INVESTIGATION OF ELECTRON BEAM TRANSPORT IN A MAGNETRON GUN WITH A SECONDARY-EMISSION CATHODE

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Results are reported from the studies of electron beam generation in the magnetron gun and beam transport over distances of 3 and 40 mm. The studies have demonstrated that the beam current and the beam dimensions remain unchanged with the beam transport over a distance of 40 mm from the gun in the increasing magnetic field, the latter being 10 to 15% higher at the Faraday cup than at the cathode.

PACS: 41.75.Fr, 87.50.Mn

1. INTRODUCTION

Powerful electron beams present one of the efficient techniques for modifying the surface properties of materials. This is of current interest for improving the strength and wear resistance of reactor structural materials, and also for extending the service life of reactor components. As the material is exposed to the beam, its layer of about the particle range in depth quickly heats up to the phase transition temperatures, and then cools down. The rates of heating and cooling are dependent on the properties of the material and the beam parameters. It has been demonstrated in refs. [1,2] that the optimum electron beam parameters for material surface modification are as follows: electron energy from 100 to 400 keV, power density on the surface of the material under treatment from 1 to 5 MW/cm^2, pulse length between 5 and 50 µs. At these beam parameters the depth of the modified layer ranges between 10 and 100 µm. The accelerating devices generally used include an electron source, a focusing solenoid and a target from the material under study.

Thermionic electron guns and explosive-emission electron guns of different modifications are generally used as an electron source. The reliability and service life of these devices are substantially dependent on the lifetime of the cathode, and this motivates the search for and the use of new types of cathodes.

Considerable recent attention has been focused on magnetron guns with cold secondary-emission cathodes, which offer a number of advantages when used as an electron source. In particular, these guns are simple in design, keep up emission after letting to air, their service life may attain 100 000 hours.

The present report describes the results from the experiments on beam generation and transport using electron sources with cold secondary-emission metallic cathodes.

2. THE EXPERIMENTAL SETUP AND RESEARCH TECHNIQUES

Experiments aimed at investigating the parameters of the beam and its transport were performed at the setup schematically shown in Fig.1. A specially shaped voltage pulse from a pulse generator 1 was supplied to the gun cathode 6, while the anode 7 was connected to the resistor R3, which was used to measure the anode current. The voltage pulse spike amplitude ranges from 30 to 100 kV, the spike-fall time makes ~ 0.3 µs, the amplitude of the flat part of the pulse ranges between 7 and 60 kV, the voltage pulse duration is ~ 8 µs, the pulse-recurrence rate is between 10 and 20 Hz.

The experiments were conducted with a magnetron gun of coaxial geometry. The cathode was 40 mm in diameter and 70 mm in length, while the anode was 70 mm in diameter and 140 mm in length. Copper and stainless steel were used to make the cathode and the anode, respectively. The magnetron gun was placed in a vacuum volume 3, where the pressure was kept to be ~ 10^{-6} Torr.

The magnetic field for producing and transporting the electron beam was generated by a solenoid 4 that consisted of 4 sections and was energized by a dc power supply. The magnetic field amplitude and longitudinal distribution could be adjusted by varying the current value in the solenoid sections. Fig.2 shows the longitudinal component distributions of the magnetic field along the *z*-axis and the magnetron gun location in the solenoid, at which the experiments were performed. The field distribution could be varied so that in the region of beam transport it changed from rising to falling. The beam transport was investigated by measuring the beam parameters as functions of the magnetic field distribution along the axis of the system, at distances of 3 mm and 40 mm from the anode.

The beam parameters were investigated using an 8-channel Faraday cup and a computer-aided measuring system. The measurement accuracy was within 1 to 2%. Measurements were taken of the beam current from each of 8 segments of the Faraday cup, and also, of the cathode voltage and the anode current. The parameters were measured during 16 voltage pulses following each other. Then, the data obtained were processed with a computer to calculate the net beam current, the net charge distribution of the beams from the Faraday cup segments, the coefficient of azimuthal beam current homogeneity ($k=I_{max}/I_{min}$, where I_{max} and I_{min} are, respectively, the maximum and minimum current values of the Faraday cup segments), etc. The data were displayed on the computer screen. The transverse dimensions of the beam were measured with the help of its imprint on the aluminum target.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The present experiments have shown that the magnetron gun with a secondary-emission cathode generates an electron beam in the cathode voltage range between 6 and 50 kV. At a cathode voltage of 50 kV and a falling magnetic field the gun forms a tubular electron beam with a net current of ~ 50 A, the anode current making ~ 1% of the net beam current.

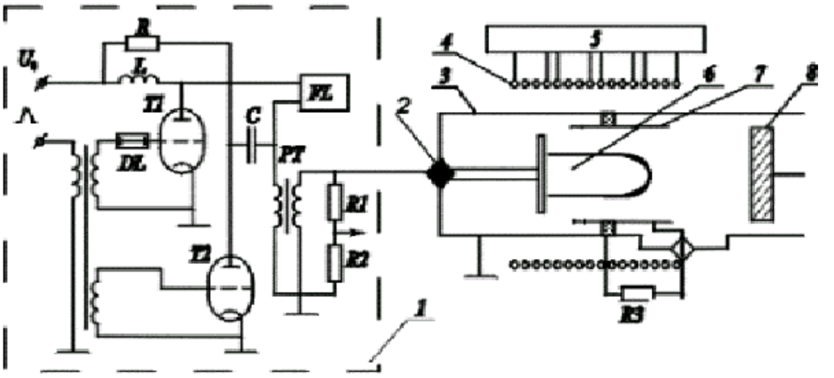

Fig.1. Scheme of the setup. 1 – modulator; 2 – insulator; 3 – vacuum chamber; 4 – solenoid; 5 – solenoid's power source; 6 – cathode; 7 – anode; 8 – Faraday cup

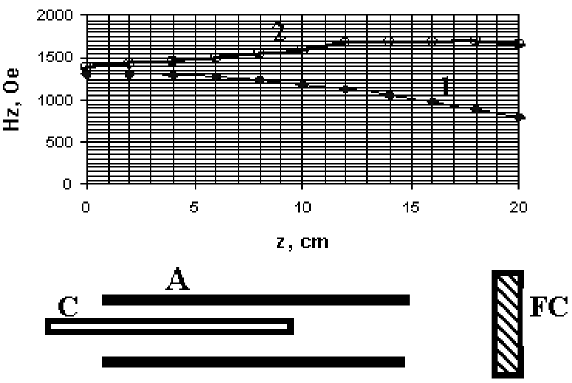

Fig.2. Magnetic field distribution and magnetron gun location (A –anode; C – cathode; FC – Faraday cup)

The effect of the magnetic field value on the electron beam generation was investigated at a constant amplitude of the open-circuit cathode voltage of 45 kV. It is shown that the electron beam formation persists with a variation in the magnetic field amplitude ΔH ~300 Oe and the beam current varies only slightly. As the magnetic field amplitude approaches the ΔH boundary from above and from below, the condition of beam generation is broken with the result that the process of secondary-emission multiplication is disrupted [3].

Studies were made into the beam transport over distances of 3 mm and 40 mm from the gun. The studies were performed for two axial distributions falling (Fig.2, curve 1) and rising (Fig.2, curve 2) of the magnetic field.

In the first case, the magnetic field distribution showed a drop from 1300 Oe at the cathode with a gradient of 40 Oe/cm to the Faraday cup. At a distance of 3 mm, the tubular electron beam had a beam current of ~ 37 A at a cathode voltage U = 36 kV. At a distance of 40 mm, the beam current amplitude remains practically the same.

In the second case, at a distance of 3 mm, with a rising (curve 2) magnetic field which varied from 1480 Oe at the cathode up to 1700 Oe at the Faraday cup, the beam current decreased down to 18 A at a cathode voltage of 39 kV. At a distance of 40 mm, the beam current remained practically the same.

Figure 2 shows the magnetic field distribution along the axis of the system and the channel of beam transport, and also the beam dimensions for two cases: falling (1) and rising (2) magnetic fields.

In the first case, when the magnetic field intensity at the cathode was 1300 Oe and fell down to the Faraday cup with a gradient of 40 Oe/cm (curve 1), at a distance of 3 mm the tubular electron beam had an outer diameter of D_1~ 45 mm, the beam wall thickness being of ~ 3 mm. At a distance of ~ 4 cm, the outer diameter D_1 increased up to 50 mm, and the beam wall thickness changes insignificantly. The coefficient of the azimuthal inhomogeneity of the beam makes ~ 1.08.

In the other case, at a rising (curve 2) magnetic field distribution from 1480 Oe at the cathode up to 1700 Oe at the Faraday cup, the outer diameter D_1 of the beam was measured to be 38 mm, the wall thickness being 2 mm. At Z = 4 cm the beam dimensions remained practically the same, and the coefficient of the azimuthal inhomogeneity of the beam, k, made up ~2.8.

Fig.3,a and 3,b shows the beam imprints receive on the aluminum target, which was at distances of 3 mm and 40 mm from the gun end rising (2) and falling (1) magnetic fields.

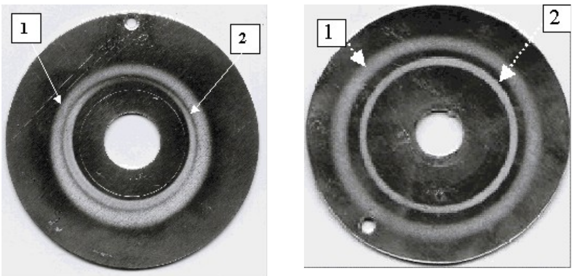

Fig.3. Beam imprint: a – at Z = 3 mm; b - at Z = 40 mm. (1 – falling magnetic field; 2 - rising magnetic field)

Thus, in the rising magnetic field (which is 10 to 15% higher at the Faraday cup than the one at the cathode) the beam transport at a distance of 40 mm proceeds without increase in the outer D_1 and inner D_2 diameters of the electron beam (Fig. 4). However, in this case the coefficient of azimuthal inhomogeneity of the beam does increase.

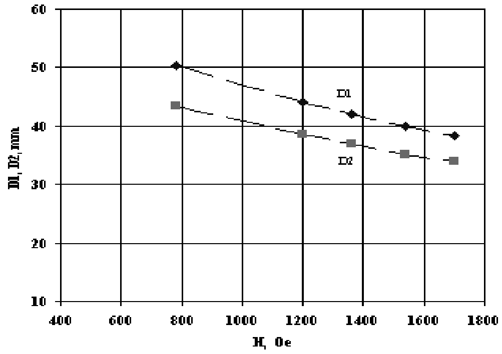

Fig.4. Outer – D_1 and inner – D_2 diameters of the beam versus magnetic field amplitude at the Faraday cup

4. CONCLUSION

The present studies have demonstrated that the beam current amplitude remains practically unchanged as the beam is transported over a distance up to 44 mm from the gun. In this case, in the rising magnetic field the beam dimensions vary only slightly, while in the falling field they increase, but the beam wall thickness remains practically the same. It has been shown that the beam current value at the target is dependent on both the amplitude and distribution of the magnetic field, this being due to the conditions of beam generation in the magnetron gun with a secondary-emission cathode.

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ИССЛЕДОВАНИЕ ТРАНСПОРТИРОВКИ ЭЛЕКТРОННОГО ПУЧКА В МАГНЕТРОННОЙ ПУШКЕ С ВТОРИЧНОЭМИССИОННЫМ КАТОДОМ

А.Н. Довбня, В.В. Закутин, Н.Г. Решетняк

Приведены результаты исследования генерации и транспортировки электронных пучков магнетронной пушки на расстояние 3 и 40 мм. Исследования показали, что ток пучка и его размеры не изменяются при транспортировке пучка на расстояние 40 мм от пушки в нарастающем магнитном поле, которое на цилиндре Фарадея больше поля на катоде на 10…15%.

ДОСЛІДЖЕННЯ ТРАНСПОРТУВАННЯ ЕЛЕКТРОННОГО ПУЧКА В МАГНЕТРОННІЙ ГАРМАТИ З ВТОРИННОЕМІСІЙНИМ КАТОДОМ

А.М. Довбня, В.В. Закутін, М.Г. Решетняк

Приведені результати дослідження генерації та транспортування електронних пучків магнетронної гармати на відстань 3 і 40 мм. Дослідження показали, що струм пучка та його розміри не змінюються при транспортуванні пучка на відстань 40 мм від гармати в наростаючому магнітному полі, яке на циліндрі Фарадея більше поля на катоді на 10…15%.