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Design and Development of mode converter for 170 GHz Gyrotron

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***Abstract*— This paper describes the design and development of quasi optical mode converter for high power 170 GHz Gyrotron. The design of mode converter has been carried out using based on geometric optics approximations. A quasi-optical mode converter has been designed to transform the $TE_{34,10}$ mode to a Gaussian beam in free space at 170 GHz. The converter consists of a smooth-wall waveguide launcher and three toroidal focusing reflectors. Simulation results showed that the beam splitting mirror relay successfully converted the fundamental Gaussian beam, produced by the launcher and two mirror relay, to two Gaussian-like beams. The mirrors have been designed and developed with Gaussian optics and vector diffraction theory. The results shows that simple elliptical mirrors and flat phase front mirror used for to produce high quality Gaussian beam.**

Index Terms— **Gyrotron, Mode converter, Focusing Mirrors, Helical cut, Transmission.**

I. INTRODUCTION

Gyrotron oscillators are high power microwave sources mainly used for electron cyclotron resonance heating (ECRH). Gyrotrons have wide applications in the field of plasma diagnostics, material processing, radar systems, communications, medical research, etc. Interest in Gyrotron has grown tremendously due to its potential application in energy generation from fusion energy under global International Thermonuclear Experimental Reactor (ITER) program [1]. Gyrotron output system consists of an output taper which connects the cavity with the quasi-optical mode converter and the RF window. Megawatt Gyrotron operates in the higher order volume cavity modes. Thus it is necessary to use a quasi-optical mode converter to transform the operating mode into a fundamental Gaussian beam for transmission. For increasing the collector electron beam interception area in long-pulse, high power Gyrotron, an output coupler that separates the spent electron beam from the output RF power, is required. It is the short wavelength, high output power and rotating asymmetric high order cavity mode of Gyrotron that have led to the need for the novel mode conversion concepts. Mode converter is a very important component for the efficient RF propagation in a high power Gyrotron. The mode launcher builds either a Vlasov and Denisov dimpled launcher that radiates microwave energy radially through a wall aperture [2]. The radiated wave is then focused by a series of mirrors that also serve to guide microwave through a window. Vlasov proposed a helically cut waveguide launcher according to the brillouin model with better performance. Further, Denisov proposed an advanced mode launcher which could improve conversion efficiency from a high-order cylindrical waveguide mode to a free space Gaussian beam, which helps to reduce the dimensions of focusing reflectors. The advanced mode converter employs a dimpled wall waveguide and a helical cut launching aperture as an antenna. A quasi-optical mode converter is the combination of an open waveguide (launcher) and a mirror system as shown in Fig.1 [3]. The mode converter is expected to provide conversion efficiency of 85%. It is advantageous to use a mode converter inside the Gyrotron vacuum envelope, directly after the cavity.

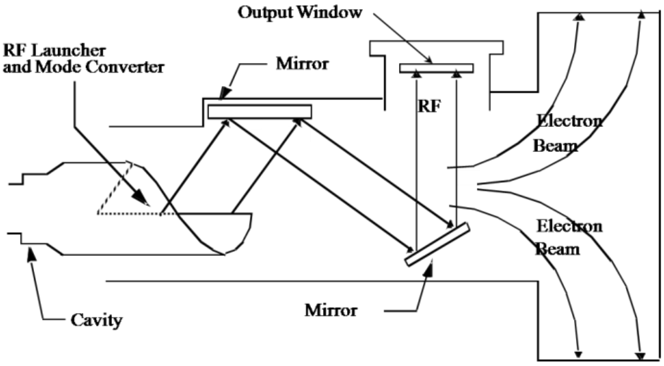

Fig.1. Schematic diagram of mode converter [3]

II. DESIGN OF MODE CONVERTER

A smooth wall mode launcher has been designed to transform the cavity mode $TE_{34,10}$ mode at 170 GHz to a Gaussian mode in free space. The preliminary design of mode launcher was carried out with geometric optics approximation. The design and analysis of mode launcher have been carried out using the LOT and Surf3D codes developed by CCR [4]. The design was accomplished using code created by CCR called the Launcher Optimization Tool (LOT). LOT optimizes the perturbations in the mode launcher to produce a more desirable field distribution at the aperture of mode launcher.

The basic theory and design equations of mode launcher have been described [5]. In high order mode gyrotrons, the dimensions of the cylindrical launcher are much larger than the free space wavelength (Diameter D $\approx 20 \sim 30\lambda$ and length L $\approx 100 - 200\lambda$), so that the beam wave in the launcher can be described in terms of geometric optics. TE and TM-modes in a circular waveguide can be decomposed into a series of plane waves, each propagating at the spread angle (θ_B) relative to the waveguide axis, also called as brillouin angle. The launcher design parameters of 170 GHz Gyrotron are

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given in Table1 [6]. These values of the launcher length, radius and helical taper angle are also optimized for the minimum return loss and the minimum insertion loss in the simulation carried out by using CST microwave studio [7]. Fig.2 shows unrolled waveguide wall of mode launcher [8] and Fig.3 shows the CST model of helical cut launcher for 170 GHz Gyrotron with mode field profile. Fig.4 shows the schematic diagram of quasi optical mirror system. It is consists of a launcher and 3-metal mirrors. Mode launcher is used for radiated the beam and mirrors are used for focusing beam. The focusing mirrors were designed with Gaussian optics and their surfaces are elliptical curved shapes. The M1, M2 are elliptical smooth curved mirrors and M3 is flat mirror (flat phase front). Fig.5 shows the cross section view of quasi optical mode converter. A Vlasov launcher, which radiates the power from the waveguide TE mode into an rf beam, followed by two mirrors that direct the rf beam to the output window [9]. We have found the quasi-optical solution for the diffraction of the rotating mode at a helical cut of a circular waveguide. The result shows that the quasi-optical representation describes the radiation field qualitatively and gives reasonable quantitative information.

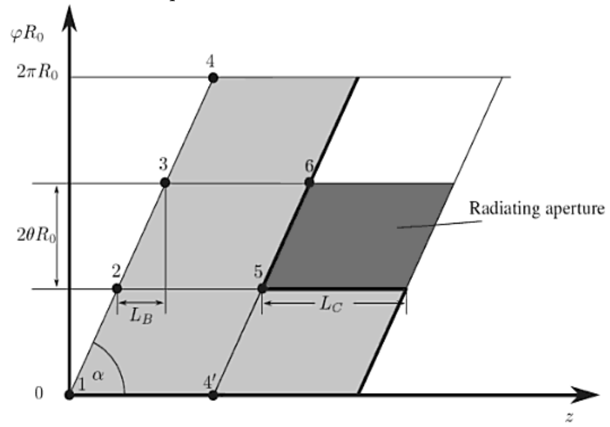

Fig.2. Unrolled waveguide wall of mode launcher [5]

The mode converter is constructed of a Vlasov launcher, which radiates the power from the waveguide TE mode into an rf beam, followed by two mirrors that direct the rf beam to the output window. We have found the quasi-optical solution for the diffraction of the rotating mode at a helical cut of a circular waveguide. The result shows that the quasi-optical representation describes the radiation field qualitatively and gives reasonable quantitative information.

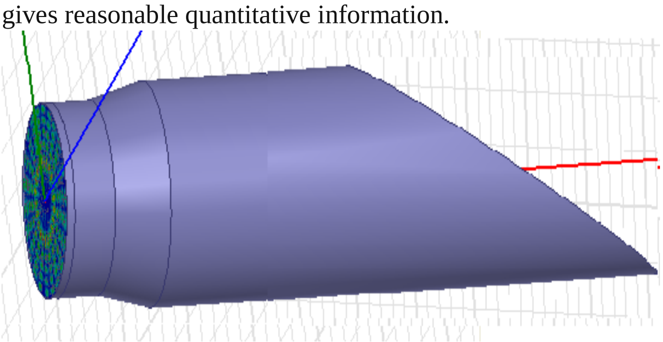

Fig. 3. Field profile of the $TE_{34,10}$ mode in launcher [7]

Table 1. Design parameters of mode launcher [3]

Parameter	Value
Input mode	$TE_{34,10}$
Launcher Length (L)	220 mm
Helical cut length (L_c)	64 mm
Launcher radius (a)	23.3 mm
Azimuthally angle (tan α)	2.2^0
Brillouin angle (θ_B)	61.17^0

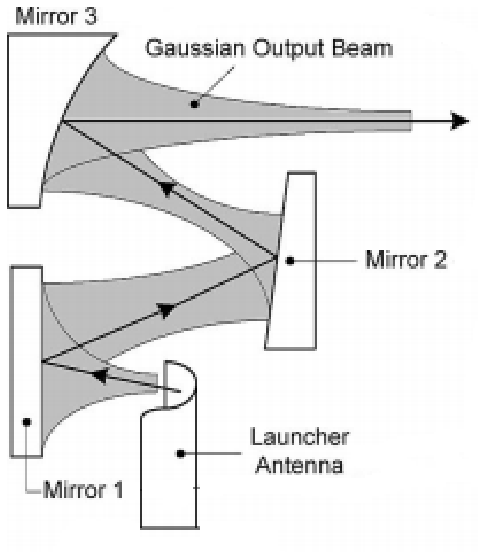

Fig.4. Schematic diagram of quasi optical system [8]

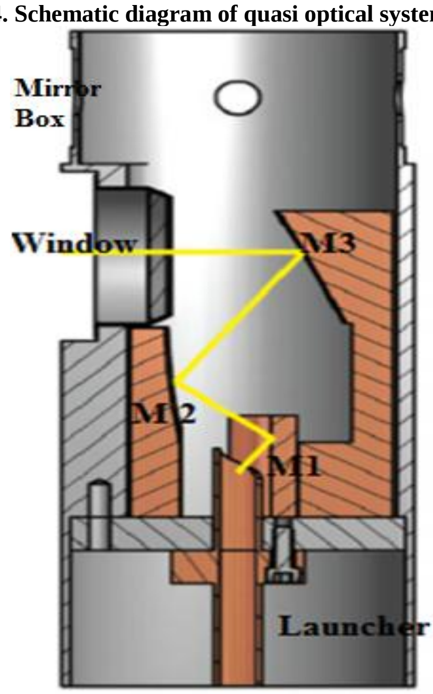

Fig. 5 Schematic cross section view of quasi optical mode converter (Helical cut launcher and M1, M2 are elliptical curved mirrors and M3 is flat mirror (phase front) inside mirror box) [8]

III. DEVELOPMENT OF MODE CONVERTER

In high power Gyrotron, most critical component is quasi-optical mode converter. Mode converter has been developed for converts RF power in to a Gaussian beam. The fabrication of mode launcher with oxygen free high conductive (OFHC) copper material has been carried out as per design. Considering the available computerized numerical controlled (CNC) machine and standard boring tool, launcher has been fabricated. The machined surface and helical cut angle have been scanned with co-ordinate measuring machine (CMM). The surface roughness of the mode launcher has been measured using surface profiler. The achieved surface finish of the mode launcher was 0.5 micron. Gyrotron mode launcher radius is kept equal to cavity radius 23.3 mm, helical cut length is found equal to 64 mm and helical taper angle is found as 61.17^{o} through optimization. Table 2 shows the design parameters of quasi optical mirror system for 170 GHz mode converter. Based on these design parameters, metal mirrors system has been developed. Fig. 6 shows the OFHC copper fabricated (a) smooth wall mode launcher with helical cut for 170 GHz Gyrotron as per design (b) 3-metal mirrors connected with SS-flange. Fig. 7 shows the fabricated quasi optical mirror system for conversion $TE_{34,10}$ mode to a Gaussian beam as per schematic diagram. First quasi optical mode converter with smooth wall helical mode launcher, 3-metalic mirrors and vacuum chamber with view front of RF window have been successfully developed at CEERI. Fabrication of mirror box with view port for mode converter has been carried out. Fig. 8 shows complete mechanical arrangement of the 3-metal mirrors with launcher assembly in SS Flange and complete assembly of mode converter with RF window. Alumina RF window is connected with 100 CF flange.

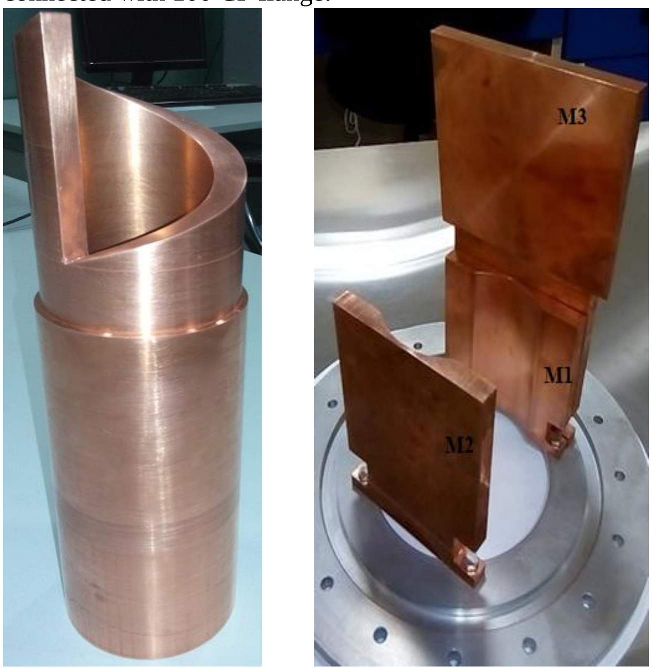

Fig. 6 (a) Helical cut smooth wall mode launcher (b) 3-metal mirrors

Table 2. Design parameters of quasi optical mirror system for 170 GHz Gyrotron [6]

Parameter	Value
First Mirror (M1)	L= 120 mm, W =120 mm, Curvature radius R_1= 60 mm
Second Mirror (M2)	L= 155 mm, W= 120 mm, Curvature radius R_2= 60 mm
Third Mirror (M3)	L= 270 mm, W= 140 mm, Taper = 13 mm and taper length L= 150 mm, phase = 60^{0}
Gap between two mirror	100 mm
Length (l_w) from window	270 mm
Reflection angle (ϒ)	42^{0}
Outer diameter of mirror box	220 mm
Length of mirror box (L)	400 mm

Fig.7 Quasi optical mirrors system of Gyrotron

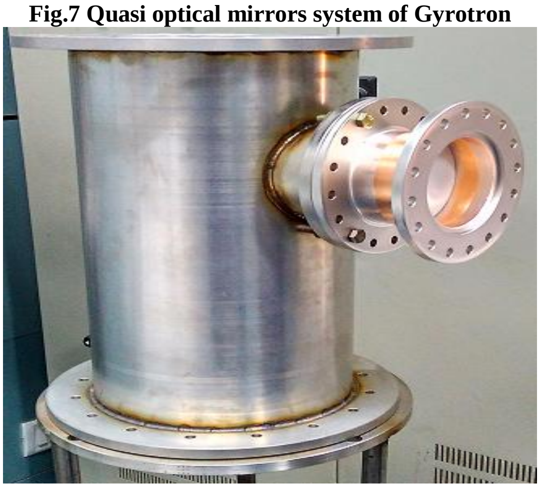

Fig. 8 Developed mode converter with RF window for 170 GHz Gyrotron.

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IV. CONCLUSION

The design and development quasi optical mode converter has been carried out in this paper. The radiated field in mode launcher can be approximated by the waveguide modes and then the radiated fields calculated using software. It provides a simple way for the simulation of the field distribution in an opened-end waveguide antenna for the calculation of the radiated field from the opened-end waveguide antenna with low fields. For this purpose, launcher is responsible for conversion of high order gyrotron cavity mode into a simple Gaussian mode. Development technology with cupper to SS has been developed with vacuum tight. It has been established that available mode converter is capable of 90% mode conversion.

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REFERENCES

[1] C J Edgecombe, Gyroton Oscillators: Their principles and practice. London (UK) Taylor & Francis Ltd., 1993.

[2] G S Nusinovich, Introduction to the physics of Gyroton, Maryland, JHU, USA, 2004.

[3] J Neilson, "Optimal Synthesis of Quasi-Optical Launchers for High Power Gyrotrons", IEEE Trans. Plasma Sci., Vol. 34, No. 3, June 2006.

[4] LOT and Surf3d: Computer codes user manual, CCR, Lexam Research, CA, USA.

[5] J Neilson, "Optimization of quasi-optical launchers for multi frequency gyrotrons," IEEE Trans. Plasma Sci., vol. 35, no. 6, pp. 1743-1746, Dec. 2007.

[6] M Blank, K Kreischer, and R J Temkin, "Theoretical and experimental investigation of a quasi-optical mode converter for a 110-GHz gyrotron," IEEE Trans. Plasma Sci., vol. 24, no. 3, pp. 1058–1066, Jun1996.

[7] CST Microwave Studio Version 11.0, Computer Simulation Technology Darmstadt, Germany.

[8] M Blank, "High efficiency quasi optical mode convertors for overmoded gyrotrons", PhD Thesis, MIT, USA, 1994.

[9] M Thumm, X Yang, A Arnold, G Dammertz, G Michel, J Pretterebner, and D A Wagner, "High-efficiency quasi-optical mode converter for a 140-GHz 1-MW CW gyrotron," IEEE Trans. Electron Devices, vol. 52, no. 5, pp. 818–824, May 2005.

AUTHOR BIOGRAPHY

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