

A VACUUM ELECTROSTATIC GENERATOR

B.H. Choi, H.D. Kang, W. Kim, B.H. Oh,
Korea Advanced Energy Research Institute
Daeduk-Danji, Choongnam, 301-353, Korea

and

K.H. Chung
Seoul National University
Shinrim-Dong, Kwanak-Ku, Seoul, 151-741, Korea

Abstract

A compact electrostatic generator designed with the principle of vacuum insulation has been developed. It consists of a rotating insulation disk with charge-carrying conductors placed around the circumference and a non-contact induction system with an electron gun. The usable voltage of 130 kV with the generating current of about 300 μ A has been obtained at the operational pressure of 1×10^{-4} torr.

Introduction

The recent progress of research and industrial applications of ion beams require very stable beams with the high energy of around 1 MeV and the current of a few mA.

A candidate of high voltage sources to produce mono-energetic beams is electrostatic generator, which has superior features such as small voltage ripple and small stored energy in the state of ultra high voltage.

A series of papers [1,2] reported some capabilities of the gas insulating electrostatic generators as high current power sources. But they have problems such as the corona discharge on the contact points and the limited life time of contacters. It is well known that vacuum has very good insulation property like insulation gases. Typically vacuum holds the breakdown field strength of around 1 MV/cm on a small gap of less than 1 mm in the broad pressure range of 5×10^{-3} – 10^{-7} torr. In practical system of long gap including

insulator supports the breakdown strength is limited to about 30 kV/cm due to the flashover phenomena on the insulator surface.

The concept of vacuum insulation instead of gas insulation for the electrostatic generator design has some advantages, such as the capability to hold the high voltage in narrow inductor gap, elimination of the electrical contact problem by utilizing the non-contact induction method, possibility of fine regulation of high voltage, and reduction of frictional wind loss and the mechanical vibration. In addition, elimination of gas handling system may enhance the compactness and the flexibilities for the accelerator system. The characteristics and the operational performance of this vacuum electrostatic generator have been described in this paper.

Experimental Apparatus

The schematic drawing of the vacuum electrostatic generator is shown in Fig. 1. It is composed of the rotating disk, non-contacting induction system at the upper part and contacting induction system at the lower part. These components are in a cylindrical vacuum chamber, made of lucite, which is evacuated to 1×10^{-4} torr by an oil diffusion pumping system.

The rotating insulation disk of 24 cm in diameter has 24 charge-carrying conductor elements of 22 mm in diameter, placed around the circumference of 20 cm. The electric contact with each charge carrying conductor is connected through contact points on the side of the rotating disk as shown in Fig. 2. The

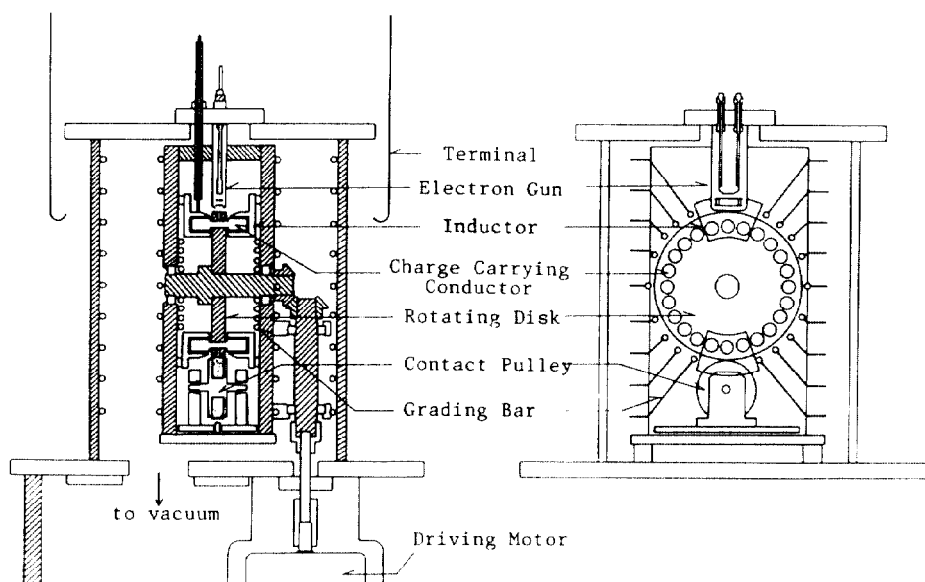


Fig. 1 Cross-sectional view of the vacuum electrostatic generator.

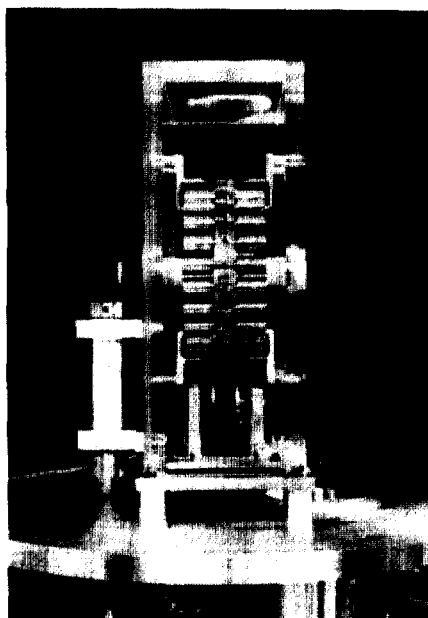


Fig. 2 The rotating insulation disk with two inductors and one contact pulley.

disk is rotated at 1800 rpm by an induction motor coupled with a vacuum sealed shaft. Under the consideration of the mechanical vibration due to high peripheral velocity, all elements on the disk are precisely fabricated and assembled, and the dynamic balance of the disk is assured.

Two different induction systems are designed in order to compare their performances for the charge induction in vacuum. The non-contacting induction system consists of an electron gun and inductor electrodes. For the purpose of preventing stray electrons emitted from the filament and reducing the heat load on the rotating disk, the electron gun

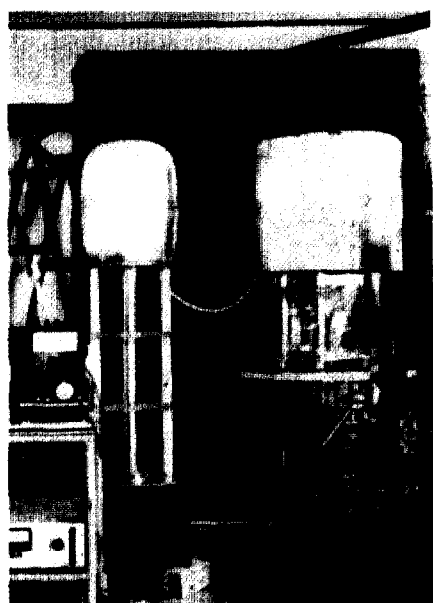


Fig. 3 Overall view of the vacuum electrostatic generator and the motor-generator set.

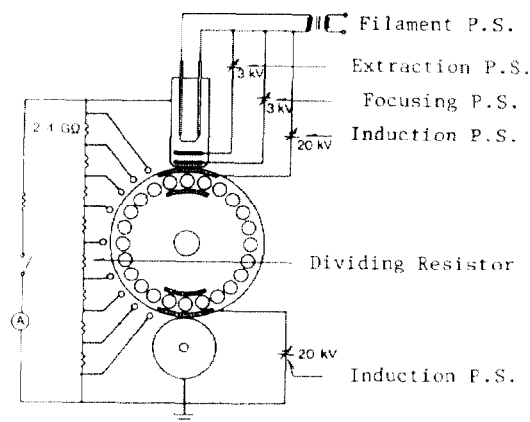


Fig. 4 The electric circuit for the test of the electrostatic generator.

assembly is designed with the extraction electrode and the focusing electrode of the slot type in a housing.

The contacting induction system consists of a conventional pulley-inductor system. The contact point of the pulley is made of the electrically conductive rubber to eliminate the vibration problem. The gap distance between the cylindrical surface of the conductors and the inner surface of the inductors is 1 mm.

For the electrostatic design of the vacuum insulation, the field strength of the triple junction [3] which is formed at the metal/vacuum/insulator interface on the rotating disk is reduced by cutting the conductor edges with the angle of 45 degree. In order to divide the generated potential, nine equally spaced grading bars and plates are placed between the high voltage terminal and the ground. Each gap between the plates is connected with one 2.4 GΩ resistor.

Near the entrance and exit parts of the inductor, the clearance is enlarged gradually to prevent the corona discharge due to a high electric field on the edge of the inductors. Electric power for the electron gun and the inductor floated in potential

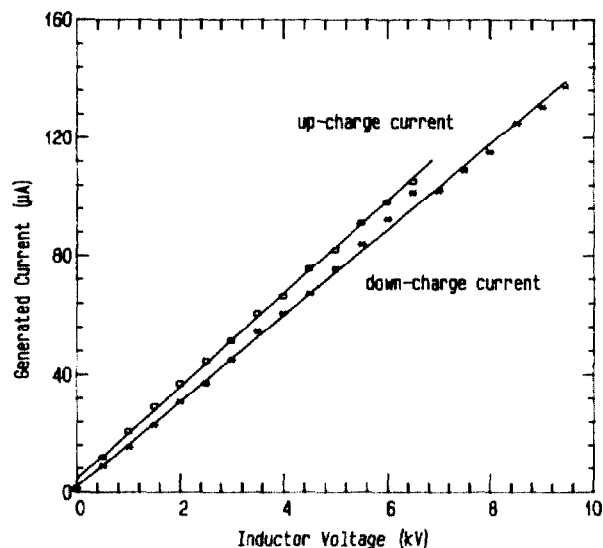


Fig. 5 The up- and down-charge currents as a function of the inductor voltage.

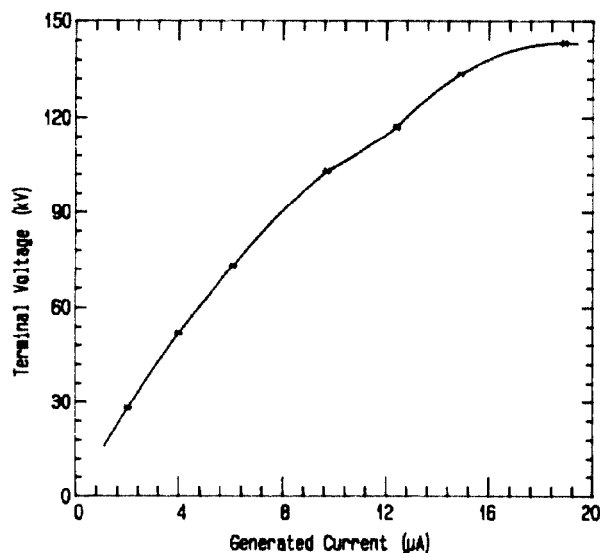


Fig. 6 The terminal voltage versus the down-charge current.

above 300 kV is provided by an motor-generator set, as shown in Fig. 3. The electric circuit for the generator operation is shown in Fig. 4.

Results and Discussion

Fig. 5 shows the generated currents as a function of inductor voltage when the high voltage terminal is grounded. The up-charge current transferred through the contact pulley is slightly higher than the down-charge current loaded from the electron gun due to the space charge effects on the insulator.

The up- and down-charge currents to the inductor are 15.7 μA and 14.5 μA per kV, respectively. The corresponding amounts of charge carried by one conductor element on the rotating disk is $2.2 \times 10^{-8} \text{C/kV}$ and $2.0 \times 10^{-8} \text{C/kV}$. It is in good agreement with the estimated capacitance of 21.2 pF between a conductor

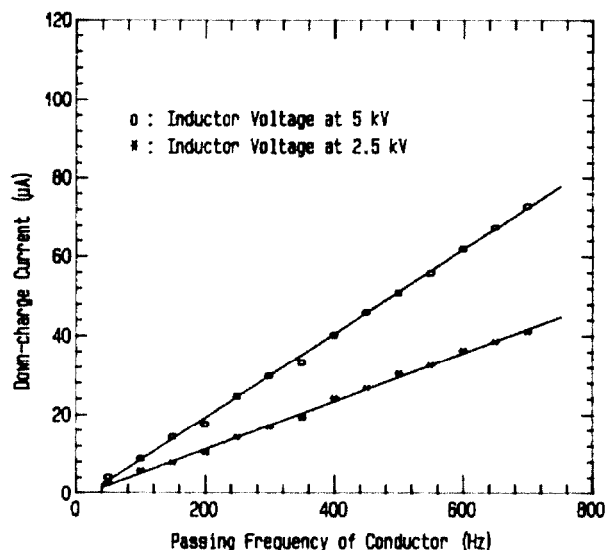


Fig. 7 Relation between the down-charge current and passing frequency of the charge carrying conductor.

and an inductor electrode which is calculated by using the mapping method.

After conditioning the inductor gaps at the voltage of 25 kV, the dark current in the gap is lowered below 0.1 μA . In spite of the above insulation strength, the actual applied voltage on the inductors are limited below 10 kV by microdischarges between charge carrying conductors when the disk rotates. The discharge phenomenon may be caused by the flashover across the surface of the insulation disk. This problem could be eliminated by improving the electrostatic design of the triple junction on the disk.

The generated voltage is measured by a generating voltmeter. Fig. 6 shows the terminal voltage as a function of generated current. The terminal voltage depends linearly on the inductor voltage below 100 kV, but is slowly saturated at the voltage of 150 kV due to the corona losses at the terminal, because it is insulated in atmosphere. Another cause for the limitation is spark discharges through the rotating disk around 150 kV.

Fig. 7 shows the generated current as a function of the passing frequency of the charge carrying conductor to confirm the proportionality between them. The down-charge current is in proportion to the frequency at each inductor voltages, and the up-charge current is also in proportion.

Conclusion

The non-contact induction system by utilizing the electron gun in vacuum is stably operated without producing the corona discharge. The generated current is in good agreement with the estimated value of $2.1 \times 10^{-8} \text{A/kV}$. It can be precisely controlled by change of the extraction voltage of electron beam as well as charge of the induction voltage.

The voltages applied in both non-contact and contact induction systems, each have the gap of 1 mm, are limited at 10 kV and 6 kV respectively due to the microdischarges in the gaps. The limitation and the difference of the applied voltage come from serious field distortion which is produced by negative or positive charges on the surface of the disk insulator.

The maximum terminal voltage is limited by spark discharges from the high voltage terminal to surrounding grounds and sometimes through the charge carrying conductors. It is expected that the careful electrostatic design, especially the triple junction in vacuum, should increase the generated voltage and current.

References

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