Investigation on a 170 GHz/230 GHz Dual Mode Megawatt-class Gyrotron For CFETR

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Abstract: *in this paper, we present an investigation on a dual-frequency dual-mode megawatt-class gyrotron. The gyrotron can operate at frequencies of 170 GHz and 240 GH with the corresponding operating modes $TE_{33.12}$ and $TE_{44.16}$, respectively. In the analyses, the startup scenarios for the operating modes have been investigated by an in-house, developed, multi-mode, time-dependent code. The simulations result show that the output power of the gyrotron can reach about 1 MW at two operating frequencies with corresponding operating conditions.*

Keywords: Dual-mode; 170 GHz/230 GHz; MW-class gyrotron.

Introduction

Gyrotron is a reliable and considerably efficient source to produce high power from millimeter wave to terahertz wave, which has applied in a variety of systems [1]. Specially, in some magnetically confined fusion research devices, many high power gyrotrons have been used in that devices for Electron Cyclotron Resonance Heating and Current Drive (ECRH&CD) [2]. Currently, in the ITER (International Thermonuclear Experimental Reactor) project, a 24 MW RF power system generated by 24 gyrotrons at 170 GHz is needed for the ECRH&CD application [2]. After successful operation of ITER, a demonstration power plant (DEMO) is planned as the first prototype of commercial fusion power plants [3]. In China, a DEMO power plant Chinese Fusion Engineering Testing Reactor (CFETR) has been planning to explore fusion energy in the future [4]. For the ECRH system of the CFETR, high power gyrotrons operating at 170 GHz and 230 GHz are required as RF sources [5]. In order to reduce the total number of tubes for sufficient ECRH power, output power per gyrotron shall be as high as reasonably possible and the expected gyrotron can achieve dual-frequency operation at 170 GHz and 230 GHz. Therefore, it is important to investigate and study a 170 GHz/230 GHz megawatt-class gyrotron for that purpose. The paper presents an investigation and study for a megawatt-class gyrotron, which can achieve dual-frequency operation at about 170 GHz and 230 GHz.

Cold Cavity Result

For the dual-mode dual-frequency gyrotron, a traditional cylindrical-cavity with three-section structure was employed as the interaction resonator, where quadratic function smoothing has been used for the gradual taper of the cavity. Normally, the expected output power per gyrotron is about 1 MW in the case of a traditional cylindrical-cavity gyrotron. In mode selection, the operating modes have been selected according to the principles: a). lower ohmic wall-loading, b). maximum relative caustic radius deviation of 3.5% from the average value. Based on above, $TE_{44.16}$ mode was choose as the operating mode at frequency of 230 GHz, firstly. And then, $TE_{33.12}$ mode was selected as the operating mode at 170 GHz based on the searching method described in [6]. The cavity structure and corresponding cold-cavity electric fields profiles are plotted in the figure 1, where the main cavity length Lc=13 mm, main cavity radius is 22.42 mm, and the angles of input taper and output taper are 2.3° ad 2.5°, respectively. The cold-cavity simulation results are listed in the table I.

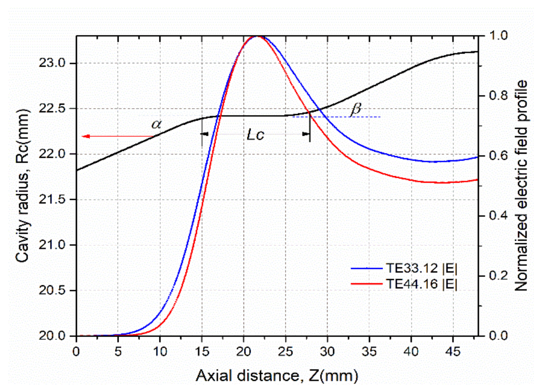

Figure 1. The cold-cavity structure and corresponding cold-cavity normalized electric field profiles.

Table 1. Cold cavity results

Mode	TE33.12	TE44.16
frequency(GHz)	171.06	229.84
Diffractive quality factor	745	1151

Hot cavity Simulation Result

In the hot-cavity simulation, the multi-mode beam-wave interaction has been analyzed by using an in-house developed time-dependent multi-mode self-consistent simulation code GYSIC [6]. In the simulations, the co-rotating modes $TE_{+33.12}$, $TE_{+44.16}$ are selected. In the initial setting, the space step of 100 um, the time step of 40 ps, and power of 0.01 mW of the excitation signal of every mode were employed for the two simulations. The start-up scenarios of $TE_{+33.12}$ and $TE_{+44.16}$ modes are plotted in figures 2 and 3, respectively. Figure 2 shows that the beam-wave interaction can stably operate at main mode $TE_{+33.12}$ after 1500 ns. The output power can reach at about 1MW at the operating point. Figure 3 presents that the main mode $TE_{+44.16}$ can achieve stable operation with the output power of 1 MW after 1200 ns. The hot cavity results are summarized in table II, in which the effective conductivities of oxygen free copper (OF Cu) for 170 GHz and 230 GHz are 23.5 MS/m and 21.3 MS/m, respectively. One can know that the output powers of two modes are about 1 MW, and the corresponding maximum ohmic losses are 1.06 kW/cm2 and 1.49 kW/cm2, which are much low than 2.0 kW/cm2.

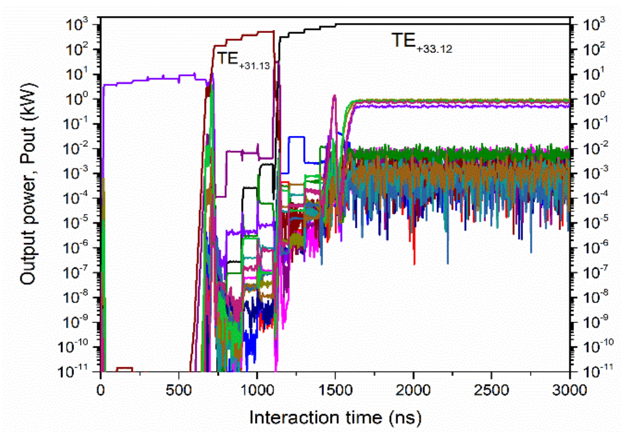

Figure 2. The start-up scenario for longer time duration with employing the conductivity of 2.35×10^7 S/m. Beam voltage increases in steps of 2 kV per 100 ns from 40 kV to 70 kV till 1500 ns and remains constant till 3000 ns, where the beam voltage of 70 kV, beam current of 48 A, magnetic field of 6.75 T, pitch factor of 1.30, and guiding center radius of 9.66 mm are selected.

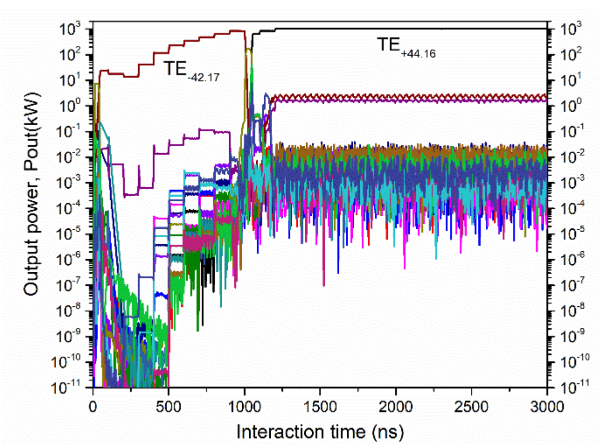

Figure 3. The start-up scenario for longer time duration with employing the conductivity of 2.12×10^7 S/m. Beam voltage increases in steps of 2 kV per 100 ns from 41 kV to 65 kV till 1200 ns and remains constant till 3000 ns, where the beam voltage of 65 kV, beam current of 45 A, magnetic field of 9.0 T, pitch factor of 1.35, and guiding center radius of 9.52 mm are selected.

Table 2. Hot Cavity Results

Mode	TE+33.12	TE+44.16
frequency(GHz)	171.116	229.897
Beam current (A)	48	45
Beam voltage (kV)	70	65
Magnetic field (T)	6.75	9.0
Pitch factor	1.3	1.35
Guiding center radius (mm)	9.66	9.52
Effective Conductivity OF Cu (MS/m)	23.5	21.3
Max. ohmic losses (kW/cm^2)	1.06	1.49
Output power (kW)	1040	1005

Conclusion

In this paper, a dual-frequency MW-class gyrotron operating at 170 GHz and 230 GHz has been investigated and simulated. The results show that the output power of gyrotron can achieve at about 1 MW at frequency of 171. 116 GHz when beam voltage is 70 kV and beam current is 48 A, and at frequency of 229.897 GHz when beam voltage is 65 kV and beam current is 45 A. One also can know that the maximum ohmic losses on the inner cavity wall are much less than 2.0 kW/cm^2 at the two operating conditions.

Acknowledgments

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