Simulation and Analysis of the $TE_{28,8}$ Mode Excitation in an Open Resonant Cavity of Gyrotron

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Abstract: *A mode generator consisting of an open resonant cavity and a quasi-parabolic mirror for the $TE_{28,8}$ mode excitation was presented. The excitation condition of the $TE_{28,8}$ mode was discussed and the obtained electric field distribution was analyzed and compared with the ideal $TE_{28,8}$ mode according to its scalar and vector correlativity.*

Keywords: low-power test; quasi-optics; $TE_{28,8}$ mode generator; open resonant cavity

Introduction

Gyrotron is an important high-power microwave source for plasma heating. In the developing process of gyrotron, it is necessary to test open resonant cavity, an important part of gyrotron, in order to obtain some parameters, such as the resonant frequency, Q factor and field pattern of the operating mode. Because the gyrotron oscillator operates at high order body mode, a quasi-optical mode converter is required to excite the high order body mode in the open resonant cavity [1, 2]. In this abstract, a mode generator, consisting of an open resonant cavity and a quasi-parabolic mirror, was simulated and analyzed for the $TE_{28,8}$ mode excitation.

Design of $TE_{28,8}$ Mode Generator

The mode generator is designed for cold test of 140 GHz gyrotron, which consists of an open resonant cavity and a quasi-parabolic mirror.

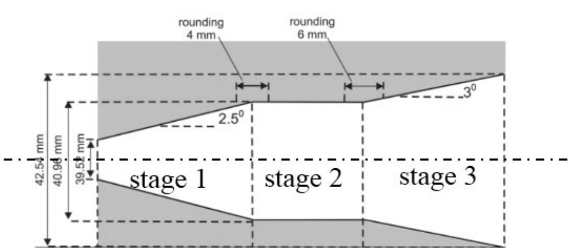

Figure 1 Schematic diagram of cavity structure

The open resonant cavity can be divided into three stages, which is marked stage 1-3 in figure 1. Stage 1(3) is a tapered circular waveguide, whose slope angle is 2.5°(3°). Stage 2 is a regular circular waveguide connecting with stage 1 and 3, whose radius is 20.48 mm.

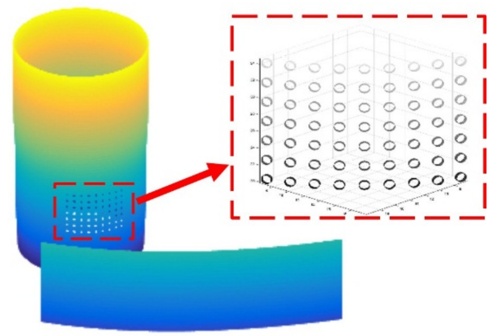

Figure 2 $TE_{28,8}$ mode generator and grid of the coupling holes in the cavity wall

Furthermore, there are a grid of coupling holes drilled in stage 2, and the number of holes is 9 holes azimuthally × 7 holes axially as shown in figure 2. The grid is 14mm long and its azimuthal extent is 60°, and the radius of all holes is 0.4 mm.

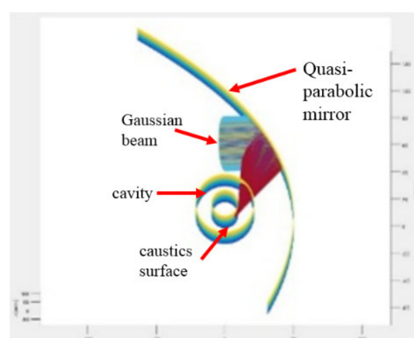

Figure 3 Schematic diagram of the quasi-parabolic mirror with optical path

In figure 3, the schematic diagram of the quasi-parabolic mirror with optical path is drawn, which can be determined by the caustic radius calculated by eigenvalue of the $TE_{28,8}$ mode and structure radius of the open resonant cavity [3]:

$$r_c = mR/X_{mn} \tag{1}$$

where X_{mn} is the n^{th} nonvanishing root of the derivative of the Bessel function of order m, and R is the radius of circular waveguide stage 2.

Parameter Analysis

The size of the coupling holes and the phase distribution of the incident wave beam have the effect on the mode excitation. It should be noted that the coupling holes should be designed in a reasonable size for obtaining the high efficiency and keeping the original electromagnetic characteristics of the open resonant cavity without any hole. Here, the incident wave beam is a Gaussian beam with an appropriate waist, which can be regarded as a plane wave near the waist.

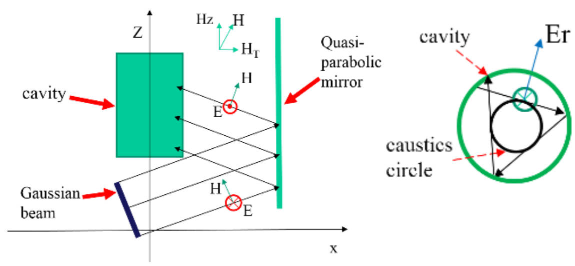

Figure 4 Polarization of the Input Beam Field

In order to obtain the $TE_{28,8}$ mode, the electric field of the beam reflexed from the quasi-parabolic mirror should be perpendicular to the z-axis, as shown in figure 4. Moreover, on the caustics surface, only the E_r component of the electric field should exist for a perfect design.

Simulation and Results

Surf 3D software is used to calculate the performance of the mode generator and to optimize its structure parameters, such as the position, number and size of the holes.

Table1 Effect of Hole Size on Mode Excitation

Radius of the hole(mm)	scalar correlativity	vector correlativity
0.35	90.8%	81.2%
0.40	90.9%	81.3%
0.45	90.7%	81.1%
0.50	90.6%	81.0%
0.55	90.5%	80.8%

The different radii of holes with corresponding scalar and vector correlativity of the $TE_{28,8}$ mode are given in table 1. Obviously, the optimal radius of the hole is 0.40 mm, the corresponding scalar and vector correlativity of the $TE_{28,8}$ mode is 90.9% and 81.3%, respectively.

Figure 5 shows the scalar correlativity of the open resonant cavity in different frequencies of the input signal from 140.12 GHz to 140.28 GHz. The max value of scalar correlativity is 90.9%, and the corresponding frequency of the input signal is 140.179 GHz, i.e., the resonant frequency of the cavity with holes is 140.179 GHz. Furthermore, the resonant frequency of the cavity without any hole is 140.203 GHz. The difference between the resonant cavity with and without holes is less than 0.02%, which indicates that the drilled holes in stage 2 has little effect on electromagnetic characteristics of the cavity.

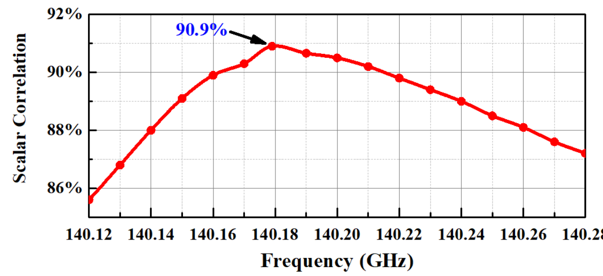

Figure 5 the Relationship Between Frequency of the Source and Correlativity

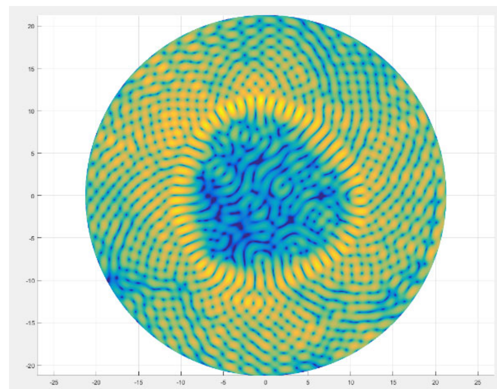

Figure 6 E-field Distribution of $TE_{28,8}$ Mode (dB)

The electric field pattern of the TE28,8 mode at the cavity output port is given in figure 6, where the corresponding scalar and vector correlativity of the TE28,8 mode is 90.9% and 81.3% respectively. Compared with the ideal TE28,8 mode field pattern, there is some variation near and inside the caustic radius because of disturbance from the other modes in the cavity. Therefore, the parameters of the mode generator need further optimization.

Conclusion

The TE28,8 mode excitation for the cold test application was simulated and analyzed, which shows the TE28,8 mode can be excited with the scalar and vector correlativity of 90.9%, and 81.3% respectively. The further optimization is under way.

References

[1]. N. L. Alexandrov, et al. “Low-power excitation of gyrotron-type modes in a cylindrical waveguide using quasi-optical techniques” Int. J. Electron., vol. 79, no. 2, pp. 215-216, 1995.

[2]. G. Dammertz, et al. "Cold test measurements on components of the 1 MW, 140 GHz, CW gyrotron for the stellarator Wendelstein 7-X."Fusion Engineering and Design 53.1-4:561-569, 2001.

[3]. T. Ruess, et al. “Computer-Controlled Test System for the Excitation of Very High-Order Modes in Highly Oversized Waveguides” Journal of Infrared, Millimeter and Terahertz Waves, 2019.