INVESTIGATION ON THE ELECTRON BEAM FORMATION IN THE MAGNETRON GUN WITH A SECONDARY-EMISSION CATHODE USING THE MAGNETIC SYSTEM BASED ON PERMANENT MAGNETS

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INTRODUCTION

The interest in the physics of processes with crossed electric and magnetic fields is aroused in connection with their wide application in the high-power vacuum electronics. Of a particular interest is the use in such devices of electron magnetic guns with secondary-emission cathodes as electron sources [1-3]. In the investigations of magnetron guns used were relatively long [1, 3] secondary-emission cathodes placed in the longitudinal magnetic field formed by the solenoid.

The present paper gives the results of investigations on the electron beam formation in the magnetron guns with secondary-emission cathodes having small longitudinal sizes in the magnetic system based on the permanent annular magnets made of NdFeB material.

EXPERIMENTAL SETUP AND INVESTIGATION METHODS

Experiments aimed to the investigation of the electron beam formation and its parameters were carried out at the facility schematically shown in Fig.1. For the electron beam powering a long (~50 µs) pulse generator was used. The present system uses a complete discharge of the storage capacitor C_1, advancing through the correcting circuit L_2R_2 to the pulse transformer. Using the low-resistance circuit: L_2 = 134 µHn and R_2 ~ 3 Ohm it is possible to decrease the voltage pulse drop during the high-current electron beam generation. The discharge of the capacitor C_2 provides a top-surge voltage pulse transmitted to cathode 4. The surge amplitude is from 10 to 45 kV, and the pulse repetition rate is from 3 to 7 Hz. Anode 5 is earth-connected via the resistor. The magnetron gun was placed in the vacuum chamber with a pressure maintained to ~10^{-6} Torr. The beam parameters were studied by means of Faraday cup 6 with 12-channel computer-assisted measuring system 7.

The investigations were carried out using the digital storage oscillograph Tektronix TDS-2014.

The cross-sectional dimensions of the beam were measured by making an indentation on the targets made of different materials.

The experiments on the electron beam formation in the magnetron gun with secondary-emission cathodes were realized using a magnetic system based on permanent annular magnets 8.

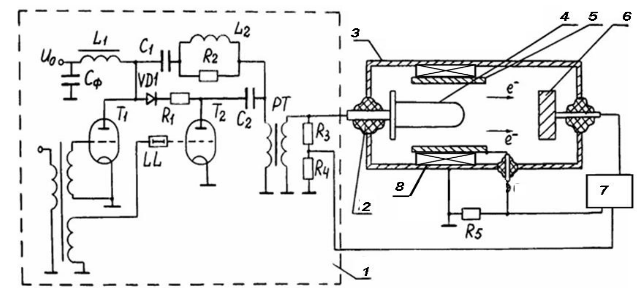

Fig.1. Schematic representation of the experimental setup: 1 – pulse generator, 2 – insulator, 3 – vacuum chamber, 4 – cathode, 5 – anode, 6 - Faraday cup, 7 – computer measuring system, 8 – permanent annular magnets.

EXPERIMENTAL RESULTS AND DISCUSSION

For experiments permanent annular magnets of NdFeB having internal diameter of 60 mm, external diameter of 80 mm and thickness of 10 mm were manufactured. The distribution of longitudinal (H_z) and radial (H_y) magnetic field components for magnetic assemblies was studied depending on the number of rings in the system. The most optimum field for the beam forming magnet system, with relation to the field homogeneity of ±5 % and its amplitude of ~750 Oe, is the magnetic system of 10 rings having 10 cm in length (Fig.2).

Since we have selected a magnetic system having the longitudinal magnetic field amplitude of ~ 750 Oe, it was necessary to select the magnetron gun geometry for realization of experiments and electron beam generation.

In the previous experiments [1] investigations were carried out using the magnetron beam with the cathode of 5 mm in diameter, the anode of 50 mm in diameter, and the maximum cathode voltage of 60 kV in the solenoidal magnetic field with amplitude of 200 Oe. It has been shown that the beam generation is reached with the drift velocity V_D ~ cE/H~0,15c . At lower cathode voltages of 26…27 kV, the electron beam was formed in the magnetic field of 900…950 Oe, and the radial component was ~10 Oe.

The estimates show that in the experiments using the magnetron gun with the anode of 56 mm in diameter and cathode of 5 mm in diameter at the cathode voltage of 20 kV it is necessary to have a magnetic field of ~750 Oe for electron beam forming. The investigation of electron beam formation and its parameters was carried out for two geometries of magnetron guns: anode diameter of

56 mm and its length of 70 mm, cathode diameters of 6 and 10 mm, cathode lengths varying from 40 to 60 mm.

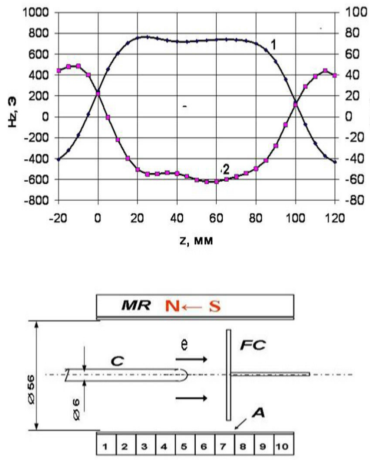

Fig.2. Distribution of Hz (curve 1) and Hy (curve 2) fields and the layout of the magnetron gun components
MR – permanent magnet, C – cathode, A – anode,
FC - Faraday cup.

Fig.2 shows the distribution of longitudinal and transversal magnetic fields on the radius of 3 mm along the magnetron gun axis with the cathode diameter of 6 mm. From the figure it is seen that the longitudinal component of the magnetic field is ~750 Oe, and the radial component is short and equals to ~ <60 Oe.

Also we have carried out experiments on the electron beam generation and measurement of electron beam parameters in the magnetron gun with the cathode diameter of 6 mm using the magnetic system based on permanent magnets. Experimental results have shown that at the cathode voltage of 15…25 kV the stable electron beam generation occurs. At the cathode voltage U ~ 17.5 kV the magnetron gun forms a tubular electron beam with a current of 3.5 A and duration of ~50 µs. Fig.3 represents the typical oscillograms of the cathode voltage (U) and the electron current onto the FC.

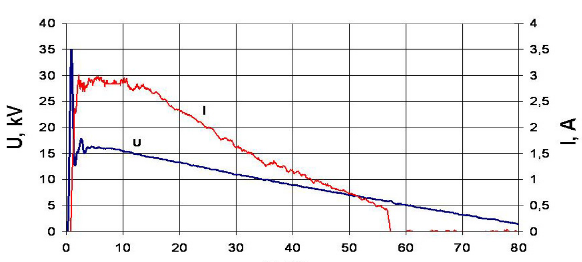

Fig.3. Oscillograms of the cathode voltage (U) and currents onto the Faraday cup (1).

As evident from Fig. 3 the electron beam generation occurs at the time of voltage surge pulse drop.

So, by the results obtained it is evident that electron beam formation was stable and the secondary-emission processes on the cathode were of long duration ~55 µs that resulted in the beam generation.

In the further experiments on the cathode diameter of 6 mm, at a distance of 4 cm from the cathode end, a reflector diameter of 16 mm, width of 5 mm was put in order to decrease the cathode length from 60 mm to 40 mm. In this case on the voltage and current pulses the rf noises were observed characterizing the electron beam generation (Fig.4). It can be assumed that because of the deficiency of primary electrons and, consequently, of the secondary ones, in the electron cloud, intense oscillations of the spatial charge density take place sufficient to sustain the secondary-emission process of electron multiplication necessary for the electron beam generation. At the cathode voltage of 19 kV the beam current was ~2.5 A, and the pulse duration was decreasing down to 15…17 µs with a sharp beam current cutoff.

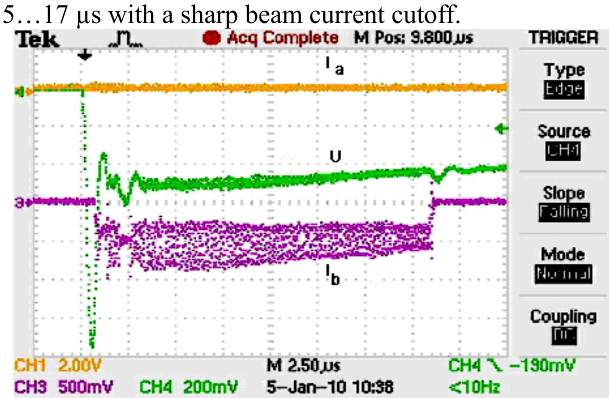

Fig.4. Oscillograms of the cathode voltage (U) and currents onto the Faraday cup (I_b) and onto the anode (I_a).

The experiments carried out in the magnetron gun with a cathode having 10 mm in diameter and the length of ~60 mm, anode diameter of~56 mm and the length of ~75 mm have shown that the magnetron gun forms a stable tubular electron beam with a duration of ~50 µs in the voltage range from 15 to 21 kV and a beam current of 3.2…6 A. The parameters of the electron beam on the aluminum target in the Faraday cup region were measured. It has been established that the internal beam diameter is ~10 mm, and the wall thickness is ~1 mm. The dependence of the beam current on the cathode voltage is shown in Fig.5. As is seen from the figure this dependence in the voltage range from 15 to 21 kV obeys to the law “3/2”.

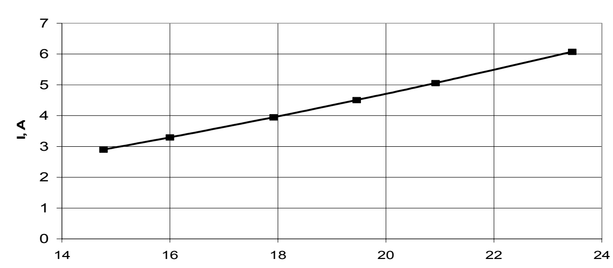

Fig.5. The beam current as a function of the cathode voltage.

The electric field influence on the electron beam formation was investigated too. According to the experimental data in the constant magnetic field the electron beam formation keeps when the amplitude is changing by 25 % of the optimum value. If the cathode voltage approaches above and below to the boundary ΔU, the conditions of beam generation are disturbed.

It should be noted that in the both cases, when the magnetron gun was investigated in the longitudinal magnetic field formed by the solenoid [4], and when the magnetron gun was investigated before in the constant magnetic field, we observed the mode of generation of beam current- and anode current bunches with duration of ~1 μs during 20 μs at the cathode voltage ~22 kV (Fig.6).The oscillation period equals to ~1.4 μs, that is in accord with the characteristic frequency of the discharge circuit. After 20 μs, when the cathode voltage amplitude U has been decreased down to the cut-off U* [2,4], the magnetron gun operates in the usual oscillating mode.

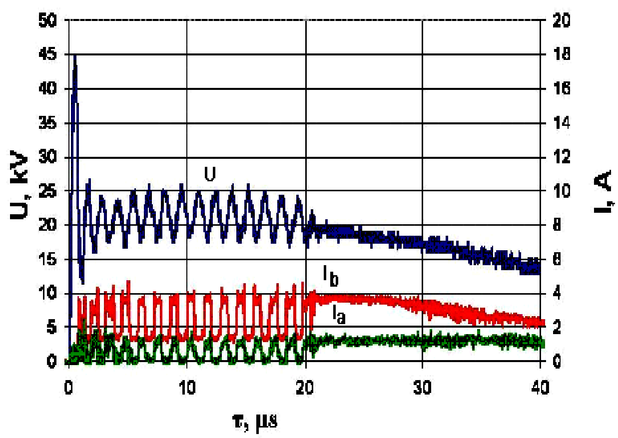

Fig.6. Oscillograms of the cathode voltage (U) and currents onto the Faraday cup (I_b) and anode (I_a).

CONCLUSION

As a result of investigations a compact magnetron gun with a secondary-emission cathode and a magnetic system on the base of annular permanent magnets was constructed.

The electron beam having a current of ~5 A at a cathode voltage ~20 kV with pulse duration ~50 μs was produced.

The mode of generation of several beam current and anode current bunches during a long-duration pulse was reached and investigated.

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