An Improved Design for High-power Coaxial-cavity Gyrotron with Misaligned Insert

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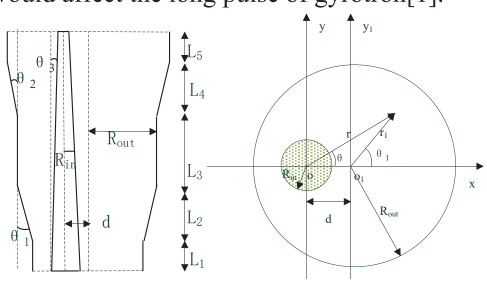
Abstract—*The misalignment of insert would cause frequency shift, decrease in interaction efficiency and uneven ohmic loss distribution on the cavity wallswhich would affect the long pulse of gyrotron. The structure of gyrotron cavity has been optimized in our recent study to reduce the effect of misaligned insert. As the misaligned distance increases, the effects become larger. In this paper, the dependence of output characters on guiding center radius is investigatedand an optimal guiding center radius is chosen to reduce the effect of misaligned insert.*

Keywords—High-power gyrotron; misaligned insert; output characters; coupling coefficient

INTRODUCTION

Coaxial cavity is the main interaction circuit of high-power gyrotron because of its ability to suppress mode competition.However,a misalignment of insert would result in frequency shift, decrease in interaction efficiency and uneven ohmic loss distribution on the cavity walls which would affect the long pulse of gyrotron[1].



(a) (b)

Fig.1. Axis-symmetric sketch (a)and cross section (b) of coaxial cavity with misaligned inner rod

In our recent research, it is found that the effects of a slightly misaligned insert could be restrained by optimizing the structural parameters of cavity, the parameters and the operating mode is shown in Table 1. However, the effects become larger in the optimal cavity with the increase of the misaligned distance. This is because the misaligned insert would weaken beam-wave coupling as the distance increases.

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TABLE Ⅰ PARAMETERS OF CAVITY

parameter	value
Operating mode	$TE_{34,11}$
Operating frequency	170 GHz
Input wave length L_1	2 mm
Input gradient section length L_2	15 mm
Beam-wave interaction section length L_3	11 mm
Output gradient section length L_4	35 mm
Output wave length L_5	2 mm
Outer waveguide radius R_{out}	21.93 mm
Insert radius R_{in}	7.3 mm
Input gradient section angle θ_1	2.5°
Output gradient section angle θ_2	2.5°
Tilt angle of insert θ_3	1°
Beam voltage U_b	65 kV
Beam current I_b	68 A
Magnetic field B **within cavity**	6.58 T
Pitch factor α	1.3

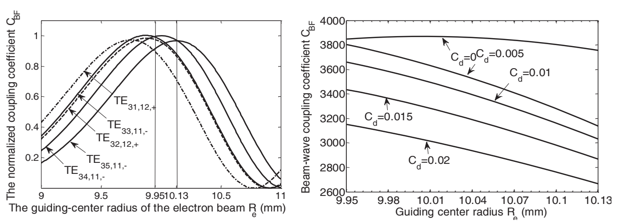
The average beam-wave coupling coefficient is used to describe the coupling strength between electron beam and electromagnetic wave in a coaxial cavity with a misaligned insert and is given as

$$C_{bf} = k_c^2 C_{mn}^2 \left\langle \left| G_{mn}(r_e,\theta) \right|^2 \right\rangle_\theta \quad (1)$$

where, $G_{mn}(\mathrm{r}_e,\theta) = \sum_m A_m Z_{m-s,m}(k_c r_e) e^{-i(m-s)\theta}$, $\langle\cdots\rangle_{\theta_c}$ indicates the average of a function over θ_c , $Z_{l,m}(k_c r) = J_l(k_c r) - Y_l(k_c r) J'_m(k_c R_{in}) / Y'_m(k_c R_{in})$, C_{mn} is the normalized coefficient of transverse electric field distribution and could be calculated by $\int_A \vec{e}_{mn}$□ ($\vec{e}_{mn}$ is the unit vector of transverse electric field distribution.), A_m is the weight coefficient of each component of the operating mode.It is obvious that the guiding center radius would affect the coupling strength. Therefore, optimizing the guiding center radius would be beneficial to reduce the effect of a misaligned insert. In this paper, the dependence of output characteristics of a coaxial cavity with a misaligned insert on guiding center radius is calculated and analyzed.

NUMERICALCALCULATION

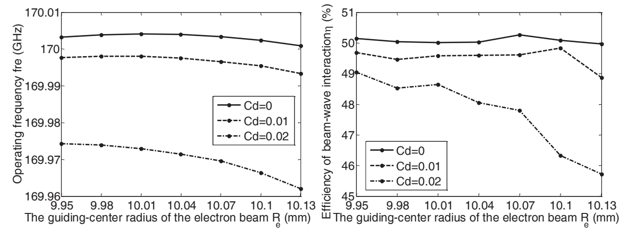
The guiding center radius is an important parameter for the suppression of competing modes. Thus, when optimizing the guiding center radius to reduce the effects of a misaligned insert, it is necessary to ensure that the coupling coefficient of operating mode is maximum compared with possible competing modes. The dependence of coupling coefficient on guiding center radius is shown in Fig.2 (a)[2].It is obvious that the coupling coefficient of the operating mode $TE_{34,11-}$ is the largest when r_e is in the range of $[9.95, 10.13]$. The guiding radius would be optimized within this range to reduce the effects of a misaligned insert.Fig.2 (b) indicates the dependence of coupling coefficient of operating mode on guiding center radius in the case of different C_d ($C_d = d/R_{out}$). The coupling coefficient C_{BF} hardly varies with r_e when $C_d = 0$. while $C_d > 0$, C_{BF} decreases with the increase of r_e. The effect of r_e on C_{BF} becomes lager as C_d increases. Therefore, choosing a small guiding center radius could reduce the effects of a misaligned insert on C_{BF} of operating mode.



(a) (b)

Fig.2. The dependence of coupling coefficient on guiding center radius(a) C_{BF} of different modes in the case of $C_d = 0$ (b) C_{BF} of operating modes in the case of different C_d

Fig.3 shows the effects of r_e on the output characters. It is clear that the effects of r_e become larger with the increase of C_d .When $C_d = 0.01$, the changes of both operating frequency and efficiency are quite small. The values of the frequency are around 169.997 GHz, and the efficiencies are around 49.5%. While $C_d = 0.02$, there are clear downward trends of both the frequency and the efficiency with the increase of r_e. When r_e is designed to be 9.95 mm, a misalignment of $0.02R_{out}$ causes a frequency shift of 15.15 MHz and a efficiency drop of 0.82%. While r_e is 10.13 mm, the same misalignment results in a frequency shift of 29.45 MHz and a efficiency drop of 1.45 %. Therefore, $r_e = 9.95\,\text{mm}$ is an optimal parameter for the cavity designed in this paper, which could not only make the coefficient of the operating mode lager than competing modes but also reduce the influence of misaligned insert on beam-wave interaction.



(a) (b)

Fig.3. The dependence of output characters on guiding center radius (a) operating frequency (b) beam-wave interaction efficiency

CONCLUSION

In this paper, the influence of guiding center radius on output characters in high-power coaxial-cavity gyrotron with a misaligned insert is discussed. On the premise that the coupling coefficient is larger than that of competing modes, guiding center radius could be optimized to reduce of the effects of a misaligned insert. The optimal radius for the cavity designed in this paper is $r_e = 9.95\,\text{mm}$. When $r_e = 9.95\,\text{mm}$, the frequency shift and the efficiency drop caused by a misaligned insert is the smallest. A misalignment of $0.02R_{out}$ causes a frequency shift of 15.15 MHz and a efficiency drop of 0.82%.

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REFERENCES

[1] Diwei Liu, Yang Yan, and Shenggang Liu. Characteristics Analysis of a Coaxial Cavity With a Misaligned Inner Rod[J], IEEE TRANSACTIONS ON ELECTRON DEVICES, 2012,51(1):230:233

[2] G. S. Nusinovich, M. E. Read, O. Dumbrajs, and K. E. Kreischer, "Theory of Gyrotrons with Coaxial Resonators", IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 41, NO. 3, MARCH 1994. pp. 433-438.