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Assessment of the possibilities to create a pulsed source in the 0.5 THz range with a power level of about 100 MW

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Abstract. The paper presents the first calculations confirming the possibility of efficient generation in a high-current relativistic gyrotron in the 0.5 THz range based on the existing Sinus-6 electron accelerator. For the selected configuration of a selective longitudinal slot resonator, the transverse quality factor of the operating mode was assessed. Taking into account the obtained characteristics, a simulation of electron-wave interaction was carried out based on a system of stationary averaged gyrotron equations and on the large particle method. It is predicted that it will be possible to achieve an output power of about 100 MW, which corresponds to an efficiency of 10%.

Keywords: relativistic gyrotron, terahertz radiation.

1. Introduction

Currently, considerable attention is being paid to the development of high-power terahertz radiation sources in the 0.3–1 THz range based on electron flows moving in a vacuum. The practical use of high-power terahertz radiation is mainly associated with problems of interaction with plasma. Powerful continuous radiation sources are designed to heat plasma in controlled thermonuclear fusion installations (tokamaks and stellarators) [1]. In turn, pulsed terahertz radiation is used to study discharge processes in gases [2], for example, to create sources of ultraviolet radiation [3].

One of the most promising sources of powerful pulsed terahertz radiation are gyrotrons with high-current relativistic beams. Thus, in [4] it was shown that in such a device a power of about 80 MW can be achieved in the range of 0.3 THz. In this work, we consider the possibility of implementing such a device with an operating frequency of about 0.5 THz.

2. Calculation results

2.1. Estimation of the electrodynamic characteristics of the THz gyrotron cavity

To ensure a single-mode generation regime, a configuration of a gyrotron with a longitudinal-slot type resonator based on the coupling of modes with multiple azimuthal indices was considered [5]. In comparison with the previously studied gyrotron in the 300 GHz range [4], it is proposed to use a larger resonator that provides coupling between the $TE_{16.4}$ and $TE_{8.7}$ modes. (Fig. 1)

For detailed modeling of a longitudinal slot resonator, the Ansys HFSS environment [6] was used. Considering that the gyrotron operates at a frequency close to the critical frequency of the operating mode, as a first approximation, we can take the value of the wave number along the resonator axis to be zero. This makes it possible to reduce the dimension of the problem by calculating the interaction only in a two-dimensional section. Since Ansys HFSS is a fundamentally three-dimensional code, the corresponding simplification is equivalent to using a thin layer along the axis of the resonator with boundary conditions in the form of an ideal magnetically conducting surface as the modeling region.

The cavity walls were specified in the form of a ring with azimuthal cuts with boundary conditions corresponding to oxygen-free copper (conductivity about $5.8 \cdot 10^7$ S/m). On the lateral surface of the region under consideration, a boundary condition was set in the form of a perfectly matched absorber (PML).

Estimates show that the transverse quality factor (i.e., corresponding to radiation losses in the transverse direction and thermal losses in the resonator walls) of the considered mode is on the order of 3000, which significantly exceeds the typical longitudinal diffraction quality factor of high-current gyrotron resonators.

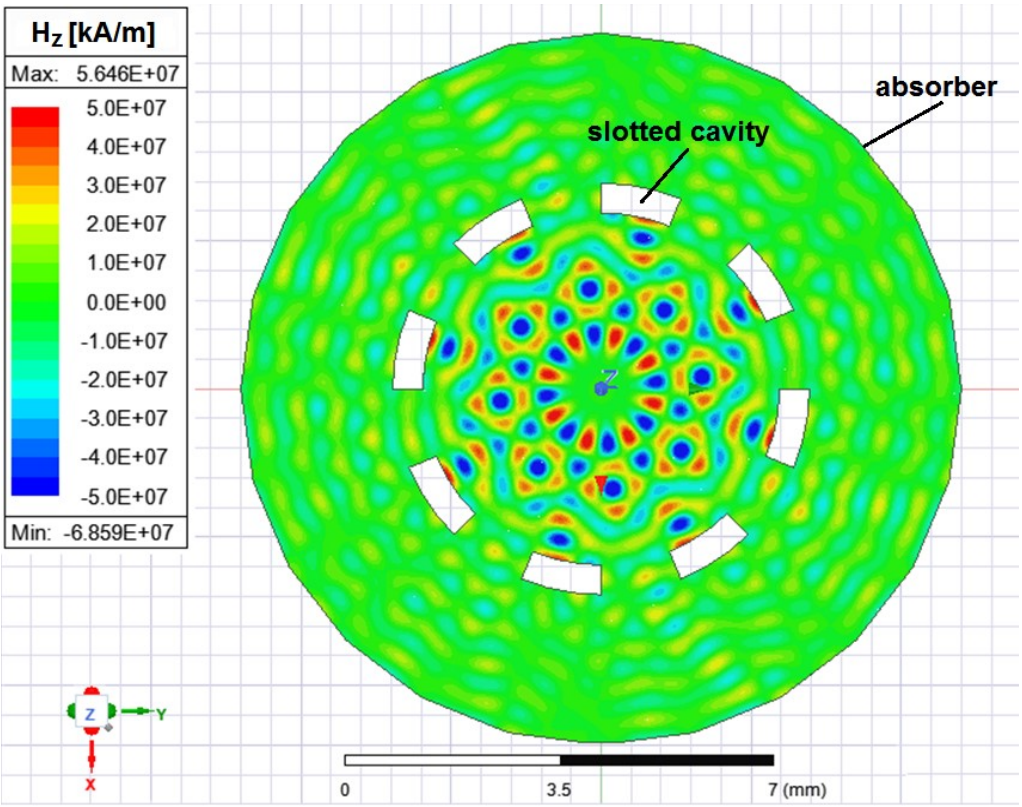
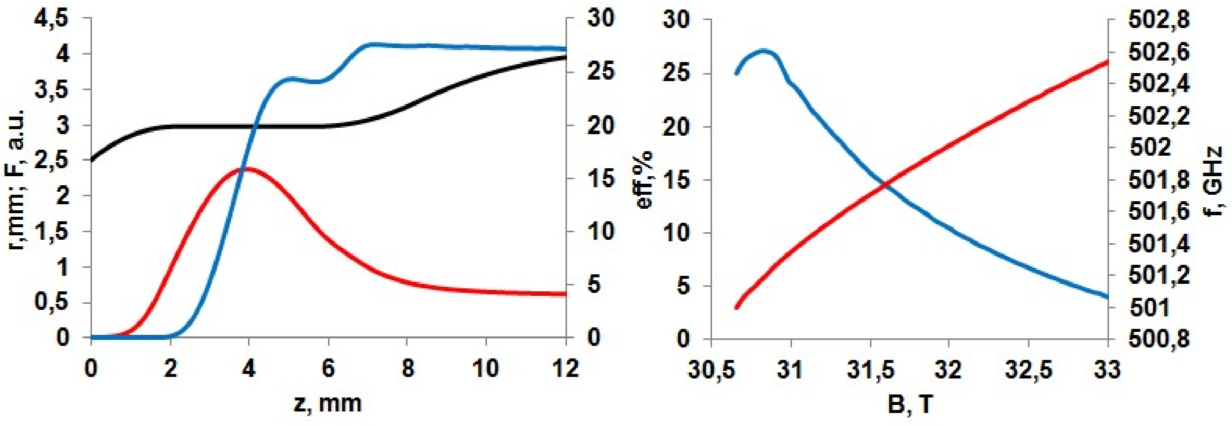


Fig. 1. Transverse distribution of the longitudinal component of the magnetic field strength of the high-Q mode $TE_{16.4} + TE_{8.7}$ in a longitudinal slotted cavity

2.2. Calculation of electron-wave interaction

At the next stage of the study, calculations of electron-wave interaction were performed within the framework of a one-dimensional stationary model of a gyrotron with an unfixed field structure [7], taking into account the previously obtained value of the transverse quality factor. The energy parameters of the beam (energy 500 keV, current 2 kA, duration 10 ns) were selected based on the capabilities of the «Sinus-6» accelerator. The pitch factor (the ratio of the transverse and longitudinal electron velocities) of the beam was chosen equal to 1. To calculate the effective coupling coefficient with the helical electron flow, the high-Q mode of the longitudinal slot resonator was represented as a sum of modes of a circular waveguide $TE_{16.4}$ and $TE_{8.7}$ with the corresponding weighting coefficients. The cavity profile was specified in the form of a section of a cylindrical waveguide, with a smooth supercritical narrowing and an output aperture with generatrices in the form of circular arcs [8]. Optimization consisted of selecting the length of the uniform section of the resonator and the radii of the circular arcs that form the aperture profile to achieve maximum efficiency. According to calculations, with an optimal resonator profile (Fig. 2), the maximum efficiency exceeds 25%, which corresponds to an output power of 250 MW.

Gyrotron calculations were also performed based on a three-dimensional version of the KARAT PIC code [9]. In simulations a Cartesian coordinate system with spatial cell dimensions of 0.075×0.075×0.06 mm was used. The deviation of the obtained generation frequency from the calculated value was no more than 1.5%. As a result it was shown that the achievement of modes with maximum efficiency is largely hampered by mode competition processes. As a result, the maximum achievable power level is reduced to values of the order of 100 MW.



(a) (b)

Fig.2. Optimized cavity profile (black curve), dimensionless longitudinal structure of the high-frequency field (red curve), dependence of efficiency on longitudinal coordinate (blue curve) – (a); calculated dependence of the efficiency (blue curve) and radiation frequency (red curve) on the magnitude of the magnetic field – (b).

3. Conclusion

The results of the calculations allow us to conclude that it is possible to create a high-current relativistic gyrotron in the 0.5 THz range based on the Sinus-6 accelerator available at the Institute of Applied Physics of the Russian Academy of Sciences. However, among the problems that require detailed study today remain the creation of a magnetic system that provides a maximum field induction value of more than 30 T, as well as the development of an electron-optical system that forms a helical electron beam with a pitch factor of ~1 in such a field. It should be noted that the problem of creating such strong magnetic fields was previously successfully solved in a terahertz pulsed gyrotron, where a magnetic field of 38.5 T was used [10].

Acknowledgement

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