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Development and studies of a high-current relativistic gyrotron with a TM-type operating mode

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Abstract. We present the main development stages of a sub-GW Ka-band gyrotron with TM_{51} operating mode. For discrimination of TE-type modes, an axial-slit resonator is proposed. The analytic theory of its cavity is developed and calculations using finite-element method and “cold” electrodynamic measurements is developed. The results of the first experiments on radiation generation are presented.
Keywords: gyrotron, high-current electron beam, mode selection in cavities.

1. Introduction

At present, development of microwave sources operating in millimeter a wavelength bands with sub-GW output power is subject to active investigation [1–3]. Among the variants of such sources are the gyrotrons energized by helical relativistic electron beams formed by explosive emission cathodes. In order to increase the interaction efficiency, it is expedient to use the TM-polarized operating modes. [4, 5]. To suppress TE modes, axially slitted cavity may be used. If the slit width is much less than the wavelength, for TM modes, such a cavity is similar to the cavity with a solid metal wall. In turn, TE modes are efficiently radiated into the external space.

2. Development of the high-current Ka-band gyrotron

Analytic estimates show that in an axially slitted cavity, TE modes can be almost totally suppressed, while the *Q*-factor of the TM modes remains relatively high [6].

Implementation-wise, a version of the cavity is of interest with a regular section made of a set of metallic blades separated by slots. Here, one should determine the optimum number of blades. Insufficient number of blades leading to increased slot width would obviously cause the decrease in external *Q* factor, which eventually would influence the total *Q* factor of the operating mode. At the same time, increase in the number of blades and decrease in the spacing between them obviously overcomplicates the cavity assembly. In order to determine the required number of blades, we applied the finite-element method to a closed cavity configuration (Fig.1a and b) with the operating TM_{51} mode (eigenfrequency in a regular waveguide is about 32 GHz). The regular section of the cavity was formed by a set of longitudinal metallic blades with 1 mm thickness, 5 mm height, and 28 mm length, regularly spaced along the azimuthal angle.

Simulations show that at the blade spacing of more than 4 mm, *Q*-factor rapidly drops down below 10 (Fig.1d). At the same time, at the spacing less than 2 mm, *Q*-factor is almost constant reaching the values of about 6000, which corresponds to the Ohmic *Q* of the cavity under consideration. As a result, we chose the configuration of the cavity comprising 31 blades with about 1.5 mm spacing.

Based on this simulations, a prototype of an axially slitted cavity was manufactured (Fig.1c) "Cold" measurements were undertaken by means of excitation of the cavity from rectangular dielectric waveguide. At the resonator output, a deflector-type mode converter of the operating mode into the directed wavebeam. Measurements demonstrate the resonant maximum at a central frequency of 31.5 GHz and a *Q*-factor of $Q \approx 130$ (Fig.1e), which is in a good agreement with estimations based on analytical theory [6].

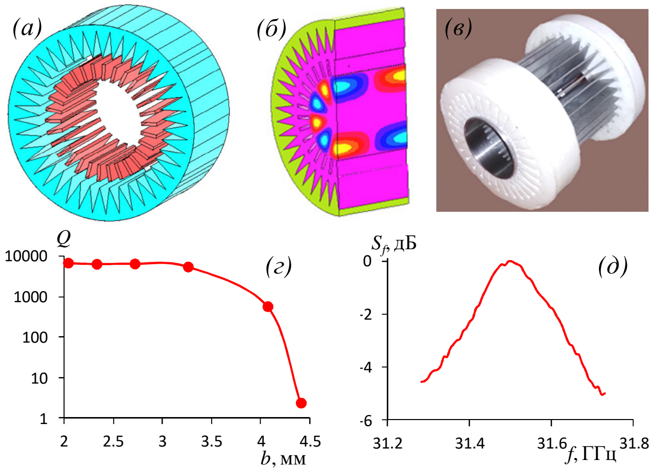

Fig.1. A model of a closed blade cavity (a), spatial profile of the excited TM_{51} mode (b), and layout of the open blade cavity prototype (c), mode Q-factor vs. slot width b (d) and measured resonant curve of TM_{51} mode (e).

3. Experimental investigation of the high-current Ka-band gyrotron

Ka-band gyrotron is under development based on SINUS-6 high-current accelerator which forms an electron beam with a current of up to 5 kA at the accelerating voltage of up to 600 kV in pulses with duration of 20 ns. The design of the gyrotron is presented in Fig.2a. A stainless-steel coaxial edged cathode (*1*) forms a rectilinear electron beam (*2*) with a current of up to 2 kA. An electron beam with guiding center radius of 8.5 mm is formed by pumping the rectilinear electron flow in the field of a kicker (*3*), which is a coil with rectilinear cross-section 3×2 mm^2 and inner radius of 12.5 mm [7]. For optimal matching of the kicker with the source of pulsed voltage, a serial ballast coil (*7*) located inside the main solenoid was used, providing simultaneously the electron beam deposition at the cavity output (*6*).

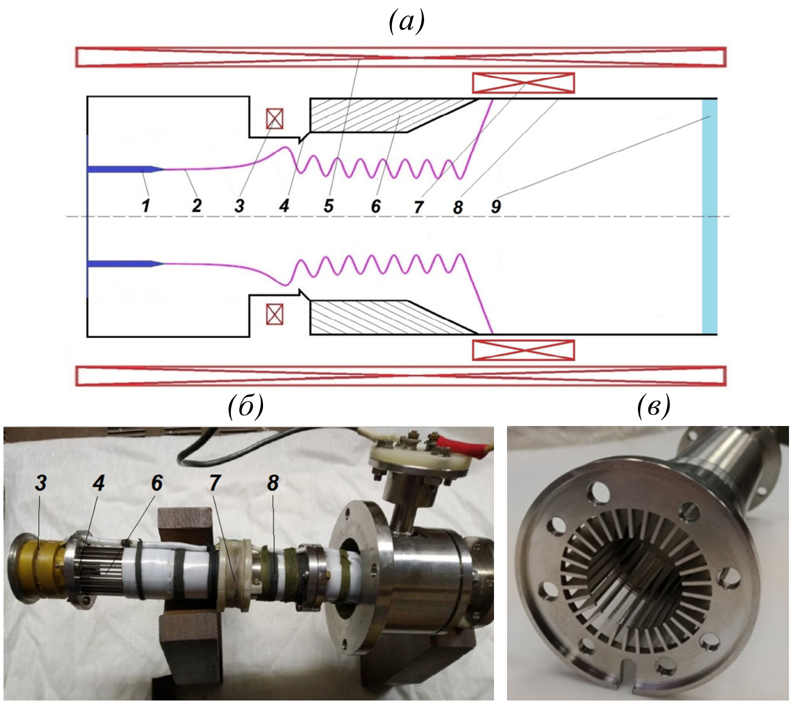

Fig.2. Layout (a) and outlook (b) of the initial variant of the gyrotron and the blade cavity (c): *1* – tubular cathode, *2* – rectilinear electron beam, *3* – kicker coil, *4* – cutoff narrowing, *5* – guiding magnetic field solenoid, *6* – blade cavity, *7* – deposition coil, *8* – output waveguiding section, *9* – vacuum window.

In Fig.2, the outlook of the gyrotron and the blade cavity is presented. In the experimental investigations at the accelerating voltage of 570 kV, beam current of 1.5 kA and guiding magnetic field of about 2 T, stable single-frequency RF oscillation regimes with pulse duration of 10 to 12 ns and power of several dozen MW were registered. However, oscillations sustained with the deposition coil shifted towards the kicker when the interaction of the beam with the operating mode in the cavity was cancelled. Accordingly, we assumed that the parasitic self-excitation of the helical beam forming section takes place.

For suppression of the parasitic self-excitation, we plan to develop a modified electron-optics system with compression of the electron beam. Such a system would be similar to the magnetron injection guns of the weakly relativistic gyrotrons. It is assumed to be more stable to self-excitation.

4. Conclusion

We demonstrate the possibility of almost total suppression of the TE-type modes in axially slitted cavities. We propose a design for such a cavity which includes a set of metallic blades placed evenly along the azimuthal coordinate.

A design of a high-current Ka-band gyrotron with sub-GW output power level operating at the TM-type mode was developed; its first experimental investigations were undertaken. We have shown that using the conventional scheme of gyrotron building with separation of the beam formation area and the electron-wave interaction area, the problem of parasitic self-excitation in the beam formation section arises.

A modification of the gyrotron was proposed aimed at overpassing the problem of self-excitation in the beam formation section and reaching the rated level of the output power.

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