Design Studies of Quasi-Optical Mode Converter for 105 GHz High-Power Gyrotron

Debasish Mondal[1], S. Yuvaraj[2], S. Adya[1], A. S. Thakur[1], M. V. Kartikeyan[1]
[1]Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee, India
[2]Department of Electronics and Communication Engineering, National Institute of Technology Andhra Pradesh, India
kartik@ieee.org

Abstract: *In this paper, the design aspects of the quasi-optical launcher (QOL) and matching optics unit (MOU) are performed for 105 GHz gyrotron. After the interaction cavity and nonlinear taper section, high power RF wave with the cavity mode of $TE_{17,6}$ need to be converted to Gaussian like mode which can be obtained from a dimpled wall QOL. The Gaussian content of the converted beam is achieved by 99% using commercially available launcher optimization tool (LOT) & Surf3D. Besides, design of a matching optics unit (includes a set of phase correcting mirrors) is carried out using in-house code Gyrotron Design Studio (GDS.V.1.2019) to correct the phase of the off-axis Gaussian beam.*

Keywords: Quasi-Optical Launcher (QOL), Gyrotron Design Studio (GDS.V1.2019), Launcher Optimization Tool (LOT), Matching Optics Unit (MOU), Gaussian beam, Gyrotrons.

Introduction

Recent resurged interest in new powerful THz radiation sources have motivated vacuum electronics community to develop gyrotrons. These gyotrons find various scientific, industrial and medicinal applications which include plasma heating in thermonuclear fusion reactor, sources in medical spectrascopes. Gyrotrons operating in the frequencies between 28-300 GHz delivering output power in the range of kilowatt to megawatt were successfully installed in tokamak and stellarator for plasma heating application [1]-[3]. D. Wagner et. al. have reported a multi-frequency gyrotron i.e. tunable between (105-140) GHz for ASDEX Upgrade tokamak experiment [4]. Perturbations in the walls of the quasi optical launcher converts the higher order cavity mode into Gaussian like beam. Further, output beam is transferred through matching optics unit [2],[5]-[8]. In this work, detail design study of output system to support 105 GHz gyrotron is carried out. Design studies are performed using LOT, Surf3D along with our in-house latest version computer code package Gyrotron Design Studio (GDS.V.1.2019) which is an upgraded version of (GDS.V.2018) incorporated all the features for the conceptual designing of gyrotron.

Quasi-Optical Mode Converter

The quasi-optical mode converter connects after the interaction cavity structure and transforms the complex cavity mode into Gaussian like mode, also it separates the high frequency RF wave and electron beam. Quasi-optical mode converter (dimpled wall) is used to convert the operating mode $TE_{17;6}$ to Gaussian (HE11) mode. The Gaussian mode of the converted beam should be as high as possible. Perturbations made on the inner wall of the launcher increase the Gaussian mode content. To improve the performance of the launcher, the quasi-optical launcher was optimized with the taper angle (0.005 Rad.), total launcher length (170 mm), and the helical cut length (40 mm). The design parameters of QOL and output mode contents are provided in Table I. The optimized wall field intensity plot has been shown in Fig. 1 where the radiated beams are converted to near Gaussian shape and the minimum field intensities (less than -30 dB) is represented by the white dotted line at the launcher cut edge. The field intensity is very less at the cut edge so as to reduce the unwanted stray radiation. The field intensities at 40 mm and 80 mm distance from the launcher cut are shown in Fig. 2(a) & Fig. 2(b), respectively where it is observed from Fig. 2(b) that the field intensity is almost Gaussian at the distance of 80 mm. A 3D view of quasi-optical mode converter by considering cartesian coordinate system with helical cut has been obtained using Surf3D as shown in Fig. 3(a) where the inner surface has been exaggerated. The launcher cut lie on the xz plane where the longitudinal cross section lie on the xy plane respectively. The field intensity analysis also has been carried out using Surf3D (shown in Fig. 3(b)) as well, where the Gaussian content factor has been optimized by 99.09%.

TABLE I
LAUNCHER DESIGN PARAMETERS & RESULTS.

Launcher length (mm)	**170**
Helical cut length (mm)	**40**
Input radius (mm)	**19.398**
Taper angle (rad.)	**0.005**
Gaussian content factor	**99.09%**

Matching Optics Unit

In MOU, the mirror position should be considered in such a way that the required RF beam should be at the centre of the window. Hence, two mirror profiles has been positioned at 250 mm and 750 mm with a separation of 500 mm from the centre of the gyrotron window to optimize the off-axis Gaussian beam (shown in Fig. 4 (a) and (b)). Any perturbations on the mirror surface need to be synthesized properly to increase the mode conversion efficiency. The incident beam waists (w_{ox} and w_{oy}) at mirror 1 are 25.00 mm and 21.16 mm, respectively. After the correction of the off-axis Gaussian beam (shown in Fig. 5) the waists are 32.2 mm and 32.5 mm (where 1 pixel = 0.2645 mm) with astigmatism of 2.15 mm at z-direction. The ellipticity of the corrected beam has been observed 0.99.

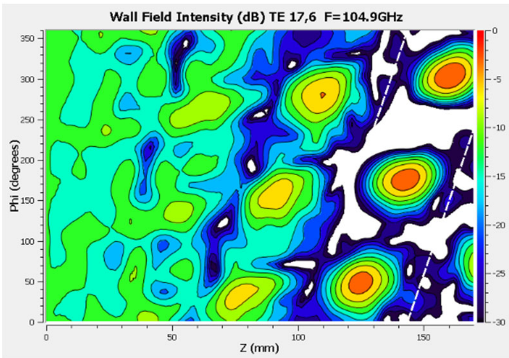

Fig. 1. Electric field intensity (dB) on the launcher surface for the $TE_{17;6}$ mode at 105 GHz.

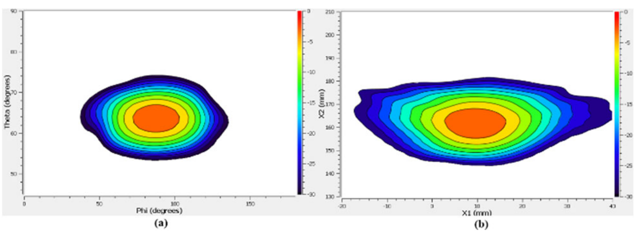

Fig. 2. Optimized far field intensity (dB) of the 105 GHz $TE_{17;6}$ mode (a) at the launcher cut using LOT, (b) at the possible position (80 mm) distance from the launcher cut.

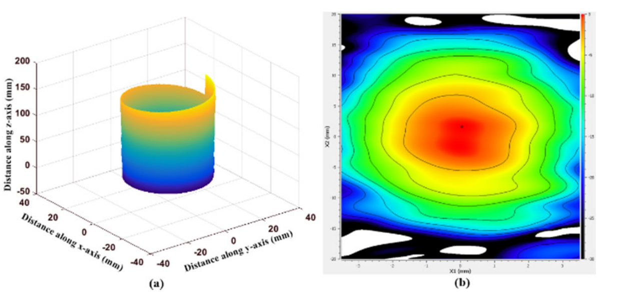

Fig. 3. (a) The inner radius profile of the quasi-optical launcher obtained using Surf3D, (b) The optimized Gaussian field intensity (dB) of the 105 GHz, $TE_{17;6}$ mode using Surf3D.

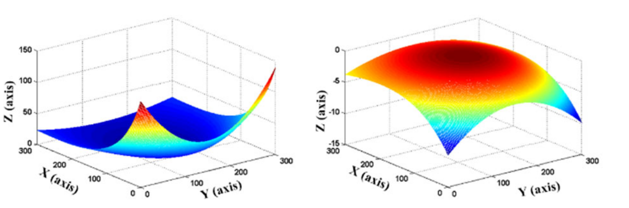

Fig. 4. The profile of (a) Mirror 1 & (b) Mirror 2 to optimize the off-axis Gaussian beam.

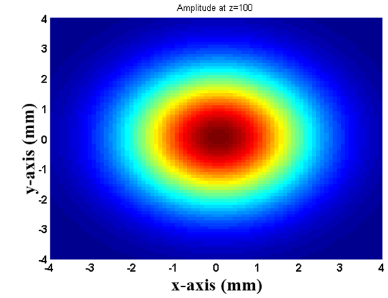

Fig. 5. The optimized Gaussian beam after making the corrections to the mirror profile.

Conclusion

In this paper, a complete study of quasi-optical launcher along with matching optics unit has been computed for the gyrotron operating at 105 GHz frequency for the probable ISM applications. A matching optics unit which connects gyrotron with the plasma experimental setup has been designed for better coupling using our in-house code GDS.V.1.2019. The Gaussian content of the output beam radiated from the launcher cut was determined as > 99%.

References

[1] M. K. A. Thumm, G. G. Denisov, K. Sakamoto and M. Q. Tran, “Highpower gyrotrons for electron cyclotron heating and current drive,” Nucl. Fusion, vol. 59, No. 073001, 2019.

[2] M. V. Kartikeyan, E. Borie, and M. K. A. Thumm, “Gyrotrons High power microwave and millimeter wave technology,” Berlin-Heidelberg, Springer-Verlag, Germany, 2004.

[3] Dhakad, Ravi Kumar, Gaurav Singh Baghel, M. V. Kartikeyan, and Manfred K. Thumm. “Output System for a 170-GHz/1.5-MW Continuous Wave Gyrotron Operating in the TE 28,12 Mode,” IEEE Transactions on Plasma Science, 2015.

[4] D. Wagner et. al., “Status of the new multi-frequency ECRH system for ASDEX Upgrade,” IAEA, Vienna, 2008.

[5] M. Thumm, “Recent Advances in the Worldwide Fusion Gyrotrons Development,” IEEE Transactions on Plasma Science, vol. 42, pp. 590-599, March 2014.

[6] Monica Blank, Kenneth Kreischer, and R. J. Temkin, “Theoretical & Experimental Investigation of a Quasi-Opticl Launcher Optimal Synthesis of Quasi-Optical Mode Converter for a 110 GHz Gyrotron,” IEEE Transactions on Plasma Science, 1996.

[7] J. M. Neilson. “Optimal Synthesis of QuasiOptical Launchers for HighPower Gyrotrons,” IEEE Transactions on Plasma Science, 2006.

[8] J. M. Neilson. “Optimal Synthesis of QuasiOptical Converters for High Power Gyrotrons,” IEEE International Vacuum Electronics Conference held Jointly with 2006 IEEE International Vacuum Electron Sources, 2006