THE MAGNETIC FIELD EFFECT ON ELECTRON BEAM GENERATION IN MAGNETRON INJECTION GUNS WITH SECONDARY-EMISSION CATHODES

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Magnetron guns with secondary-emission cathodes appear promising for the use as electron sources in high-power microwave devices [1, 2]. For stable beam generation, the magnetic field in the gun is calculated to be between 0.5 to 5 kG, depending on the cathode voltage amplitude and the gun dimensions. On the other hand, the beam transport in the resonance system of the microwave device also calls for rather high magnetic fields. The generation of these fields of significant extent to produce and transport the beam is a rather grave problem. It is generally solved by using water-cooled solenoids [3], that gives rise to considerable difficulties. In recent years, constant magnets have been used [3] to generate extended solenoidal magnetic fields. So, it was of interest to investigate both the generation of such fields and their effect on beam production and parameters in the magnetron gun.

In experiments on electron beam production in magnetron guns with secondary-emission cathodes, two methods have been used to generate magnetic fields:
(i) condenser discharge through a pulsed solenoid and
(ii) direct current supply to a water-cooled solenoid.

In case (i) (Fig. 1), at a high field uniformity along the solenoid axis (±5%) and the field value between 5 and 6 kG, the pulse repetition rate is about 1 Hz. This method of magnetic field generation is inconsistent with the operating conditions of microwave devices, where the pulse frequency is hundreds of Hz. On the other hand, with the magnetron gun operating at a low pulse frequency, the cathode surface gets contaminated, for the time between the pulses, with impurities appearing in the anode-cathode gap under the electron bombardment action. This may result in a vacuum breakdown of the gap [4].

In (ii) case, the generation of a constant magnetic field by passing direct current through the solenoid calls for a high power supply and water-cooling. In this case, the magnetic field value is restricted by heating of solenoid, and the magnetic field distribution along the solenoid axis has a worse uniformity (Fig. 1). The constant magnetic field enables operation at a high pulse rate.

Permanent magnets from different magnetic materials are used in microwave devices to generate constant magnetic fields for the beam transport [4]. Identical magnets can also be used to produce electron beams in magnetron guns. Experiments were made to produce a longitudinal field by the use of axially magnetized NdFeB rings. The model of total length 4.7 cm, consisting of 0.3 cm thick rings, 4 cm in I.D. and 1.9 cm in O.D., generated a magnetic field of 0.9 kG on the axis of rings. Over a length of 4 cm the field nonuniformity was ±10% (Fig. 2). At present, experiments are performed to investigate the possibility of creating extended (10-20 cm) magnetic fields with 2 to 3 kG fields for their subsequent use in magnetron guns and magnetic periodic focusing systems to transport the beam.

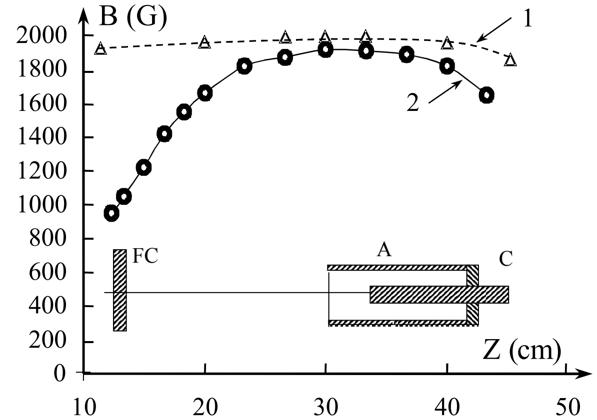

Fig. 1. Magnetic intensity distribution along the solenoid axis and magnetron gun location (FC - Faraday cup, A - anode, C - cathode).
1 – pulsed magnetic field; 2 constant magnetic field.

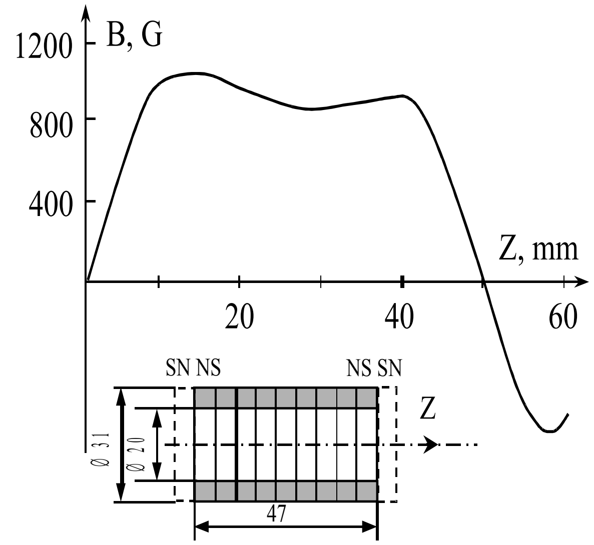

Fig. 2. Intensity distribution of the magnetic field generated by a set of NdFeB rings.

Experiments were made to investigate the effect of longitudinal magnetic field value and distribution on bean current generation in the experimental device described in ref. [1]. Threshold dependence of beam current rise and falloff was obtained as a function of pulsed magnetic field strength. Thus, in the magnetron gun with a cathode diameter of 5 mm and an anode diameter of 26 mm, for the cathode voltage between 38 and 40 kV the current appeared at a pulsed magnetic field intensity B~1350G. The current value was measured to be ~16 to 20 A and was only slightly dependent on the magnetic field value ranging from 1500 to 3000 G. Over this range, the gun perveance is independent of the magnetic field value. At B~3200 G an abrupt disruption of the process of secondary-emission multiplication of electrons took place, and the current was not registered by the Faraday cup. The function obtained is associated with variations in trajectories and conditions of energizing by electrons in the interelectrode gap as the magnetic field value is changed. Variations in the magnetic field distribution in the gun lead to changes in the shape and height of beam current pulse amplitude. Thus, as the magnetic field in the magnetron gun (cathode diameter - 5 mm, anode diameter - 50 mm, cathode voltage - 60 kV) changed from 1.4 kG to 2 kG, the beam current changed from 1 to 10 A.

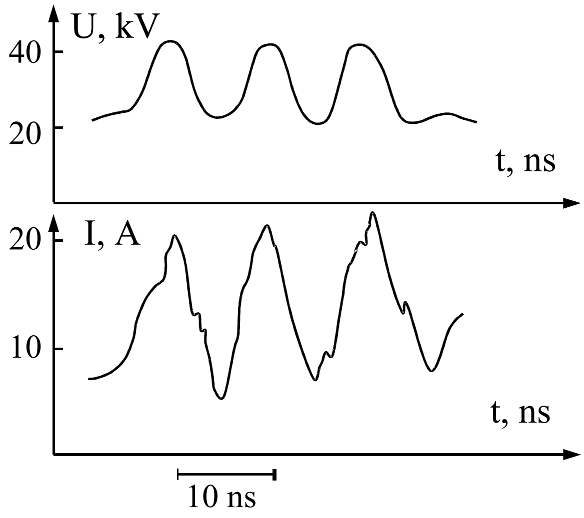

Fig. 3. Oscillograms of voltage (top) and current (bottom) pulses

Experiments on magnetron guns with different geometrical dimensions (cathode diameter 5 ... 40 mm, anode diameter 22 ... 78 mm) have shown that their operating conditions provide for the spiking mode of beam current modulation with a frequency between 1 and 200 MHz. According to the experimental conditions (magnetic field strength, cathode voltage), either a full disruption of the process of secondary-emission electron multiplication or a modulation making 10 to 70% of the amplitude beam current (Fig. 3) was observed. We assume this to be due to the conditions of space charge appearance and their oscillations. The frequency of these oscillations depends on both the electron cloud density and the magnetic intensity. As the increasing magnetic field reached a certain value, the current pulse top was flattened.

Magnetron guns can provide high powers in the electron beam. For example, at a cathode voltage of 100 kV and a magnetic field of 1100 G, the magnetron gun with a cathode 40 mm in diameter, and an anode, 78 mm in diameter, generated a beam current of about 50 A, this corresponding to a beam power of 5 Mw.

Another way of increasing the beam power lies in using the system including several (6 to 10) magnetron guns having small transverse dimensions. Experiments were carried out with systems consisting of 6 and 8 magnetron guns. In the first case, for the cathode diameter of 5 mm, anode diameter of 26 mm, cathode voltage of 40 kV, magnetic field strength of 2 kG, the total beam current reached 100 A. In the second case, for the cathode diameter of 5 mm, anode diameter of 22 mm, cathode voltage of 20 kV, magnetic field strength of 1.4 kG, the total beam current was about 30 A. Presently, this gun is being put into operation to provide a beam power up to 6 Mw.

The results give evidence that these guns can be used in high-power microwave devices, and the magnetic field value must range from 1000 to 2500 G. This can be achieved with the use of the magnetic systems described above.

CONCLUSION

The undertaken experiments have shown that a variation in the magnetic field can give rise to space charge oscillations in the interelectrode (anode-cathode) gap of the magnetron gun. These effects observed during beam generation and transport must be taken into account when using a magnetron gun in high-power microwave devices.

REFERENCES

1. A.N. Dovbnya, V.V. Mitrochenko,, N.G. Reshetnyak, V.P. Romas’ko, Yu.D. Tur, V.V. Zakutin. Obtaining the linear electron beam by using the magnetron injection gun with cold secondary-emission metallic cathodes. Proc. of PAC 97, Vancouver 1997, v.3, pp.2820-2822.
2. Y.M. Saveliev, W. Sibbett, D.M. Parkes. Cross-field secondary-emission electron source. Plasma Physics. v. 4, No.7 (1997) pp.2319-2321.
3. I.I. Kifer. Tests of ferromagnetic materials (in Russ.). M.-L. Gosehnergoizdat publ. 1962. 543 p.
4. A.N. Dovbnya, V.V. Zakutin, V.F. Zhiglo, V.P. Romas’ko, N.G. Reshetnyak. Experimental study of a magnetron gun with a cold cathode. Vopr. Atomn. Nauki i Tekhn., ser. YaFI, iss. 1/28/1997, pp. 53-57.