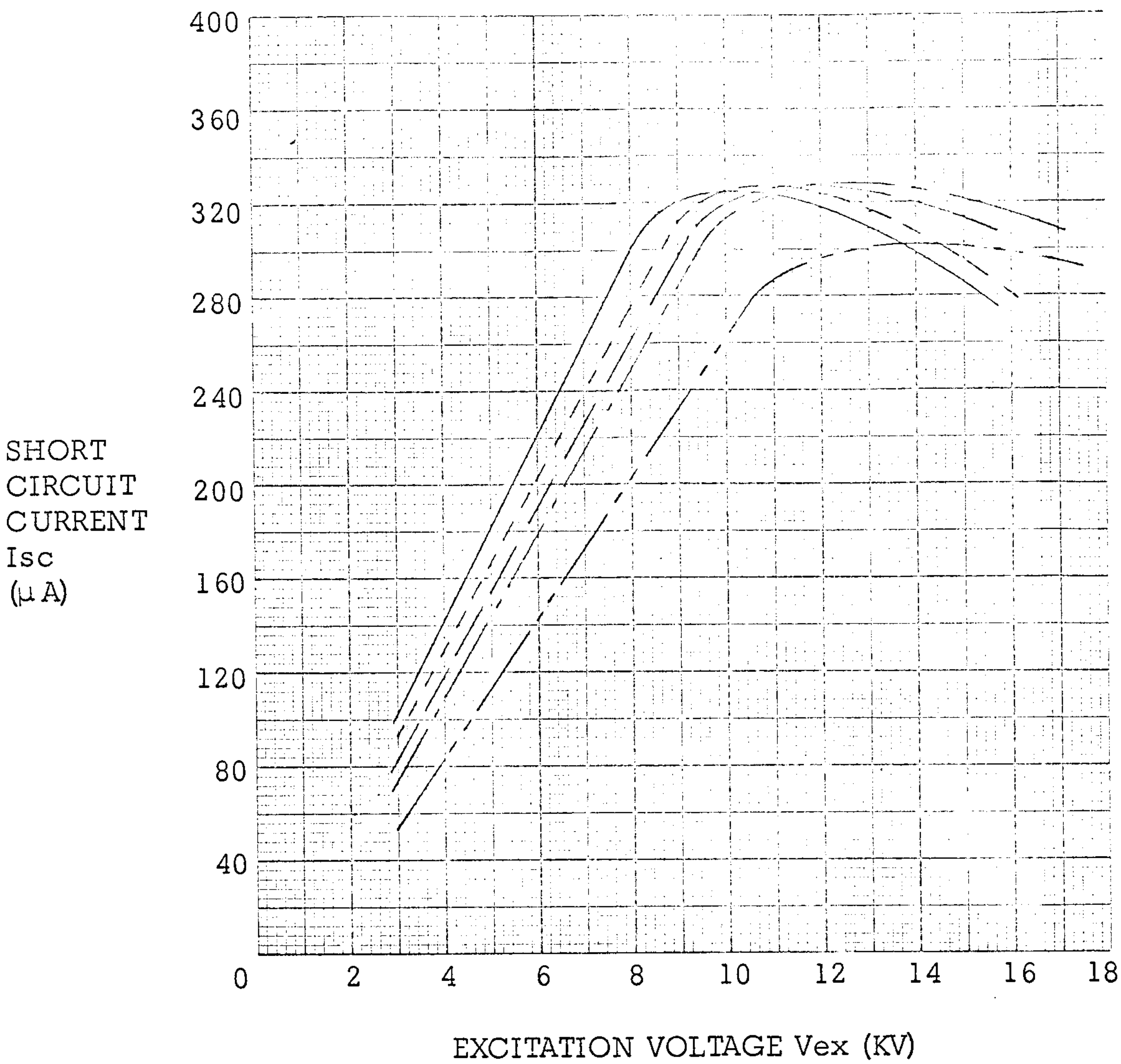


Rotor Thickness

——— 3/16 inch
- - - - - - 7/32 inch
—— —— 1/4 inch
——- - — 5/16 inch
——- - - — 3/8 inch

3550 rpm
0.010 gap
4-pole semiconducting stator

Test 4B. Output Voltage vs. Output Current for Constant Oblique Field Electrostatic Generators with Various Rotor Thicknesses

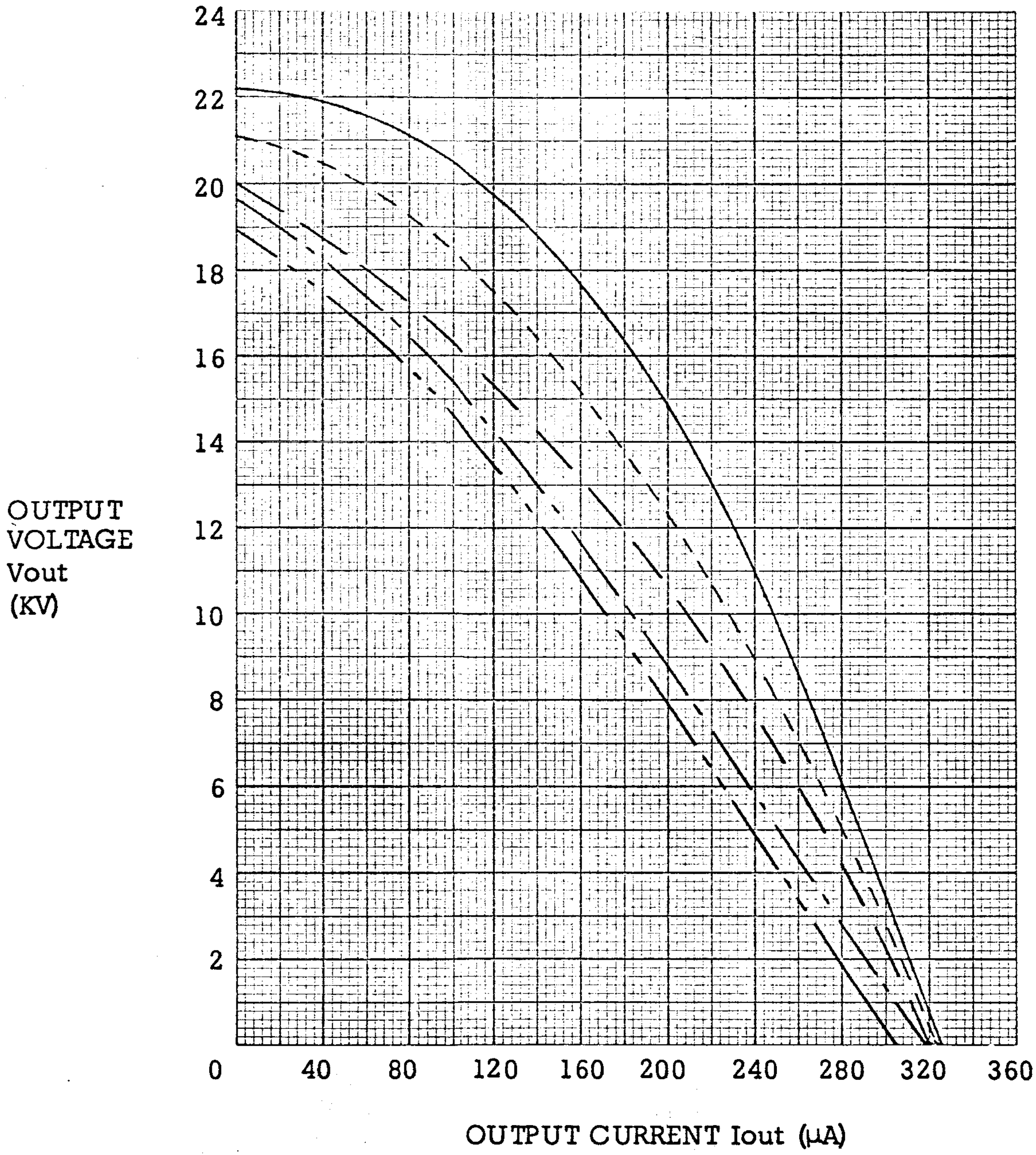


Rotor Thickness

- ———— 3/16 inch
- – – – – – 7/32 inch
- —— —— 1/4 inch
- —— - —— 5/16 inch
- ——- - —— 3/8 inch

3550 rpm
0.010" gap
8-pole semiconducting stator

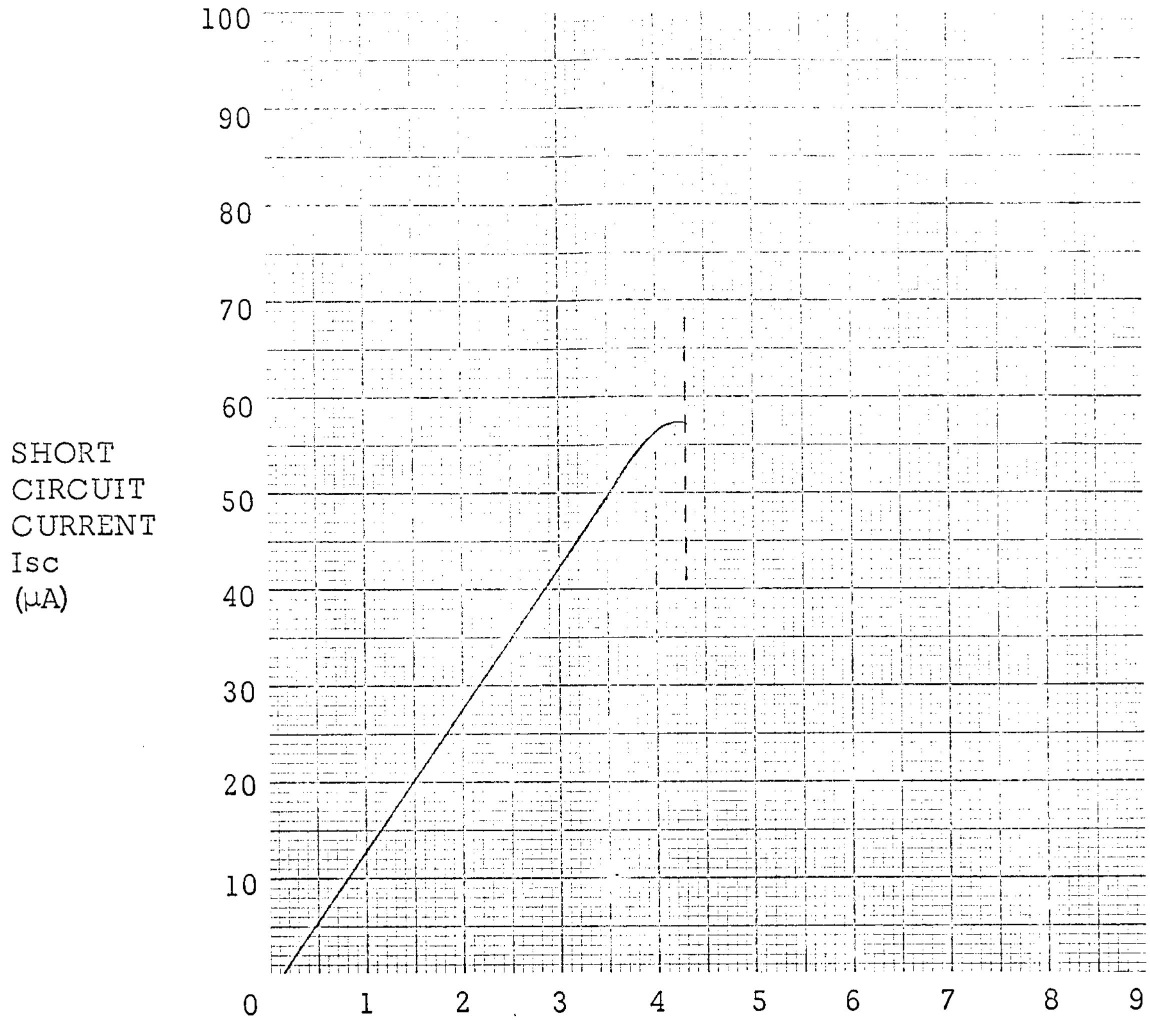
Test 5A. Short Circuit Current vs. Excitation Voltage for Constant Oblique Field Electrostatic Generators with Various Rotor Thicknesses



Rotor Thickness

————	3/16 inch	3550 rpm
- - - - - -	7/32 inch	0.010 gap
—— ——	1/4 inch	8-pole semiconducting stator
—— - ——	5/16 inch	
—— - - ——	3/8 inch	

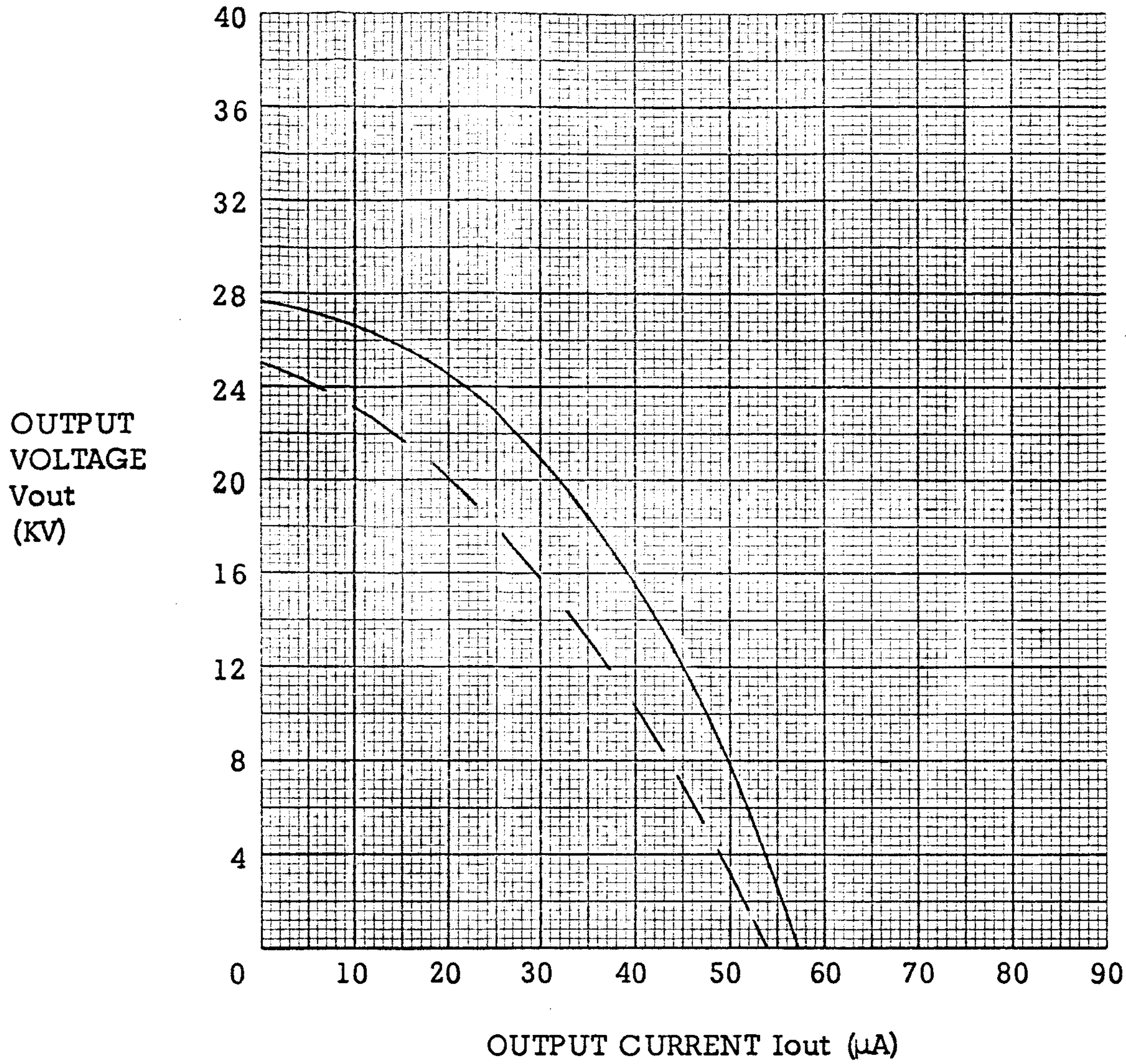
Test 5B. Output Voltage vs. Output Current for Constant Oblique Field Electrostatic Generators with Various Rotor Thicknesses



4.3 KV Breakdown

3550 rpm
0.040" gap
4-pole bare inductor stator

Test 6A. Short Circuit Current vs. Excitation Voltage for Multiple Capacitor Electrostatic Generator



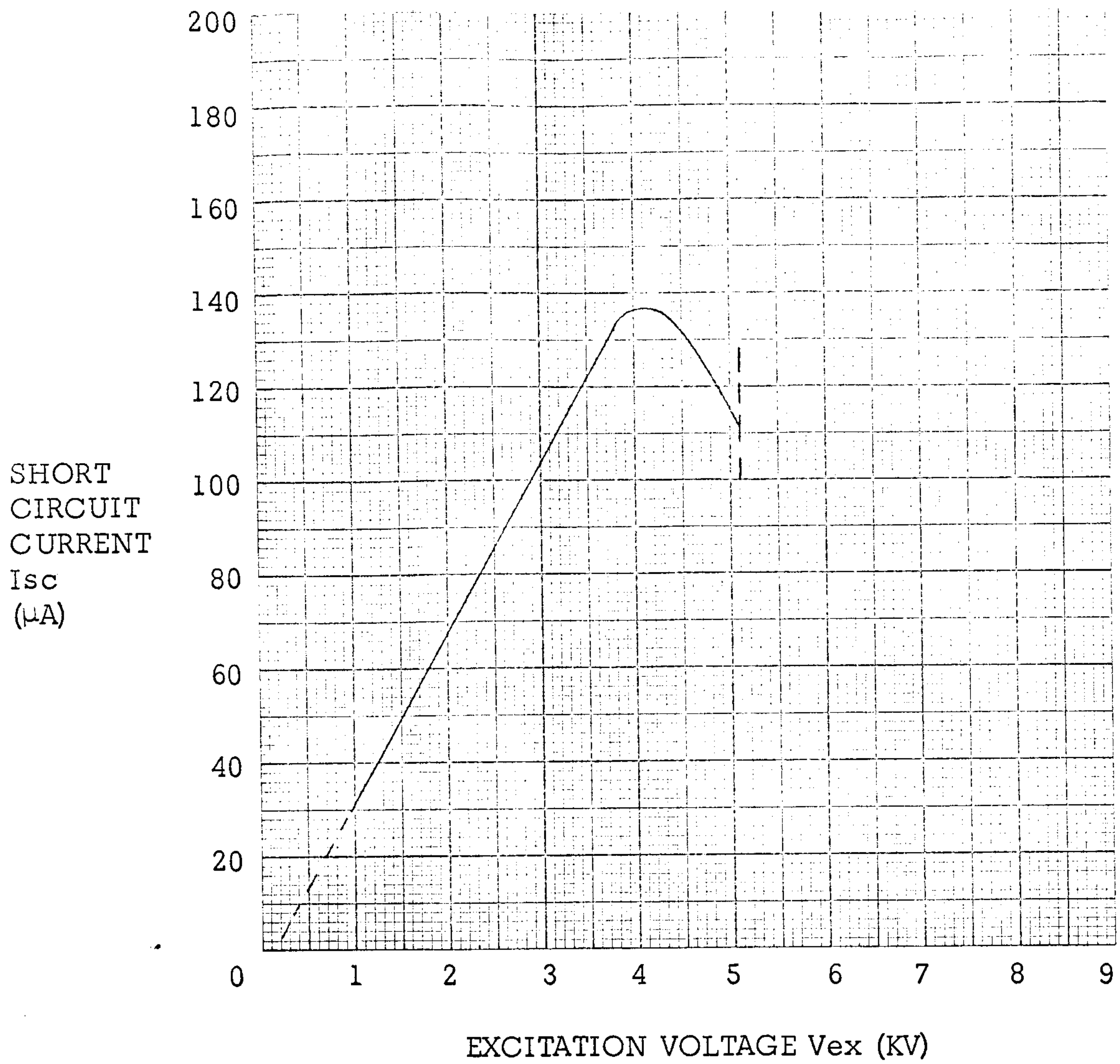
Excitation Voltages

———— 4.2 KV
— — — 4.0 KV

3550 rpm
0.040" gap
4-pole bare inductor stator

Maximum Power Output: 645 milliwatts

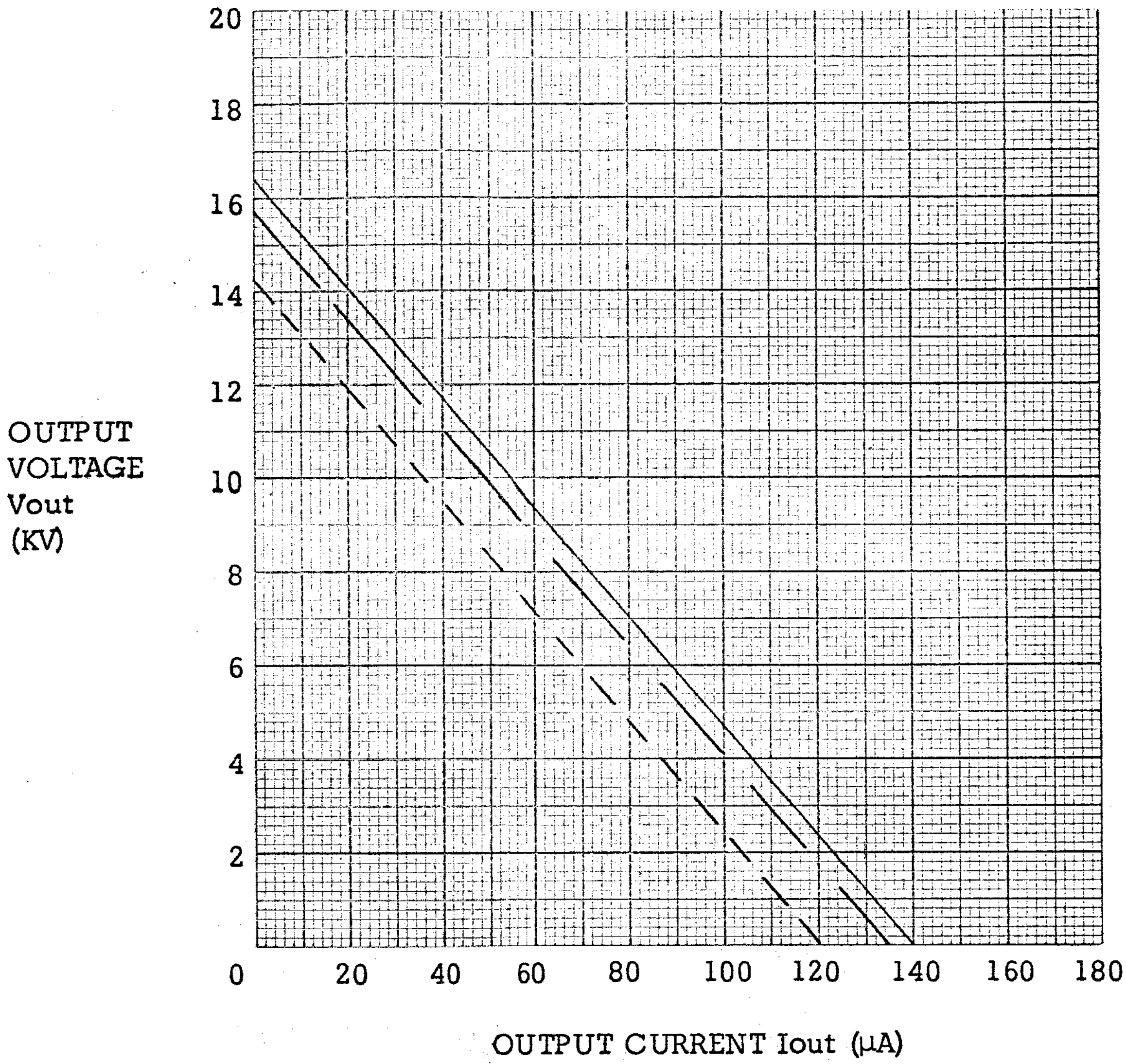
Test 6B. Output Voltage vs. Output Current for Multiple Capacitor Electrostatic Generator



3550 rpm
0.040" gap
8-pole bare inductor stator

5.2 KV breakdown

Test 7A. Short Circuit Current vs. Excitation Voltage for Multiple Capacitor Electrostatic Generator

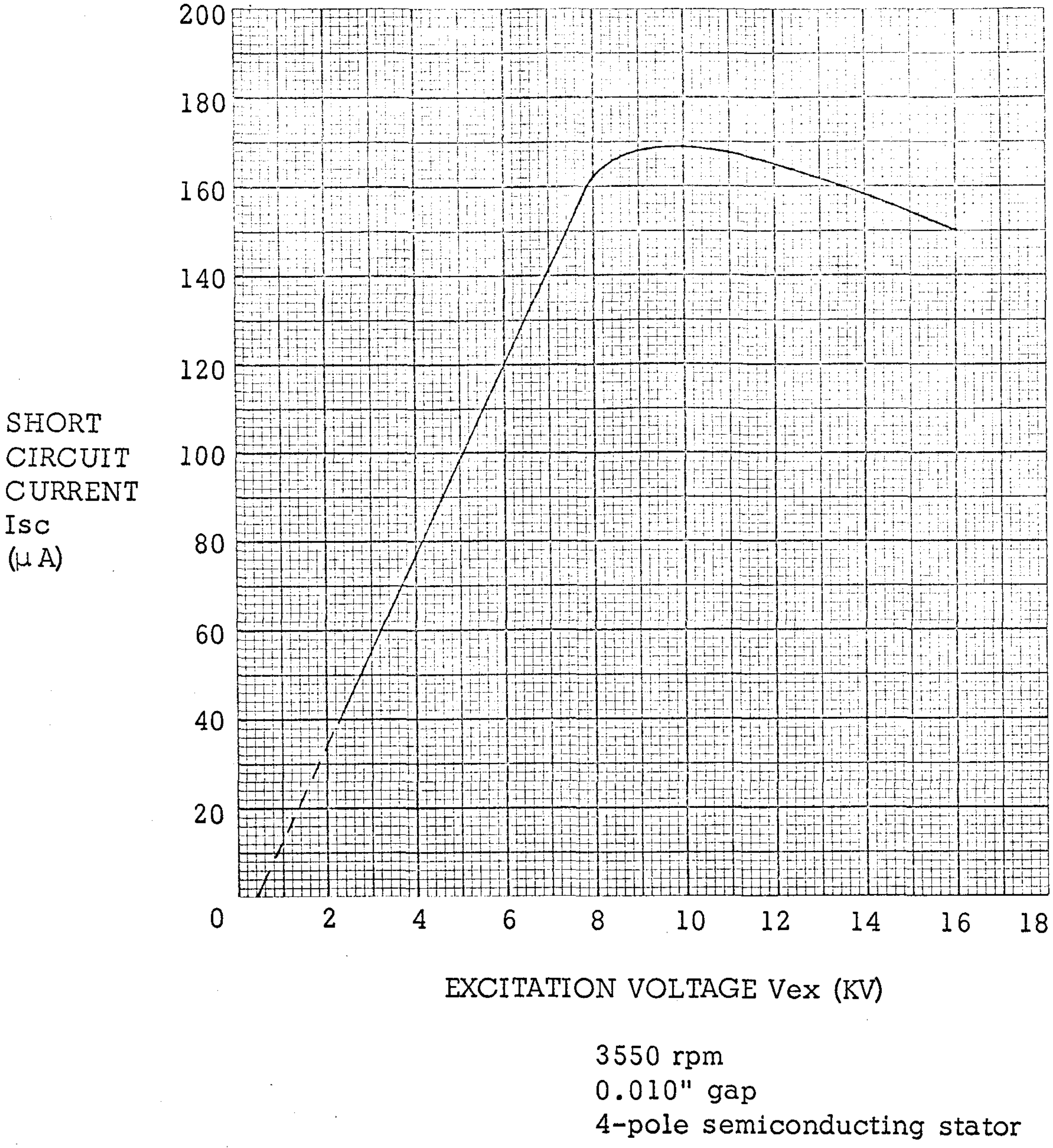


Excitation Voltages

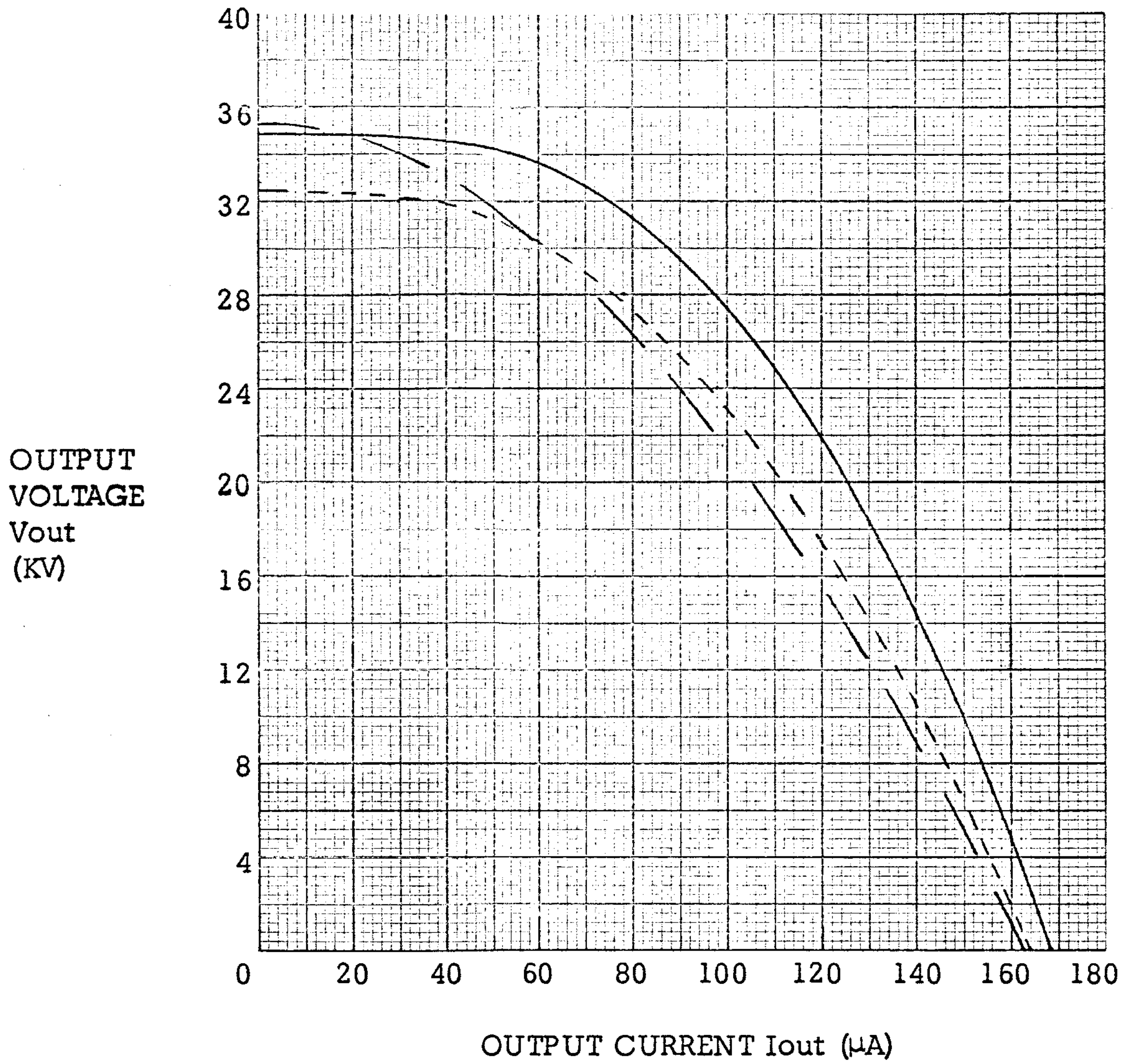
— — — 4.5 KV	3550 rpm
———— 4.0 KV	0.040" gap
- - - - - 3.5 KV	8-pole bare inductor stator

Maximum Power Output: 570 Milliwatts

Test 7B. Output Voltage vs. Output Current for Multiple Capacitor Generator



Test 8A. Short Circuit Current vs. Excitation Voltage for Constant Oblique Field Electrostatic Generator



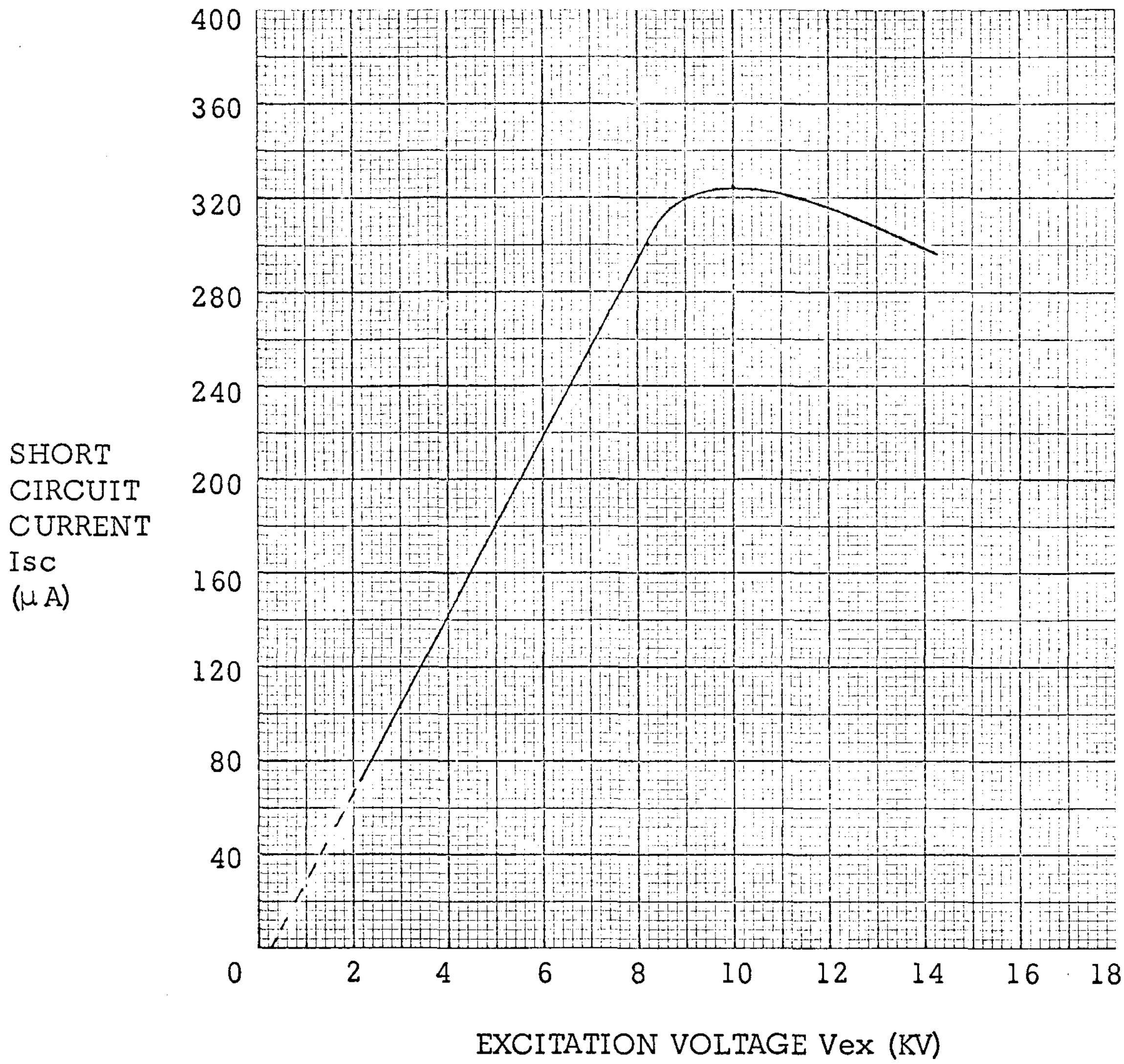
Excitation Voltages

- - - - - - 12 KV
———— 10 KV
— — 8 KV

3550 rpm
0.010" gap
4-pole semiconducting stator

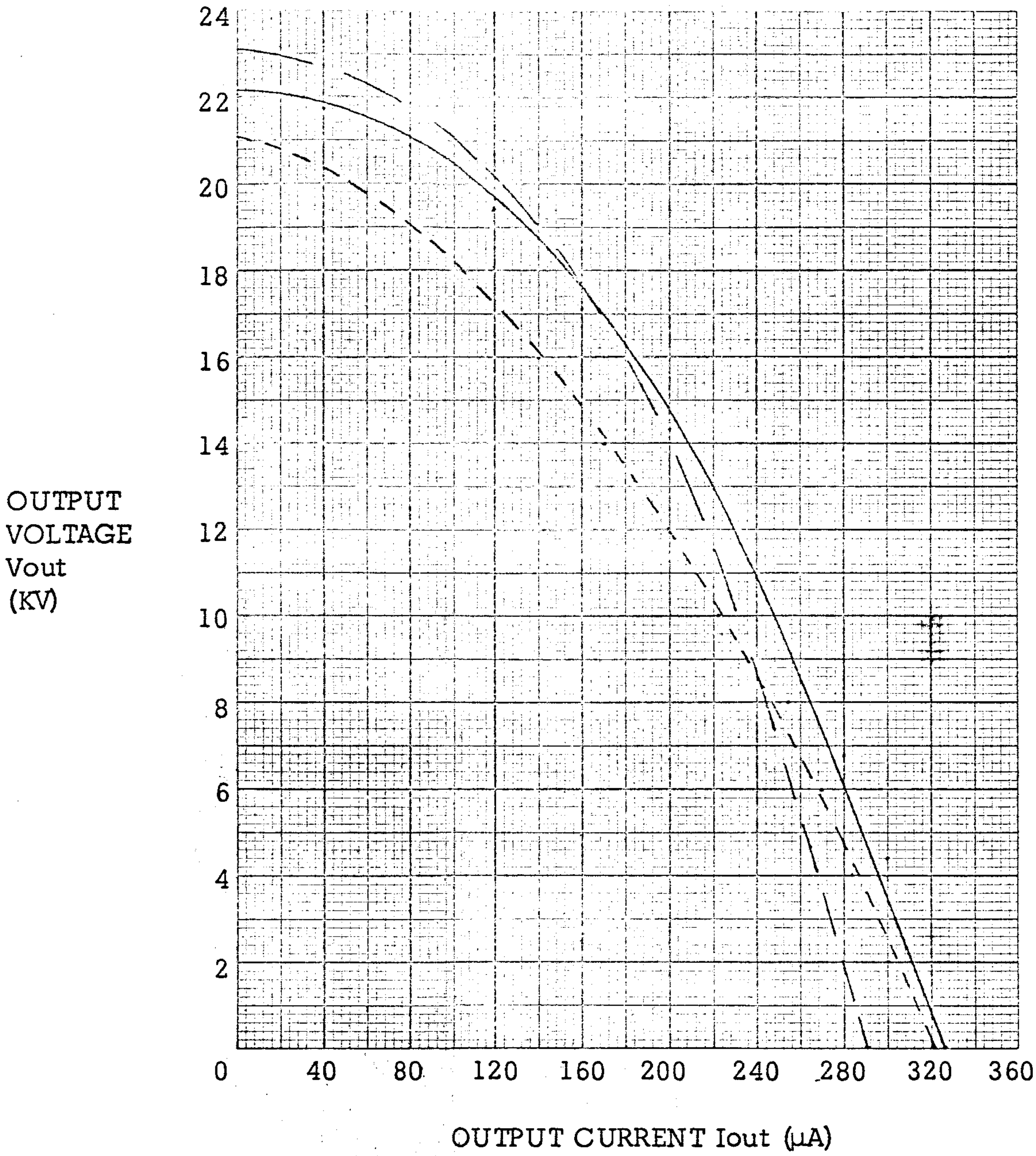
Maximum Power Output: 2.75 Watts

Test 8B. Output Voltage vs. Output Current for Constant Oblique Field Electrostatic Generator



3550 rpm
0.010" gap
8-pole semiconducting stator

Test 9A. Short Circuit Current vs. Excitation Voltage for Constant Oblique Field Electrostatic Generator



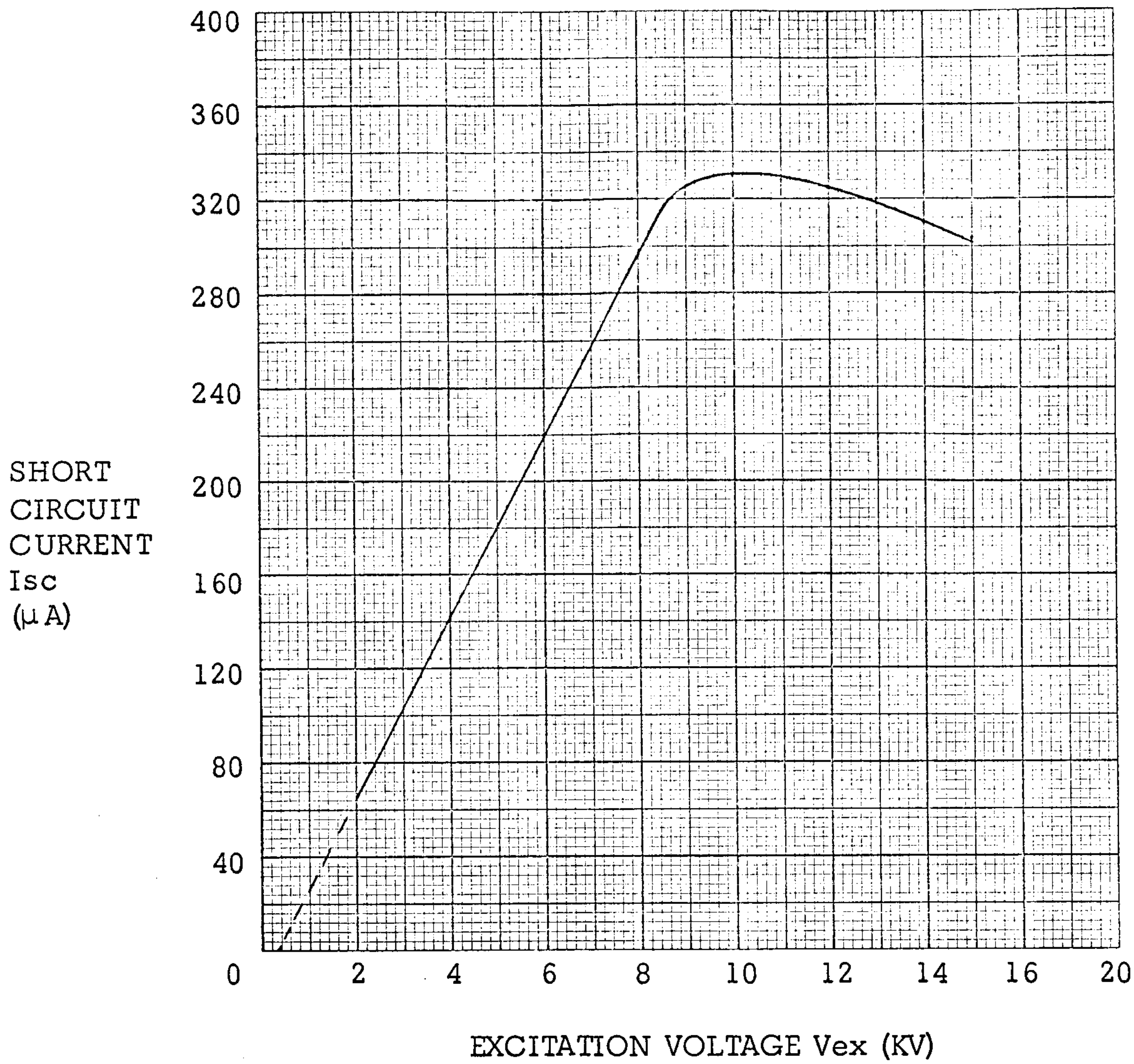
Excitation Voltages

- - - - - 12 KV
——— 10 KV
—— —— 8 KV

3550 rpm
0.010" gap
8-pole semiconducting stator

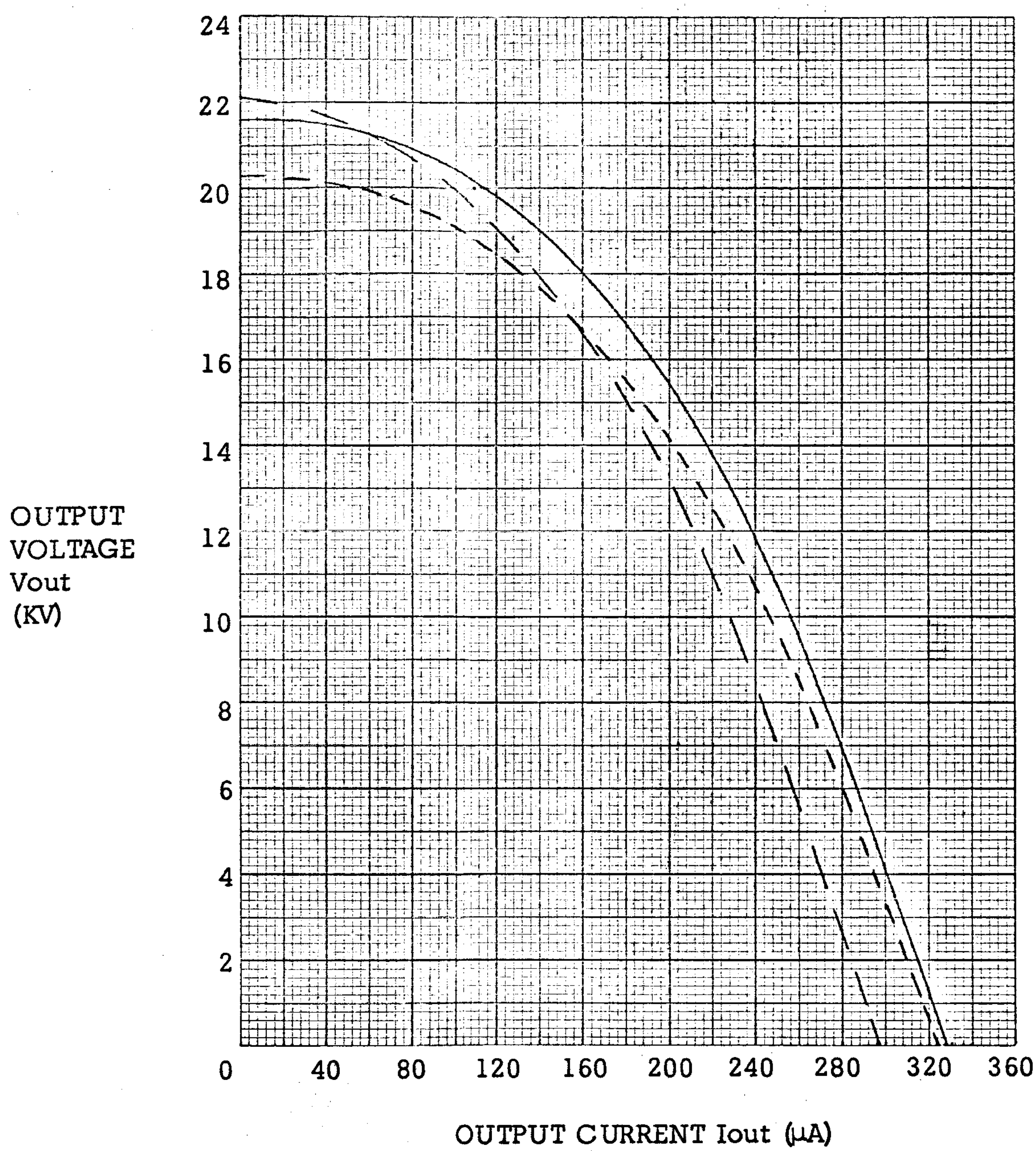
Maximum Power Output: 2.9 Watts

Test 9B. Output Voltage vs. Output Current for Constant Oblique Field Electrostatic Generator



3550 rpm
0.010" gap
8-pole internally connected
semiconducting stator

Test 10A. Short Circuit Current vs. Excitation Voltage for Constant Oblique Field Electrostatic Generator



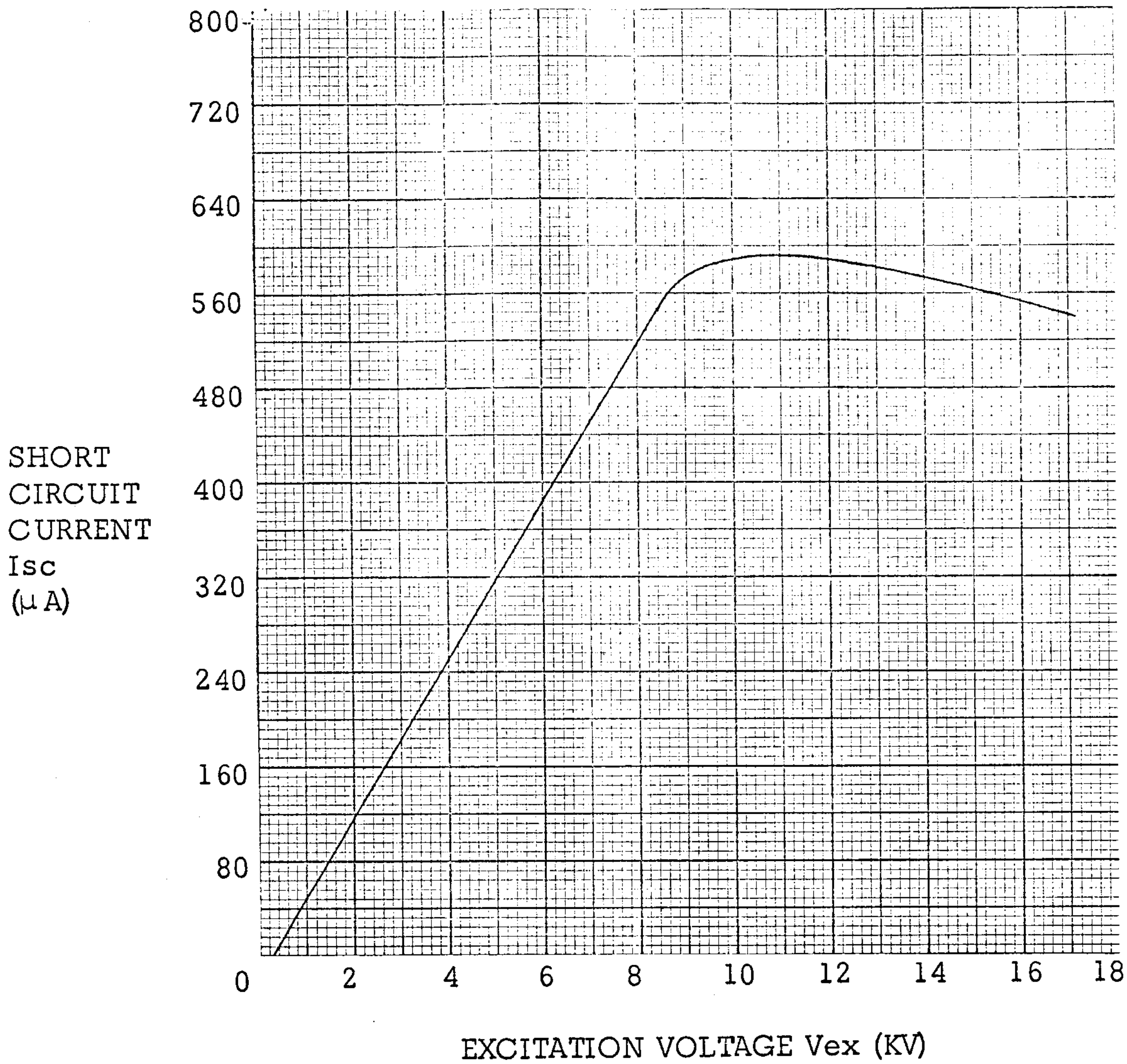
Excitation Voltages

- - - - - 12 KV
———— 10 KV
—— —— 8 KV

Maximum Power Output: 3.1 Watts

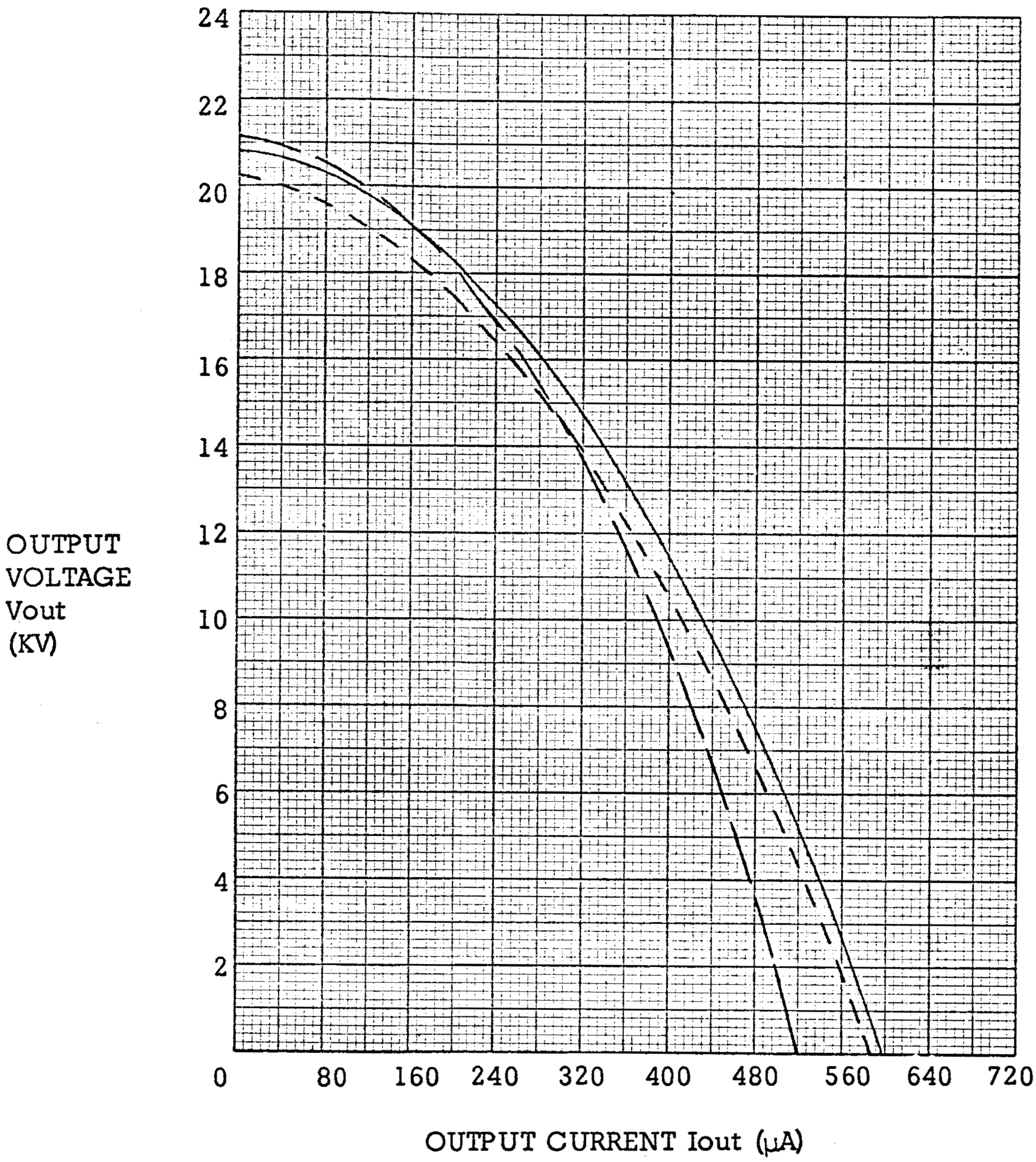
3550 rpm
0.010" gap
8-pole internally connected semiconducting stator

Test 10B. Output Voltage vs. Output Current for Constant Oblique Field Electrostatic Generator



3550 rpm
0.010" gap
8-pole 2-stage semiconducting stator

Test 11A. Short Circuit Current vs. Excitation Voltage for Constant Oblique Field Two Stage Electrostatic Generator



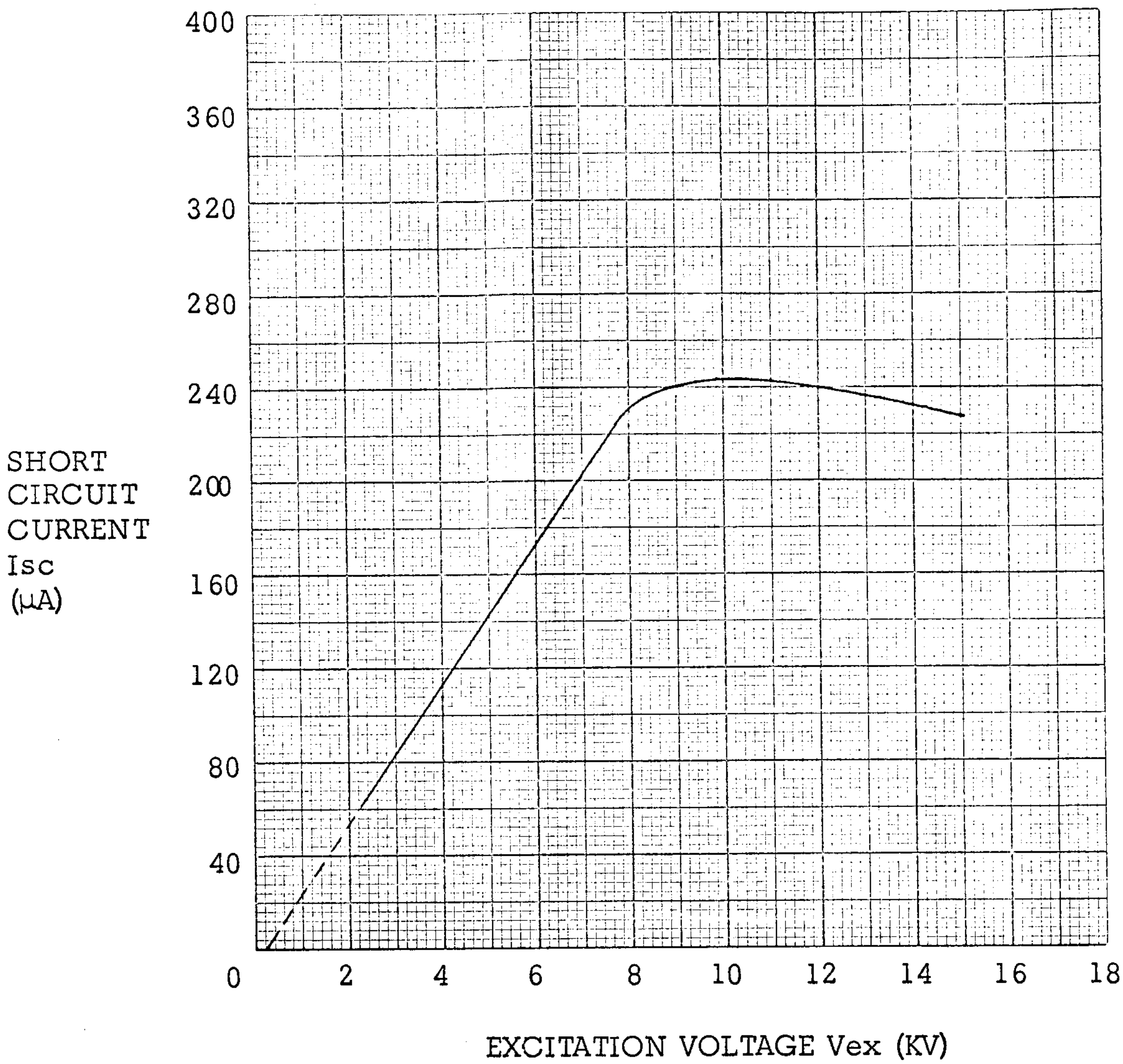
Excitation Voltages

- - - - - 12 KV
——— 10 KV
— — 8 KV

3550 rpm
0.010 gap
8-Pole 2-stage semiconducting stators

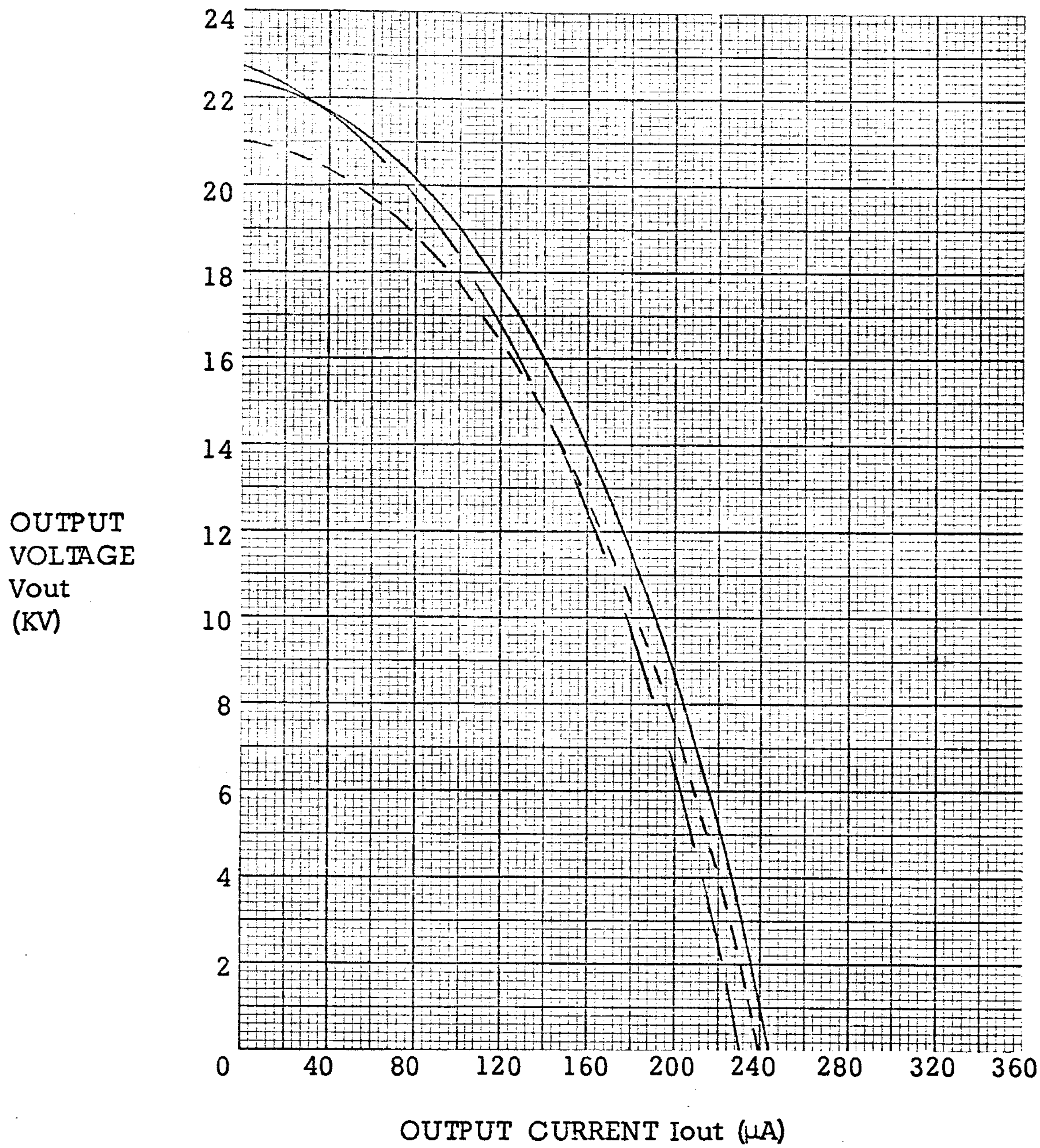
Maximum Power Output: 4.8 Watts

Test 11B. Output Voltage vs. Output Current for Constant Oblique Field Two-Stage Electrostatic Generator



3550 rpm
0.010" gap
6 poles of 8-pole semiconducting stator

Test 12A. Short Circuit Current vs. Excitation Voltage for Constant Oblique Field Electrostatic Generator



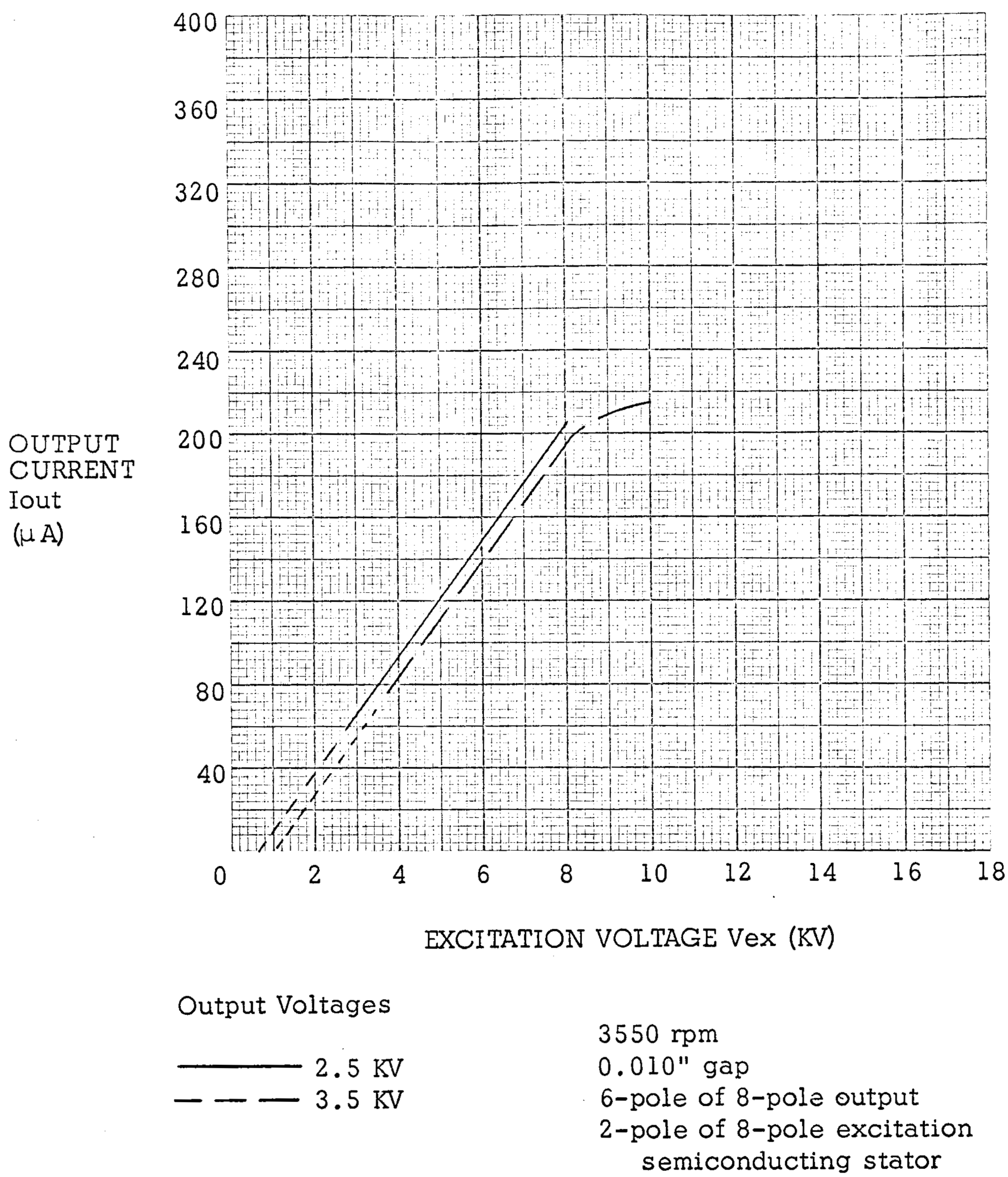
Excitation Voltages

- - - - - 12 KV
———— 10 KV
—— —— 8 KV

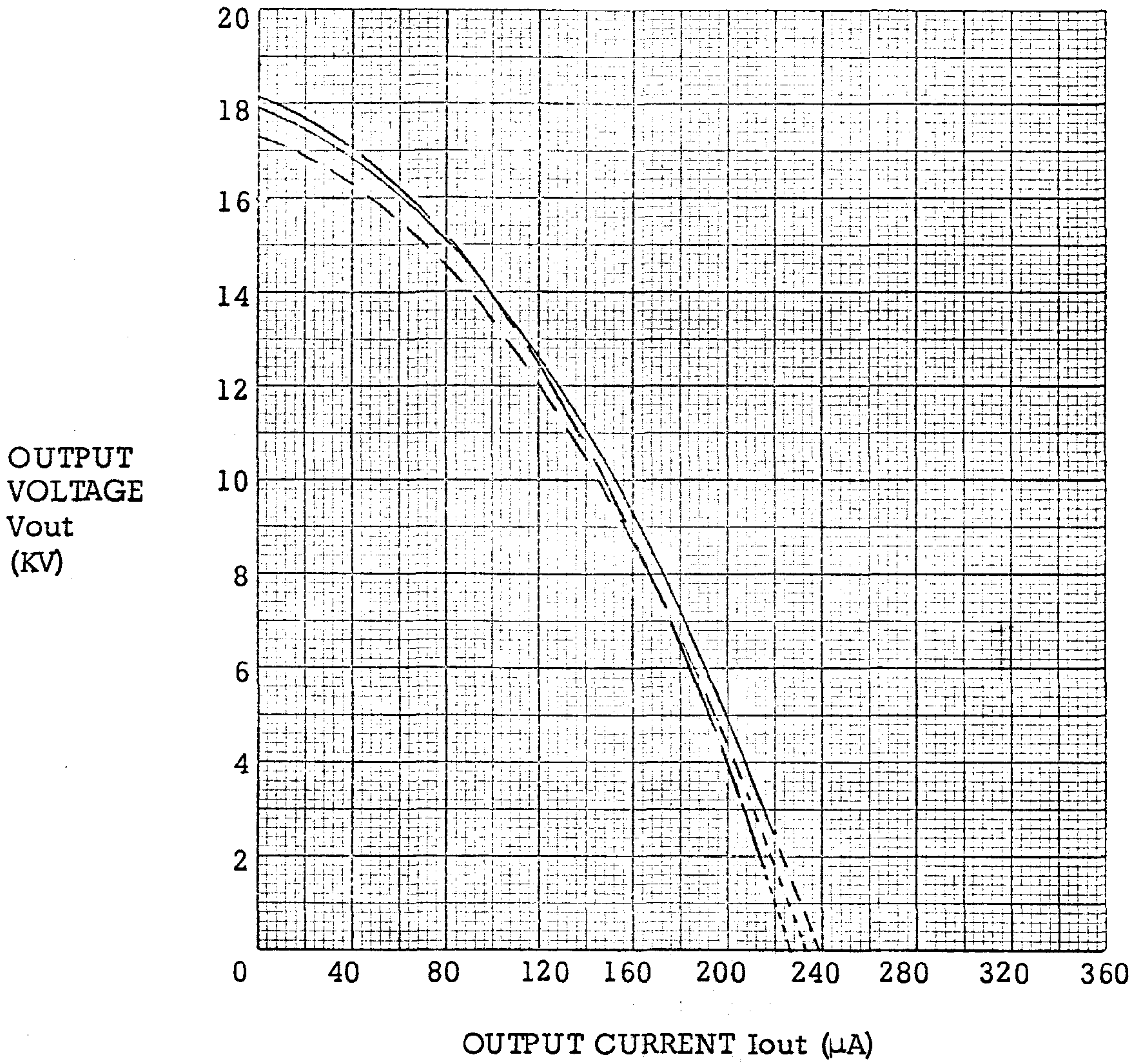
3550 rpm
0.010" gap
6 poles of 8-pole semiconducting stator

Maximum Power Output: 2.3 watts

Test 12B. Output Voltage vs. Output Current for Constant Oblique Field Electrostatic Generator



Test 13A. Output Current vs. Excitation Voltage for Constant Oblique Field Self-Excited Generator



Excitation Voltages

- - - - - - 12 KV
———— 10 KV
—— —— 8 KV

3550 rpm
0.010" gap
6-pole of 8-pole output
2-pole of 8-pole excitation
semiconducting stator

Maximum Power Output: 1.5 Watts

Test 13B. Output Voltage vs. Output Current for Constant Oblique Field Electrostatic Generator

7. Conclusions and Recommendations

The objective of the contract, i.e., to test under the same conditions different configurations of generators, has been met.

No emphasis should be placed on the absolute values obtained since no attempt was made at optimizing generator size or rotating speed and furthermore the generators were operated in air at atmospheric pressure, a poor dielectric indeed.

The powers obtained are as follows (Figure 9):

Single capacitor generator:	14.5 milliwatts
Multiple capacitor generator:	570 milliwatts
C.O.F. generator:	2.9 watts

We can now compare these performances with those obtained with other generators.

The ratio of the power of the three-element machine to that of the two-element machine is approximately 3. This is consistent with the ratio of 4 given by Lodochnikov, et al (Ref. 8).

A C.O.F. generator was built by Cosmic, Inc. for the Aero Propulsion Laboratory of the U. S. Air Force (Reference 5) and produced 12.5 watts at 15,000 rpm in air. As the power is proportional to the rotating speed, this result corresponds to 2.95 watts at 3,550 rpm or exactly the same as the generator tested here.

The single capacitor generator of Reference 3 has a diameter of 20 inches and is capable of 179 watts at 6,000 rpm in a vacuum. To find what the output of the generator tested here would be for that size and rpm one must multiply the output by (see Section 5 above)

$$\frac{6,000}{3,600} \quad x \quad \left(\frac{20}{5}\right)^3 = 107$$

which would give 1.55 watts, i.e., roughly one hundredth the power of the generator of Reference 3. As pointed out earlier, the power of a generator increases as the square of the field which it is possible to maintain in the gap. This field, in the experiment of Reference 3, performed in a very clean vacuum, was about ten times that of the air experiments reported here. It can therefore be said that the results reported here are consistent with those reported by other experimenters.

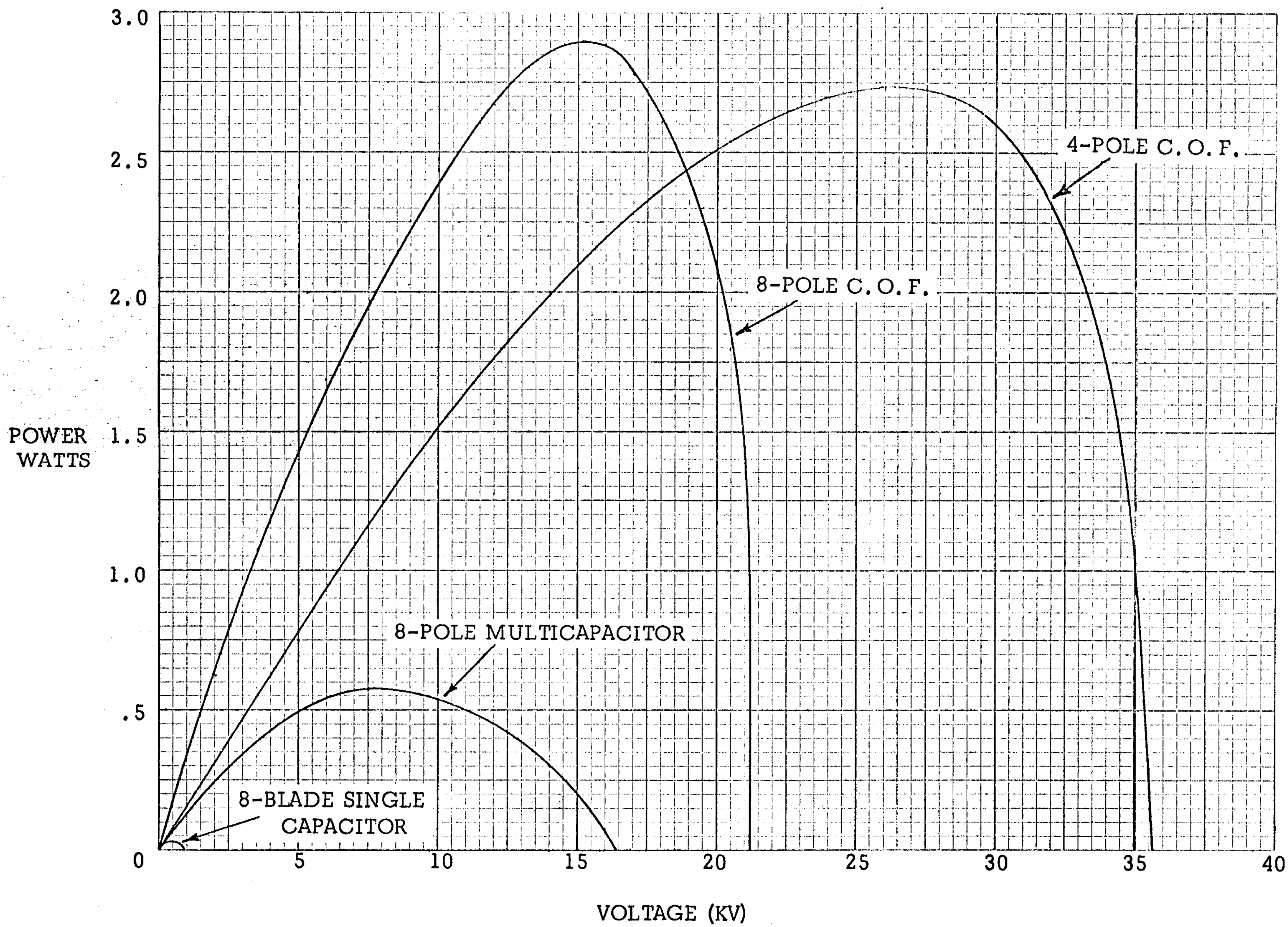


Figure 9. Power as a Function of Voltage for Various Generators.

A conclusion of interest regarding the C. O. F. generator is that, as shown in Figure 9, the power does not vary much with the number of poles, making it possible to produce the same power at different voltage levels with the same rotor, varying only the number of stator poles.

Another conclusion is that the power of the C. O. F. generator appears substantially higher than that of the single capacitor generator. In fact under the conditions of the tests accomplished here the power of the C. O. F. was 200 times that of the single capacitor generator. Whether this ratio will have the same value for machines operated in a vacuum is an important question which will await the construction of a brushless version of the constant oblique field machine.

The good results obtained with the C. O. F. generator in air would certainly justify the construction of a brushless version to operate in a vacuum and benefit from the insulating properties of vacuum.

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ABSTRACT

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Two different designs of electrostatic generators of the same size have been tested under the same conditions in air at atmospheric pressure. Ten arrangements of a constant oblique field, and three of a single capacitor are tested. For each configuration, a curve of short circuit current as a function of excitation voltage and curves of output voltage versus output current for several values of excitation voltage are given. The power of the constant oblique field machine in air is about 200 times that of the single capacitor machine. Extrapolations to vacuum insulation and comparison with other experimental data are given.