CHARACTERISTICS OF ELECTRON BEAM PRODUCED BY MAGNETRON DIODE WITH A SECONDARY-EMISSION CATHODE

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Abstract

Investigations were made of the azimythal homogeneity, parameters of an electron beam and its sizes in a magnetron gun with a cold metallic secondary-emission cathode depending on the value and distribution of magnetic field. It is shown that such a source generates an electron beam with an azimuthal homogeneity ±4%.

INTRODUCTION

A secondary-emission magnetron gun with a cold metallic secondary-emission cathode [1-2] will serve as an annular electron beam source in microwave devices (klystrons, gyrotrons etc.). Among its advantages are a potentially long service life and a high-current density. The guns of this type operate by the principle based on the secondary-emission electron multiplication and electron beam generation in crossed electron and magnetic fields. When a voltage pulse is applied on the cathode, primary electrons go out into the gap between electrodes. In the course of voltage increasing (up to the overshoot peak) these electrons removing from the cathode are accumulated in the cathode-anode gap. On the overshoot falloff the primary electrons gain the energy higher than the first critical potential, bombard the cathode and provoke the processes of secondary-emission multiplication, electron cloud formation and beam generation. An important parameter of the electron source is the azimuthal homogeneity of a beam. In the case of its perturbation in the oscillation spectrum there additional frequencies appear and the efficiency of devices decreases [3]. The present paper describes the studies on the influence of the magnetic field amplitude and distribution in the magnetron gun on the beam current value, its azimuthal homogeneity and beam sizes on the target.

EXPERIMENTAL SETUP AND RESEARCH METHODS

Experiments to investigate the beam parameters were performed at the setup schematically shown in Fig. 1. A specially shaped voltage pulse with a peak at the top from a pulse modulator [4] was applied to the gun cathode, its anode was connected to the ground via a resistor R3. The overshoot amplitude is adjusted within 60 ... 100 kV, the amplitude of the flat part of the pulse was 20... 55 kV, the overshoot falloff duration was ~ 0.3 µs, the pulse duration at half-height was ~ 8µs, the pulse repetition rate ranged from 10 to 20 Hz (curve 2 in Fig. 2).

The studies were made on the magnetron gun of a coaxial construction which had a cathode, 40 mm in diameter and 70 mm in length; an anode, 70 mm in internal diameter and 140 mm in length; cathode material was copper, anode material was steel. The magnetron gun was placed in the vacuum chamber, where a vacuum of ~ 10^{-6} Torr was maintained. The magnetic field for beam generation and transport was created by the solenoid (consisting of 4 sections with which the magnetic field could be adjusted by varying the current value in the sections of the solenoid). The solenoid was energized by the constant-current source.

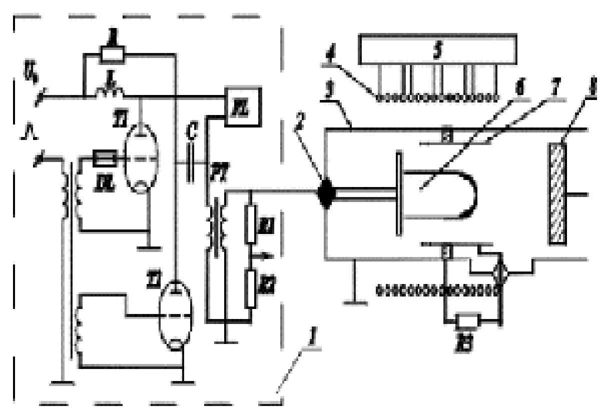

Figure 1: Schematic of the experimental setup. 1 - modulator, 2 - insulator. 3 -vacuum chamber, 4 -solenoid, 5 -power supply of the solenoid, 6 - cathode, 7 - anode, 7 - Faraday cup.

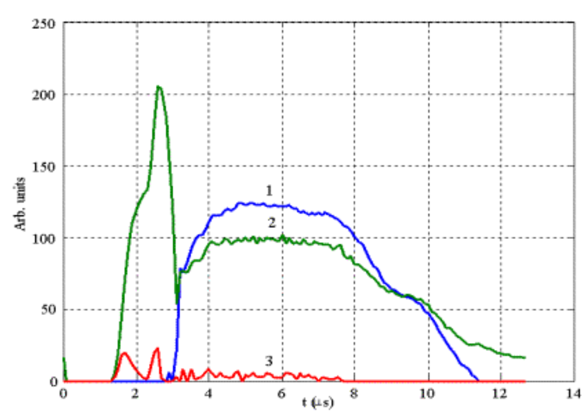

Figure 2: Pulses of voltage (2), beam current (1) and anode current (3), Along the vertical: 1 - 0.4 A/div,2 - 0.5 kV/div, 3 - 0.04 A/div.

The studies of beam parameters were performed by means of a 8-channel sectionalized Faraday cup and a computer-assisted measuring system [5]. The pulses from each of Faraday cup sections come to the matched attenuator unit, which allows to match the signal

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amplitudes for a further conversion and processing in the ADC and PC. The pulsed signals are registered in steps of 50 ns or 100 ns simultaneously in 12 channels in the digital form. The system provides processing of 32 pulses following one after the other. The measurement error is within 1 to 2 %. Measurements were taken of the beam current from each of 8 segments of the Faraday cup, of the cathode voltage and the anode current. These parameters were measured at the given temporal points and were averaged over 16 pulses following one after the other. Then the computer processing of results was performed and we have calculated: the total beam current, the coefficients of maximum deviation of current/voltage pulse heights from the average value. the coefficient of the azimuthal beam homogeneity ($k = I_{max}/I_{min}$, where I_{max} and I_{min} are, respectively, the maximum and minimum values of currents from the Faraday cup segments), the distribution of a full charge of beams from the Faraday cups, the relative distribution of beam currents during the pulse.

The transverse beam dimensions were measured by obtaining prints on the aluminium target, the prints being made separately for each mode of beam generation (cathode voltage and magnetic field of a given value were maintained in every series of measurements).

EXPERIMENTAL RESULTS AND DISCUSSION

In the course of studies a beam generation mode was obtained, in which the magnetron gun forms a tubular electron beam with a beam current of 50 A at a cathode voltage amplitude of ~50 kV. The beam current pulse length is ~ 7 μs, the pulsed beam power is ~2.5 MW, the microperveance is ~4, the pulse repetition rate is 15 Hz, the magnetic field strength in the cathode region is 1200 Oe. The stability of the total beam current, and also of the current from each of eight Faraday cup segments, during 16 voltage pulses following one after another, made up ~2 to 3% at a voltage pulse amplitude of ~2%.

The dependence of the current, azimuthal homogeneity and beam sizes on the amplitude and magnetic field distribution along the gun axis has been investigated. It has been found that the azimuthal homogeneity of the beam and the current value on the Faraday cup depends, to a great extent, on the longitudinal magnetic field distribution. Fig. 3 demonstrates the distributions of the longitudinal Hz magnetic field along the magnetron gun axis and the beam transport space for three cases. In the first case (curve 1) the longitudinal magnetic field component along the cathode decreases in the direction to the Faraday cup. In the second case (curve 2) the longitudinal magnetic field components has a practically constant value along the gun axis. In the third case (curve 3) the longitudinal magnetic field component is smoothly rising.

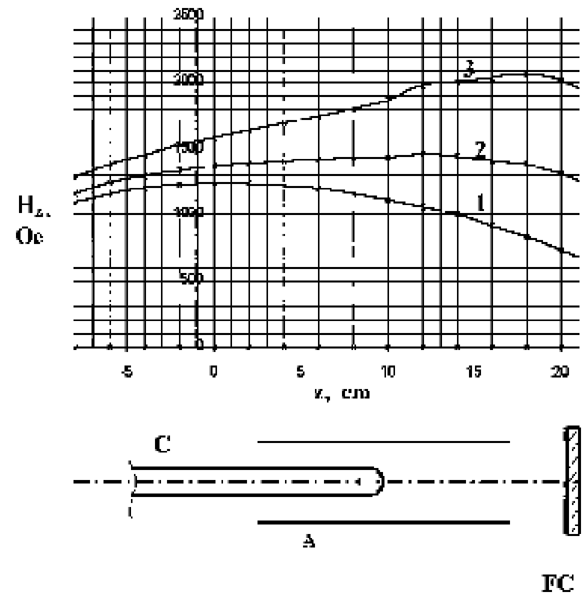

Figure 3: Distribution of the longitudinal H_z magnetic field components and arrangement of elements along the axis z of the system. C - cathode, A - anode of the magnetron gun, FC - Faraday cup.

Fig. 4 shows the distribution of the charge of beams from each of 8 Faraday cup segments (depending on the channel number), i.e. by the azimuth for these cases. It is seen from the figure that the beam charge value at a falling magnetic field is practically constant along the tubular beam azimuth, and is considerably changing at a rising magnetic field. At a magnetic field, falling along the axis of the system system to the Faraday cup, the coefficent of azimuthal inhomogeneity of the beam **k** is minimum and equals to 1.08 (Fig. 4 above). In the homogeneous magnetic field **k** equals to 1.2, and at a rising magnetic field the coefficient of azimuthal inhomogeneity of the beam **k** is 2.8.

In Fig. 5 the coefficient **k** of the azimuthal beam inhomogeneity and the total beam current **I** are presented as a function of the magnetic field amplitude in the Faraday cup region. It is seen from the figure, that the coefficient of the azimuthal inhomogeneity is sharply increasing (curve 2 in Fig. 5), and the beam current decreases practically linearly (curve 1 in Fig. 5) with magnetic field increasing in the vicinity of the Faraday cup. The measurement results are obtained at a cathode voltage of ~40 kV.

The dependence of electron beam parameters on the magnetic field direction along the gun axis is studied. Study the beam current as a function of the cathode voltage at a falling magnetic field distribution for the both directions. It is seen that the beam current amplitude obeys the “3/2” law. It means that the beam current amplitude is practically independent on the magnetic field direction, while the azimuthal beam homogeneity is depending, to a great extent, on the magnetic field direction. For example, in the rising magnetic field, for one magnetic field direction, the coefficient of azimuthal beam inhomogeneity is 1.08, and for another direction it is 1.8.

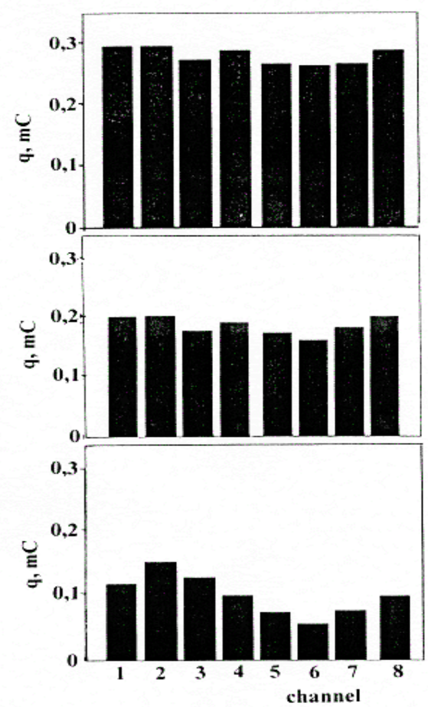

Figure 4: Beam charge distribution **q** (mC) along the measuring channels at falling (below), rising (above) and constant magnetic field distribution.

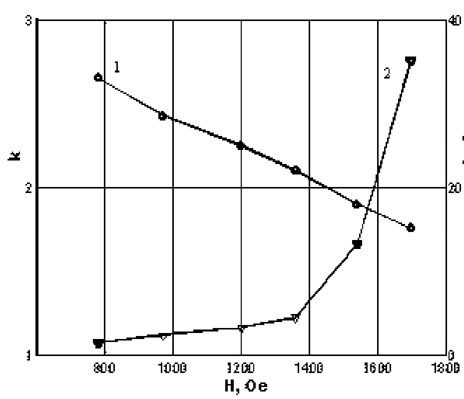

Figure 5: Coefficient of the azimuthal beam inhomogeneity **k** (curve 2) and the total beam current **I** curve **I**) as a function of the magnetic field amplitude in the vicinity of the Faraday cup.

Measurements of the electron beam size were performed on the aluminium target placed in the region of the Faraday cup. At a cathode voltage of 35 kV and a falling magnetic field, the magnetron gun generates an electron beam having a current of 36 A, an outer diameter of 50 nm, and a wall thickness of ~3 mm. At a rising magnetic field the beam current dropped down to 21 A, and the outer beam diameter diminished to 38 mm, the wall thickness being less than 2 mm.

In paper [2] the electron beam thickness practically was independent on the magnetic field strength that can be connected with a distinction in the geometry of an output parts of the magnetron gun and with the use of a solenoid with a homogeneous magnetic field distribution.

The investigation performed show that the azimuthal It should be noted, that the increase of the coefficient of azimuthal inhomogeneity in the rising magnetic field was observed also in the course of investigations of the magnetron gun with a thermocathode, which was used for the gyrotron operation [3]. In these investigations the obtained coefficient of azimuthal inhomogeneity **k** was 10.

CONCLUSIONS

The azimuthal electron beam inhomogeneity, being an important parameter of the microwave sources, has been investigated. As a result of experiments the coefficient of azimuthal inhomogeneity of ± 4% was reached, the beam current stability being from 2 to 3%.

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