Short-wavelength gyrotrons with quasi-regular and sectional cavities

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Abstract. In gyrotrons, in order to increase the generation efficiency at a high cyclotron harmonic, it was proposed to use the transition to stable operation in the TWT mode by adding irregularity (absorber) on the wall of the cavity. The paper presents the results of the study of such a scheme. The results of a theoretical study of frequency tuning with a change in the operating magnetic field in a terahertz gyrotron with a quasi-regular sectioned cavity with periodic phase correctors are also presented.

1. Introduction

Traditional high-power subterahertz gyrotrons, demanded by a number of important modern applications, provide radiation power up to 1 MW in the quasi-continuous regime at frequencies up to 0.17 THz and about 1 kW [1] in long pulses at frequencies up to 1.3 THz [2]. At the same time, to achieve a frequency about 1 THz, strong magnetic fields (over 30 Tesla) are required. The use of generation at high harmonics significantly increases the availability of terahertz gyrotrons to consumers. However, in addition to electron-optical problems, such problems arise in such gyrotrons associated with the weakness of the electron-wave interaction at high cyclotron harmonics. In particular, there is a need to use long operating cavities to ensure the start of gyrotron excitation. This entails an increase in the share of ohmic losses caused by extremely high diffraction Q-factors of operating waves. To solve this problem, it is proposed to use a cavity with a scattering inhomogeneity, as well as a quasiregular cavity with wave correctors. The latter configuration was also investigated from the point of view of frequency tuning with a change in the operating magnetic field.

2. Frequency tuning a short-wavelength gyrotron with irregular cavity

A rather simple and technologically advanced approach aimed at solving the problem of reducing the diffraction Q-factor of the operating wave in long gyrotron cavities is based on using a quasi-regular cavity consisting of several regular sections, separated by short irregularities ensuring a phase incursion between sections equal to π [3]. In such a system, the longitudinal mode, relatively far from the cut-off (and, accordingly, having a relatively

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low diffraction Q-factor) is excited in the gyrotron-like regime. Based on this approach, a three-sectioned cavity of pulsed moderately relativistic (80 kV, 0.7 A) gyrotron operating at the third harmonic at frequency about 1 THz, was proposed.

Such a system was theoretically investigated from the point of view of frequency tuning with a change in the operating magnetic field. A decrease in the magnetic field in such a configuration corresponds to the transition to operation in backward-wave oscillator regime (BWO). For this case, the dependence of the electron and wave efficiency as well as the frequency on the magnetic field is shown in Fig. 1. In such a sectioned cavity, the wave efficiency at the magnetic fields corresponding to gyrotron excitation of the third longitudinal mode (region (b) in Fig. 1) is close to the wave efficiency in regions of magnetic fields corresponding to the excitation of the first longitudinal mode (region (a) in Fig. 1). This is due to the fact that if the third mode has the advantage of operating in a highly efficient gyrotron regime, then the first mode excited in the BWO mode has a high quality factor due to the lower group velocity of radiation output from the cavity.

With a constant power of stationary generation, the frequency difference is about 0.1%, which is approximately equal to the frequency tuning bandwidth. Thus, by simply switching the working magnetic field, one can provide a fairly noticeable (for the gyrotron) change in the stationary generation frequency without changing the output radiation power. The excitation dynamics a mentioned gyrotron in the case of abruptly switching magnetic field is shown in Fig. 2. When the magnitude of the operating magnetic field is switched, after a short-term transient process stationary generation is established with the same level of output power (fig. 2 a), but with notably different frequency. The dependence of the frequency on the normalized time with a varying magnetic field is shown in Fig. 2 b. It is important that this effect also occurs when simulating the gyrotron operation in a CW regime. This makes it possible to quickly control the generation frequency during one pulse of the output radiation.

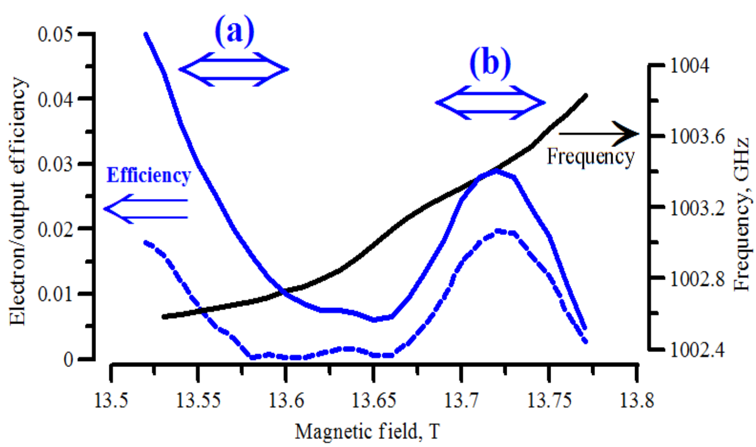

Fig. 1. Dependence of frequency, electron and wave efficiency of a terahertz LOG with a sectioned cavity on the operating magnetic field. Region (a) corresponds to the excitation of the lowest gyrotron mode in the TWT regime, region (b) corresponds to the excitation of the third longitudinal mode in the gyrotron regime.

3. Enhancement of generation efficiency by stable excitation of high axial modes in the TWT regime

A possible way to improve the gyrotron operation is a transition from operation at the lowest axial mode to waves with higher (n=2,3, …) axial indices, which have lower (~1/n) diffraction Q-factors. Hovewer, under usual conditions, the generation in the second (or higher) longitudinal mode in the TWT mode is unstable due to the excitation of the lower longitudinal mode [4]. We study the excitation process of high axial mode in the TWT regime within the framework of nonstationary spatio-temporal simulations of the 0.5A / 30 keV / 0.39 THz large-orbit third-harmonic gyrotron harmonic [5]. When switching to operation in the TWT mode, i.e. when the operating magnetic field decreases, the second longitudinal mode is first excited (Fig. 4a), then after some transition process it is suppressed by the lower longitudinal mode. To ensure the stability of the excitation of the second longitudinal mode, it is proposed to use an irregularity (absorber) in the middle of the operating cavity, i.e. in the place of change of sign for the second longitudinal mode. In this case, the mode with two longitudinal variations is practically free of distortion (Fig. 4 b) and is steadily excited with a sufficiently high efficiency and a much smaller share of ohmic losses (about 50% versus 70-80% for a regular cavity).

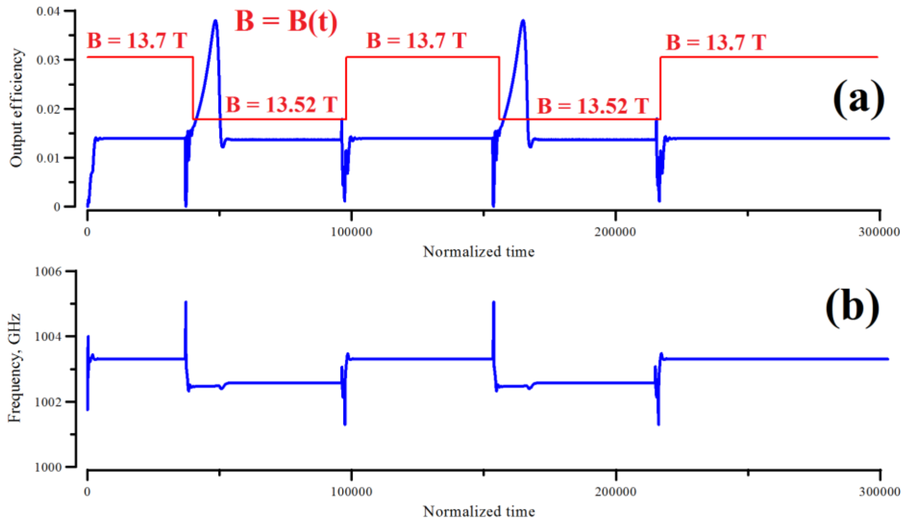

Fig. 2. (a) Dynamics of excitation of a gyrotron with a sectioned cavity when switching the operating magnetic field. The dependence of the magnetic field on time is shown schematically (red lines).
(b) Dependence of the generation frequency on the normalized time with a varying magnetic field.

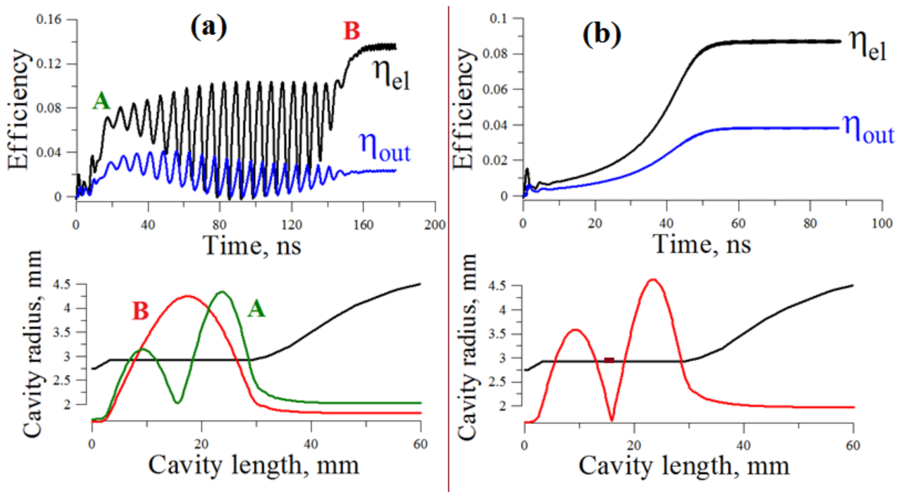

Fig. 4. Dynamics of excitation of the gyrotron during the transition to operation in the TWT mode for the case of a regular (a) cavity and a cavity with an absorber (b).

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