Design and Study of W-band Gyrotron with Output Power of 150 kW Level

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Abstract: *Based on the linear theory and the self-consistent nonlinear theory, a 94 GHz complex cavity gyrotron is designed with the pair of TE7.2/TE7.3 operating mode in this paper. Through operating at the high-order mode and second harmonic, the gyrotron can output hundred-kilowatt power at low magnetic field. Furthermore, the influences of electron beam parameters on interaction efficiency are analyzed in detail. As a result, the output power of 173 kW, corresponding to 34.83% efficiency, has been achieved with the beam voltage 71 kV, the beam current 7 A, the pitch factor 1.3 at the DC-magnetic field of 1.83T.*

Keywords: gyrotron; low magnetic field; hundred-kilowatt power; complex cavity

Introduction

As an irreplaceable source of high-efficiency electromagnetic radiation, gyrotron is widely used in fusion plasma heating, data communication, high-resolution radar and active denial system and so on[1-2]. Due to its unique field of application, W-band gyrotron is worth studied. In order to operating at low magnetic field and obtaining high output power, the higher-order mode and second harmonic gyrotron[3] is selected in our study. While to suppress severe mode competition, the structure of gradually tapered complex cavity[4] is significantly adopted in the designed gyrotron. In the following part, the simulation results of cold cavity will be given. Furthermore, the hot-cavity calculations are studied, and the influence factors of beam-wave interaction efficiency are also analyzed. Finally, the complex cavity gyrotron operating at the beam voltage 71 kV, the beam current 7 A, and the magnetic field 1.83 T with output power 173 kW is designed reasonably.

Numerical Simulation Results

Cold-cavity analysis: By using an in-house developed nonlinear simulation code[5] and massive simulation calculations, the complex cavity operating at 94 GHz is designed. Fig. 1 shows the simulation results of cold cavity, which can be seen that the TE7.2 mode mainly exists in the first cavity, and the TE7.3 mode is only starting up at second cavity and keeping steady at output taper. Meanwhile, the resonant frequency and diffraction quality factor of operating mode and competition modes are calculated and given in Table 1, which can be seen that the cold-cavity characteristics of operating mode is far from the competitive modes. The results demonstrate that the structure of the interaction cavity is designed reasonably and the choice of the TE7.2/TE7.3 mode can well avoid mode competition.

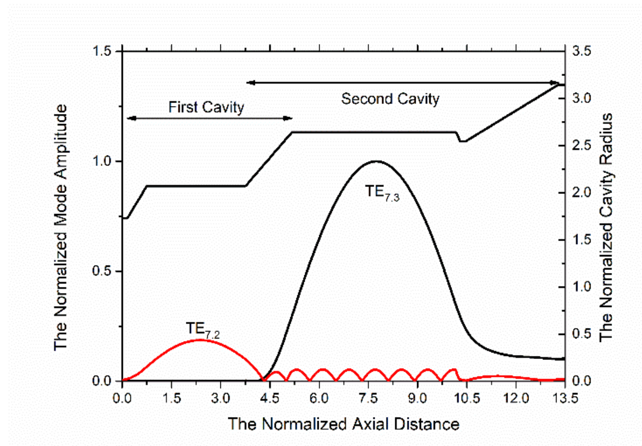

Figure 1. Normalized cold cavity field profiles and geometry of the complex cavity.

Table 1. The resonant frequency and diffraction quality factor of operating mode and competition modes.

Related mode	$TE_{7.2}$/ $TE_{7.3}$	$TE_{2.5}$	$TE_{0.5}$	$TE_{4.4}$	$TE_{1.3}$
Resonant frequency (GHz)	94.298	93.27	93.96	91.09	48.99
quality factor	3838	3603.6	3738.6	3259.4	328.1

Hot-cavity simulation: Based on the calculation results of cold cavity, the beam-wave interaction has been simulated. The influences of the magnetic field, the beam voltage and the beam current on interaction efficiency are analyzed, which is very essential that it can help to obtain an optimum operating point in the experiment.

Given the beam voltage of 70 kV, the beam current is 5 A and the beam radius is 3.25 mm. Under different pitch factor, the electron efficiency as functions of magnetic fields is shown in Fig. 2. It can be seen that the changes of magnetic field have a large effect on the interaction efficiency. Under different pitch factor, there is a better operating point. When the magnetic field is 1.83 T, the interaction efficiency is highest.

Under the condition that a beam current I = 6 A and a pitch factor α = 1.3, the efficiency of beam–wave interaction as functions of the beam voltage U are plotted in Fig. 3. The picture shows that the maximum efficiency of the designed gyrotron is over 33% at the beam voltage of 71 kV and the magnetic field of 1.83 T.

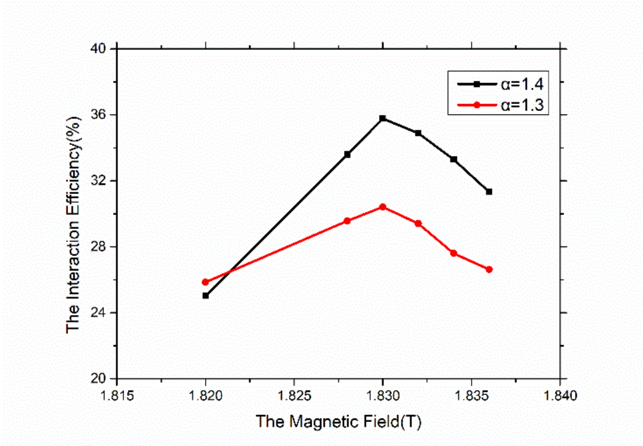

Figure 2. The interaction efficiency as functions of magnetic fields under different pitch factor.

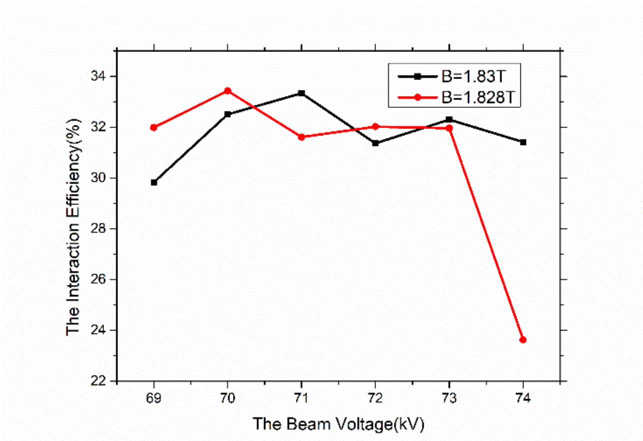

Figure 3. The interaction efficiency as functions of the beam voltage under different magnetic fields.

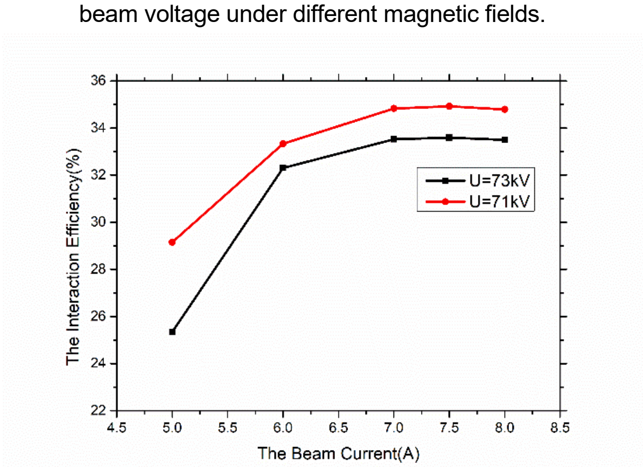

Figure 4. The interaction efficiency as functions of the beam current under different beam voltage.

When pitch factor is 1.3 and magnetic field is 1.83 T, the efficiency as functions of the beam current under different beam voltage are plotted in Fig. 4, which shows the beam current of 7 A is better choice. Fig. 5 shows that the maximum efficiency of 34.83% is obtained at the magnetic field of 1.83 T, which is consistent with the results in Fig.2.

Therefore, the best point of operating parameters for this designed gyrotron is the beam voltage of 71 kV, the beam current of 7 A, and the magnetic field of 1.83 T.

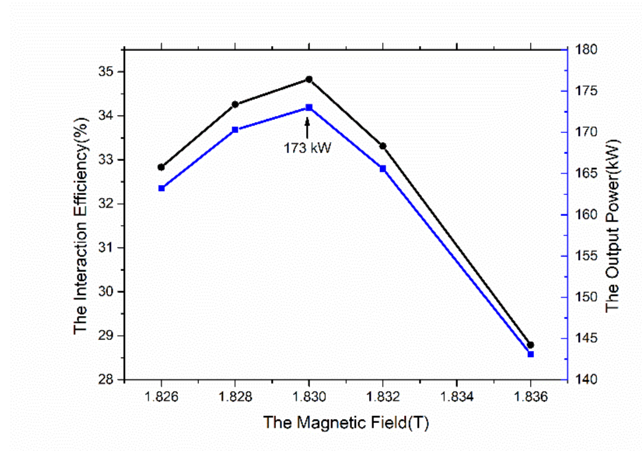

Figure 5. The interaction efficiency as functions of magnetic fields when the beam voltage is 71 kV and the beam current is 7 A.

Conclusion

According to the simulation study of the cold-cavity and the hot-cavity, the complex cavity gyrotron was designed with output power of 173 kW, under low magnetic field of 1.83 T, when the pitch factor is 1.3, the beam current is 7 A, the beam voltage is 71 kV, and the beam radius is 3.25 mm.

Acknowledgments

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