Design on a 100 kW-level Gyrotron Operating at 30 GHz

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Abstract: *in this paper, we present a design on a 30 GHz 100 kW-level gyrotron. The cold-cavity of the gyrotron has been studied by using an in-house gyrotron simulation code and CST microwave studio, respectively. Meanwhile, in the hot-cavity analyses, the behavior of multi-mode beam-wave interaction has been studied in detail by using PIC simulation with the help of CST particle studio. The results present that the gyrotron can operate at* $TE_{0.3}$ *mode stably with the output power of 150 kW under the operating conditions: beam voltage of 50 kV, beam current of 10 A, magnetic field of 1.14 T, and pitch factor of 1.3.*

Keywords: mm-wave; 30 GHz; gyrotron; 100 kW-level; CST design.

Introduction

Gyrotron is a reliable and considerably efficient source to produce powerful electromagnetic wave ranging from millimeter wave (mm-wave) to terahertz wave, which has application in a variety of systems including materials processing, medical imaging, and plasma heating [1]. Specially, in mm-wave band, a powerful RF source is not only required in some experimental plasma device [2], but also needed in some industrial applications [1, 3]. Such as, some Ka-band gyrotrons have been designed and employed in ECR (electron cyclotron resonance) ion source system [4]. In the application of materials processing, compared to the centimeter waves, the heating efficiency of mm-wave radiation is better, meanwhile, the attenuation in dielectric materials of mm-wave is better too[3]. Presently, a hundred kilowatts RF source at around 30 GHz is required for some special application. For that purpose, a 100 kW level gyrotron operating at 30 GHz is being designed. In this paper, we present the theoretical design on that gyrotron by using an in-house gyrotron simulation code and CST software [5] [6].

Cold-cavity analysis

For the gyrotron, a traditional three-section structure is employed as the cavity. In the design, $TE_{0.3}$ mode has been selected as the operating mode. By using an in-house developed gyrotron simulation code, the cavity structure has been designed for $TE_{0.3}$ mode at 30 GHz. The corresponding cavity structure and normalized cold-cavity electric field profile are plotted in the figure 1, where $\alpha = 6.3^o$,$\beta = 4.5^o$, *Lc*=50 mm, and radius of main cavity is 16.2 mm. Meanwhile, for comparison with the numerical results, the 3-D model of this cavity has been built in CST microwave studio for calculating diffraction Q and resonance frequency. Figure 2 presents the CST model and the external quality factor (corresponding to the diffraction quality factor of open-end cavity) of $TE_{0.3}$ mode. The results of calculations of cold cavity are listed in the table I. Table I demonstrates that the difference of results in diffraction quality factor and resonance frequency between CST microwave studio and numerical code is slight, and the main mode can operate at 30 GHz in the designed cavity.

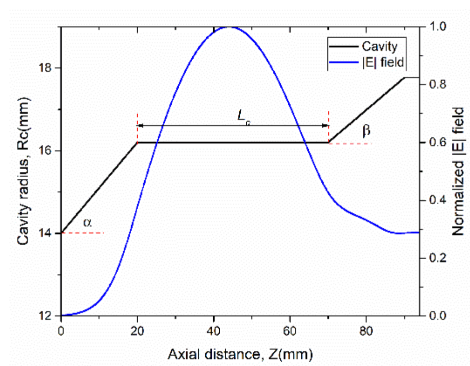


Figure.1. the cold-cavity structure and corresponding cold-cavity normalized electric field profile.

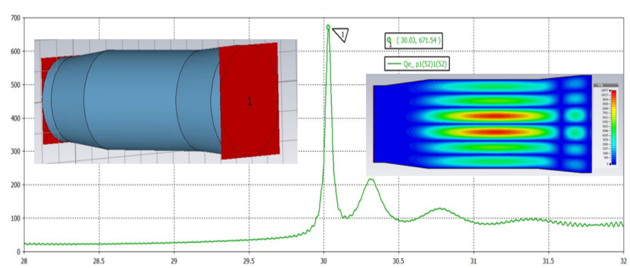


Figure.2. the CST model and the corresponding external quality factor Q_e of $TE_{0.3}$ mode (no.52 in CST), where $Q_e = \frac{\omega_0 \Gamma_d}{4}$ (Γ_d is the group delay time).

Table 1. The results of cold-cavity

	Numerical	CST
Mode	$TE_{0.3}$	$TE_{0.3}$
Diffraction Q	641	671
Frequency	30.05 GHz	30.03 GHz

Hot-cavity simulation

After analyzing the cold-cavity, the hot-cavity analyses have been done by using PIC simulation with the help of CST particle studio. Figure 3 presents the simulations results on output power and frequency as the functions of magnetic field. It shows that the maximum output power of 150 kW is obtained in CST simulation under the magnetic field of 1.14 T, and TE0.3 mode can steady operate at magnetic fields between 1.14 T to 1.18 T. The process of multi-mode beam-wave interaction is presented in figure 4, where 60 modes have been considered in the simulation. It shows that the main mode $TE_{0.3}$ steady work after 80 ns.

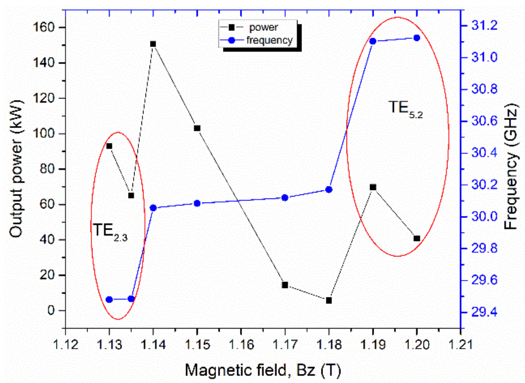
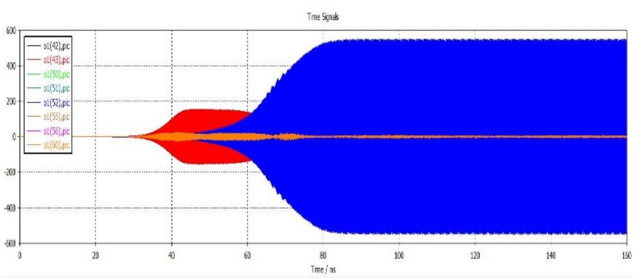
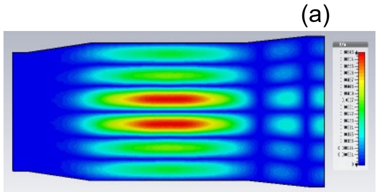
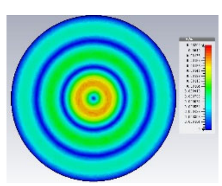


Figure 3. The CST simulations results on output power and frequency as the functions of magnetic field, where the beam voltage is 50 kV, beam current is 10 A, pitch factor is 1.3, and the guiding center radius is 8.6 mm.



(a)





(b) (c)

Figure 4. The CST particle studio simulation results with magnetic field of 1.14 T. (a) amplitudes of modes versus interaction time, where no. 52 is $TE_{0.3}$ mode, no.42/43 are $TE_{4.2}$ mode in different linear polarizations, no. 50/51 are the $TE_{2.3}$ mode in different linear polarizations, no.55/56 are the $TE_{5.2}$ mode in different linear polarizations, no. 60 is a TM mode; (b) the longitudinal electric field distribution at interaction time of 160 ns; (c) the transverse electric field distribution of output port at interaction time of 160 ns.

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