Design of a Quasi-Optical Mode Converter for a Dual-Frequency Coaxial-Cavity Gyrotron

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***Abstract*—A quasi-optical mode converter is under development for an 170/204 GHz coaxial-cavity gyrotron at KIT. It is operated in the $TE_{34,19}$ mode at 170 GHz and the $TE_{40,23}$ mode at 204 GHz. A mirror-line launcher should be used for such modes with the ratio of caustic to launcher radius of approximately 0.32. The optimum value of the launcher radius has been found to allow for a high Gaussian-mode content at both frequencies.**

I. INTRODUCTION

Multi-megawatt-level gyrotrons will be used for electron cyclotron resonance heating and current drive in a future Demonstration Fusion Power Plant (DEMO) [1,2]. Currently, it is assumed that the heating frequency will be at 170 GHz and taking into account a moderate upshift factor of 1.2, the corresponding optimum Electron Cyclotron Current Drive (ECCD) frequency will be at 204 GHz [3]. The couple of frequencies (170/204 GHz) satisfy the natural transmission resonance criteria of a single-disc RF diamond window with thickness of 1.85 mm, corresponding to multiples of the half-wavelength (~34 GHz frequency steps). With such a diamond window, it is possible to develop high-power gyrotrons operating at these two frequencies.

A modular short pulse pre-prototype of the coaxial-cavity gyrotron operating in the $TE_{34,19}$ mode at 170 GHz has been reported in [4]. It provides an RF output power of more than 2 MW in short-pulse operation (ms range). That pre-prototype includes a quasi-optical mode converter to transform the $TE_{34,19}$ operating mode into a Gaussian beam. The quasi-optical mode converter consists of an oversized cylindrical waveguide launcher and three beam shaping mirrors. As the ratio of the caustic to the radius of the launcher is about 0.323, a mirror-line launcher is used to the transform the $TE_{34,19}$ volume mode [5]. Operating in the $TE_{34,19}$ mode, both the simulation and the experimental results show very high Gaussian-mode contents of the RF beam at the output window, namely 96.3% and 96%, respectively [4,5]. Currently the existing short pulse modular pre-prototype gyrotron is being upgraded towards an additional operation at 204 GHz [6]. Considering the $TE_{34,19}$ mode at 170 GHz, the $TE_{40,23}$ mode is selected for the operation at 204 GHz. The existing launcher has been tested with the $TE_{40,23}$ mode. However, the simulation results show that the Gaussian-mode content is just 91.6% at the launcher aperture. It does not satisfy the requirement on the Gaussian-mode content of the RF beam in a high-power gyrotron, which should be higher than 95% (ITER requirement). The parameters of the launcher for the pre-prototype gyrotron and the operating modes are shown in Table I. The slope of the launcher wall taper is 0.002, the length of the launcher is 310 mm. Table I verifies that the parameters of the two operating modes are very similar. Hence, it should be possible to design a launcher with a relative high conversion efficiency for both modes.

TABLE I. PARAMETERS OF THE OPERATING CAVITY MODES

Operation mode	*Launcher radius R_0(mm)*	*Oversize factor*	*Caustic radius (mm)*	*Cut length (mm)*	*Brillouin angle (degree)*	*Gaussian-mode content*
$TE_{34,19}$ @ 170GHz	32.5	1.1	10.5	71	65.4	96.3%
$TE_{40,23}$ @ 204GHz	32.5	1.1	10.29	71.6	65.29	91.6%

II. LAUNCHER DESIGN FOR DUAL FREQUENCY OPERATION

All the parameters but the Gaussian-mode content shown in Table I are determined by the launcher radius. According to our experience in the design of quasi-optical mode conversion launchers, the optimum value of the oversize factor is 1.07. In order to find the optimum for both the $TE_{34,19}$ mode and the $TE_{40,23}$ mode, different launcher radii have been tested in the design. In order to keep the length of the launcher and the Brillouin angle to be the same as those of the launcher for the single-frequency pre-prototype gyrotron, the launcher radius is decreased to 32.0 mm and the slope of launcher wall taper is increased to 0.0027. A new mirror-line launcher has been designed in terms of the numerical method presented in ref. [5].

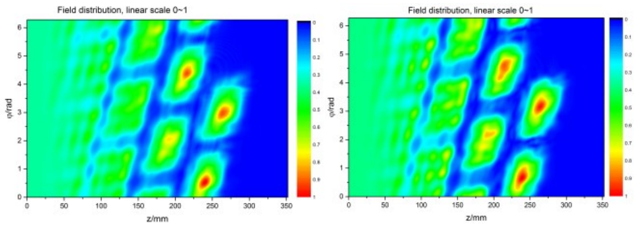

Fig. 1 Field distribution on the launcher wall (linear scale 0~1): operating in the $TE_{34,19}$ mode at 170 GHz (left) and in the $TE_{40,23}$ mode at 204 GHz (right).

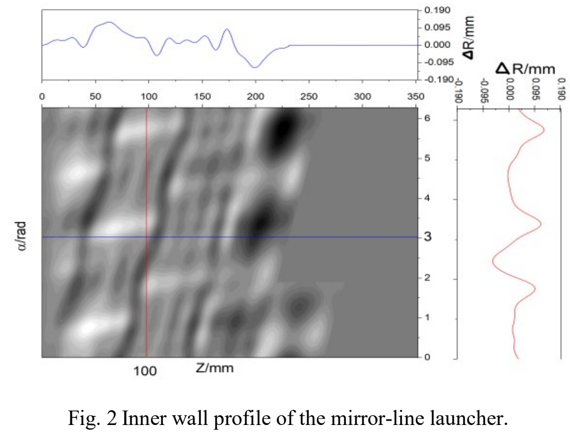

Fig. 2 Inner wall profile of the mirror-line launcher.

The launcher is first optimized for the $TE_{40,23}$ mode at 204 GHz, and then the wall profile is modified for the $TE_{34,19}$ mode at 170 GHz, so that the launcher can provide relative high conversion efficiency for both the $TE_{40,23}$ mode and the $TE_{34,19}$ mode. The simulation results show that the Gaussian-mode contents at the launcher aperture are 97.17 % and 96.58 % when the launcher operated in the $TE_{34,19}$ mode at 170 GHz and in the $TE_{40,23}$ mode at 204 GHz, respectively. The field distributions are shown in Fig. 1, the wall profile is shown in Fig. 2, where $-0.191\ \text{mm}<\Delta R<0.193$ mm on the whole wall of the launcher.

III. DESIGN OF MIRROR SYSTEM

A mirror system containing one quasi-elliptical and two beam shaping mirrors is under development for the dual-frequency coaxial-cavity gyrotron. The aperture radius of the output window is 49 mm, so the RF beams should be transformed into a Gaussian distribution with the beam waists to be smaller than 24.5 mm located at the window plane. A quasi-elliptical mirror is used in the pre-prototype of the coaxial-cavity gyrotron. The top view of the quasi-elliptical mirror is shown in Fig. 3, where L_1=100 mm and L_2=2100 mm. The caustic radius R_c is corresponding to the center of the launcher aperture. The quasi-elliptical mirror is used to guide and focus the RF beams radiated from the launcher. Fig. 4 shows the calculated field distributions after being scattered by the quasi-elliptical mirror. Fig. 4 shows the field distributions at 150 mm after the quasi-elliptical mirror. In Fig. 4 (a) and (b), the beam radius in y direction is about 114 mm. The two beam shaping mirrors can be designed in terms of the method presented in rf. [7]. In order to satisfy the requirement of the beam waist to be smaller than 24.5 mm, the first beam shaping mirror should be designed to transform the RF beams into a Gaussian-like beam with a virtual beam waist in y direction to be 2.28 mm for the operation at 204 GHz and 3.56 mm for the operation at 170 GHz. However, for a paraxial Gaussian beam, the beam waist should be larger than 2.25λ, λ is the wave length. Accordingly, the paraxial conditions are 3.97 mm and 3.31 mm for the RF beams at 204 GHz and 170 GHz, respectively. From its existing position at L_1=100 mm, the quasi-elliptical mirror has to be moved more close to the launcher to decrease the beam size in y direction. The value of L_1 should be well chosen to control the beam size and to avoid the wave beam scattered by the quasi-elliptic mirror to be blocked by the launcher. A new mirror system is under development.

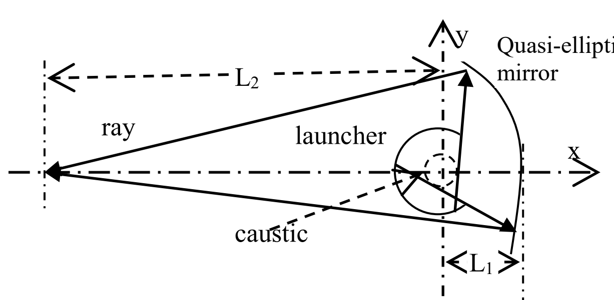

Fig. 3 Top view of the quasi-elliptical mirror.

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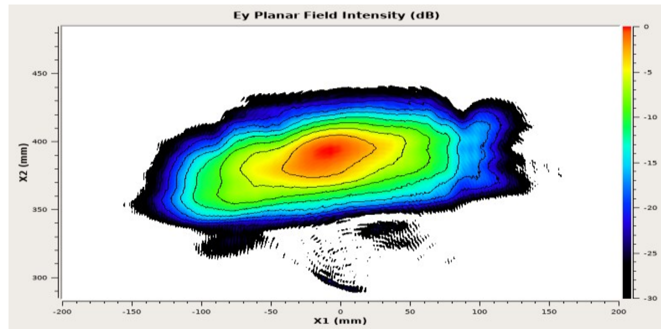
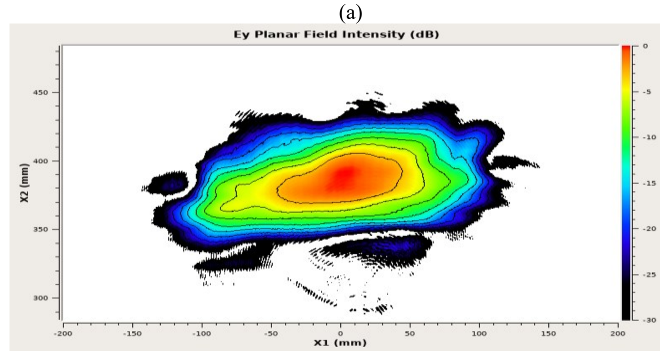


(a)



(b)

Fig. 4 Field distribution of the RF beams (in dB scale) at 150 mm after the quasi-elliptical mirror (a) operating in the $TE_{34,19}$ mode at 170 GHz and (b) operating in the $TE_{40,23}$ mode at 204 GHz.

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