Capacity of an Irregular Gyrotron Cavity to Provide an Increase in Output Power

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***Abstract*— The maximum possible output power enabled by excitation of traveling-wave high-order axial modes of a cavity with irregularities for a second harmonic 527-GHz gyrotron is evaluated. The influence of mode conversion induced by cavity irregularities on gyrotron performance is investigated.**

Keywords—gyrotron, output power, traveling-wave regime, mode conversion

I. INTRODUCTION

High-power terahertz (THz) wave sources are highly demanded by numerous THz applications [1], including DNP-NMR spectroscopy [2], and EUV lithography [3]. Among them the most advanced are the gyrotrons. However, as the gyrotron frequency rises, the output power drops due to increase in power losses by ohmic cavity heating. Such power losses can be reduced with an increase in axial index and diffractive losses of the operating mode [4]. At the same time, as the axial index increases, the electron beam-wave coupling strength and interaction efficiency decrease, especially for high-order-axial-modes (HOAM) excited in the backward-wave (BW) regime. Generally, this leads to a decrease in gyrotron output power. Exception can be a power increase for traveling-wave (TW) HOAMs, which exhibit a compromise between ohmic losses and beam-wave coupling strength.

Usually an excitation of a TW HOAM is unstable due to the competition from the low-order axial modes (LOAMs). A way to suppress LOAMs is to use irregularities in profile [5] or electrical conductivity [6] of the gyrotron cavity. Unlike competing LOAMs, the operating mode is little affected by these irregularities placed at the minima of its field amplitude. In this study, the most high-power TW operating mode is found for a second harmonic 527-GHz gyrotron [7]. For selective excitation of this mode, a cavity with azimuthally symmetric irregularities is employed. Using a nonlinear self-consistent coupled-mode approach to beam-wave interaction modeling [8] the effect of mode conversion caused by cavity irregularities on gyrotron efficiency is analyzed.

II. RESULTS

Consider the power-handling capability of the second harmonic 527-GHz gyrotron [7]. The tube is powered by an electron beam with current $I_b = 0.07$ A, voltage $V_b = 16.7$ kV, radius $r_b = 0.97$ mm, and pitch factor $\alpha = 1.85$. For a nominal length L=2.2 cm of a conventional uniform cavity [7], simulations predict a peak output power of 20 W, which is reached by the operating fundamental axial $TE_{11,2,1}$ mode. Increase in cavity length can enable excitation of TW HOAMs with increased peak output power. Assuming no mode conversion in the uniform gyrotron cavity and using the single-mode approximation (SMA), it was found that the highest output power can be generated by the operating TW $TE_{11,2,5}$ mode with increase in cavity length up to L=7.1 cm (Fig.1). Excitation of this mode in the conventional cavity is hindered by competing LOAMs. For suppression of competing modes, we equip this cavity with azimuthally symmetric irregularities, which are located at minima of the field amplitude of the operating TW mode (Fig.2). Due to the small cavity output angle (0.36°) the number of field amplitude variations exceeds the axial index of the operating mode [7].

In SMA, the influence of cavity irregularities on the starting current of the operating and parasitic modes is shown in Figs. 3(a) and 3(b). The results of the coupled-mode

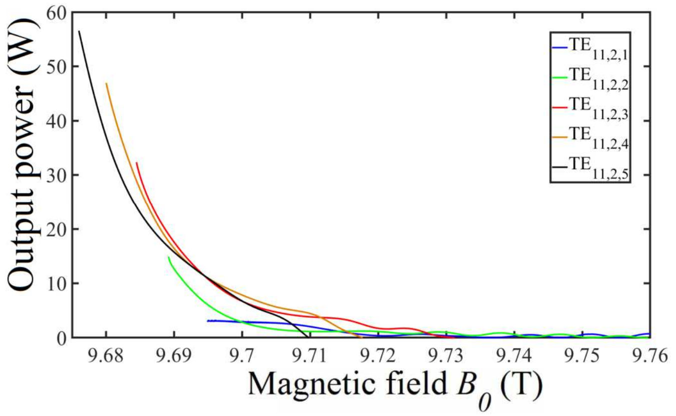

Fig. 1. Output power calculated in SMA for the $TE_{11,2,q}$ (q=1,2,…,5) modes of the second-harmonic 527-GHz gyrotron versus operating magnetic field B_0 (L=7.1 cm).

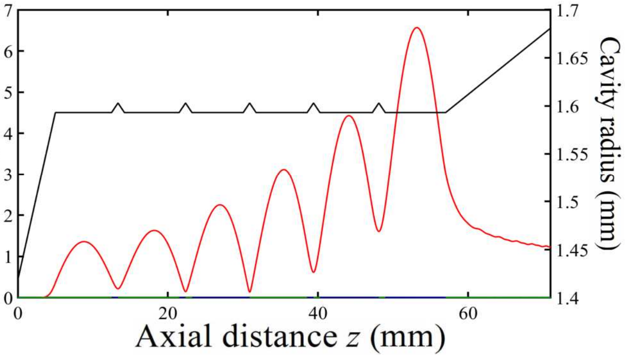

Fig. 2. Amplitude of operating $TE_{11,2,5}$ mode of the second-harmonic 527-GHz gyrotron found from multimode approach B_0=9.68 T.

approach [8] are also depicted for comparison purpose. It can be seen that coupled-mode approach and simplified SMA are in close agreement. This is due to a minor mode conversion caused by irregularities in the gyrotron cavity.

A good agreement between SMA and advanced approaches can also be seen in Figs. 4, which depicts the output power for the modified cavity. It is clear that irregularities in the cavity enable a 3-fold increase in peak output power of the 527-GHz gyrotron from 20 W to 60 W.

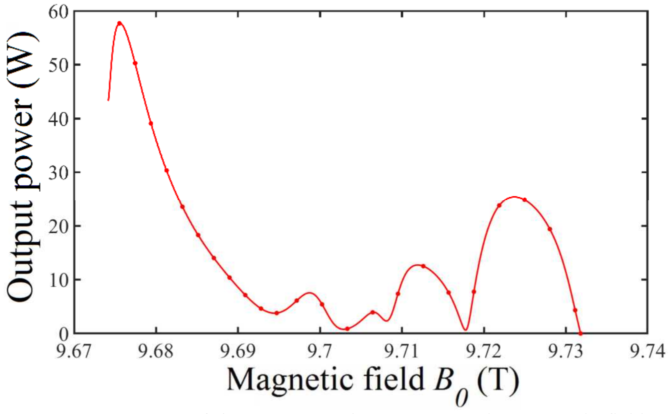

Fig. 4. Output power of the $TE_{11,2,5}$ mode versus operating magnetic field B_0 for the second-harmonic 527-GHz gyrotron with modified cavity in SMA. The results of the multimode approach are indicated by markers.

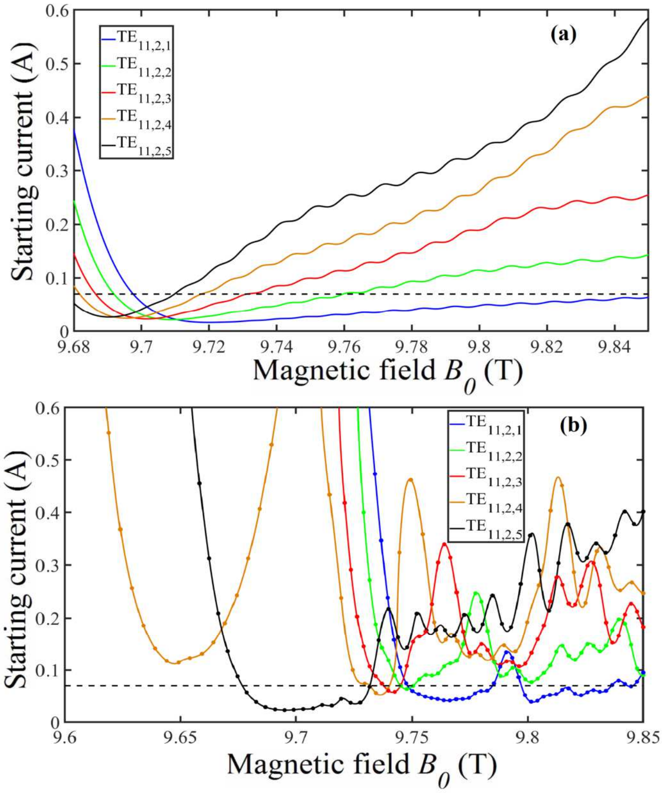

Fig. 3. Starting currents of the $TE_{11,2,q}$ (q=1,2,…,5) modes versus operating magnetic field B_0 for the second-harmonic 527-GHz gyrotron with (a) uniform, (b) modified cavity in SMA. The results of the multimode approach are indicated by markers.

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