3D-Design of Magnetron Injection Gun for 42GHz Second Harmonic Gyrotron

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Abstract: *This paper presents the 3D design simulation of MIG for 42GHz, 100kW second harmonic Gyrotron operating at $TE_{0,3}$ mode. Initially, the analytical design approach was opted using design trade-off equations and then the 3D simulation has been performed by using CST Particle Studio. The beam parameters, velocity ratio, and velocity spread was obtained 1.35, 3.3% respectively.*

Keywords: Velocity ratio, velocity spread, anode cathode distance, beam compression ratio

Introduction

Gyro-devices are capable to deliver hundreds of kilowatts power at millimeter and sub-millimeter wavelengths [1-2]. The electron beam source of Gyro-device is Magnetron Injection Gun (MIG). The triode type MIG configuration is more preferable over its diode type counterpart as former gives more flexibility to control the beam parameters. The triode type MIG is consisting of a cone shaped cathode, a modulating anode and an accelerating anode. MIG is a key component to produce the high quality gyrating electron beam and its cathode operates under the temperature limited condition [3-4]. Velocity ratio (α) and beam velocity spread of the electron beam are two deciding parameters of good quality gyrating electron beam and the optimization of MIG design was carried out based on these two parameters. The beam interaction takes place in the cavity region between azimuthal electric fields and transverse velocity of the electrons. The desirable velocity ratio would be greater than one for net energy efficient transfer from beam to the RF-Wave. However, it should not be beyond the certain limit otherwise; the back propagation of electron beam will arise due to the magnetic mirroring effect [5-8]. The gyrotron, operating at 28, 42, 82.6GHz frequencies are significantly used in TOKAMAKS systems of INDIA for plasma heating purposes [9].

For the better understanding of device physics and further analysis of electron beam, 3D design simulation approach is more preferable in comparison to the 2D design simulation. Commercially available 3D-Electromagnetic software i.e. CST Particle Studio [10] is used for 3D simulation of MIG. This paper presents the 3D-design of Magnetron Injection Gun for a Gyrotron operating at 42GHz and capable to deliver the power 100kW.

Design Inputs

Triode type MIG played a very successful role in operation of gyro-devices. The design input parameters for MIG are listed in Table I.

TABLE I. DESIGN INPUTS FOR 42GHZ 100KW TRIODE-MIG

S.No.	*Design Parameters*	*Design Values*
1.	Frequency of operation (f)	42 GHz
2.	Output power (P)	≈ 100kW
3.	Operating mode	$TE_{0,3}$
4.	Beam current (I)	≈ 4-6A
5.	Beam voltage (V)	≈ 60-70kV
6.	Magnetic field on cavity centre (B_0)	0.845T
7.	Beam compression ratio (b)	≈ 10-12
8.	Velocity ratio (α)	≤ 1.5
9.	Emitter cathode angle	> 25^0

Magnetic Guiding System

The operating frequency of a gyrotron is directly proportional to the applied DC magnetic field strength in interaction region and former is related to latter through the relation $\omega \approx SeB/m\gamma$, where S and B are the harmonic number and applied DC magnetic field respectively [11-12]. In this case, the gyrotron will be operating in second harmonics and therefore, reduced magnetic field (half of the fundamental harmonic) i.e. 0.8475Tesla is required on interaction cavity center. The magnetic compression ratio b = 11 has been chosen with a cathode radius 11.50mm. The optimized magnetic field profile is shown in the Fig. 1.

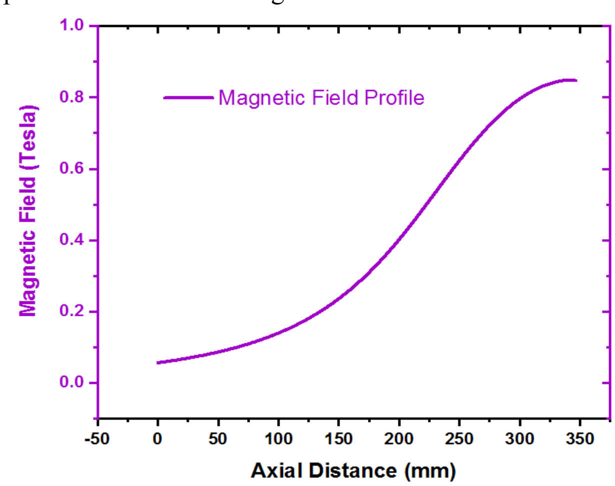

Fig. 1. Optimized Magnetic Field Profile from the Cathode to the Cavity Center

Simulation Results and Discussion

The geometry of MIG was modeled in CST software (Fig. 2) and optimized to obtained desire beam parameters. All simulated results are shown in Fig. 3, 4 and Fig. 5. Figure 3 shows the beam trajectory of optimized MIG. The variation of velocity ratio of electron beam from end of modulating anode to cavity center is shown in Fig. 4. Variation of velocity spread with axial distance is also studied (Fig. 5).

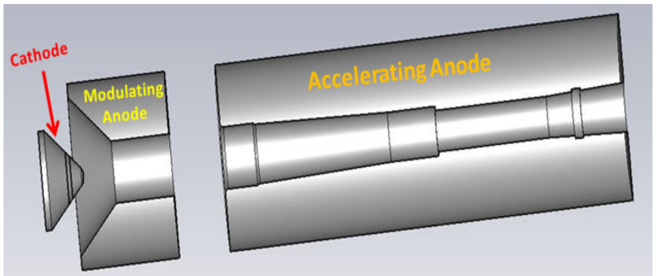

Fig. 2. 3D-View of 42GHz, 100kW, Triode-type MIG configuration

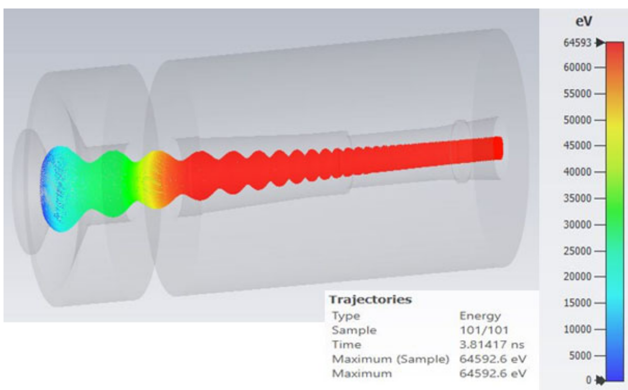

Fig. 3. 3D-MIG Simulation of Beam Trajectory inside the Geometry

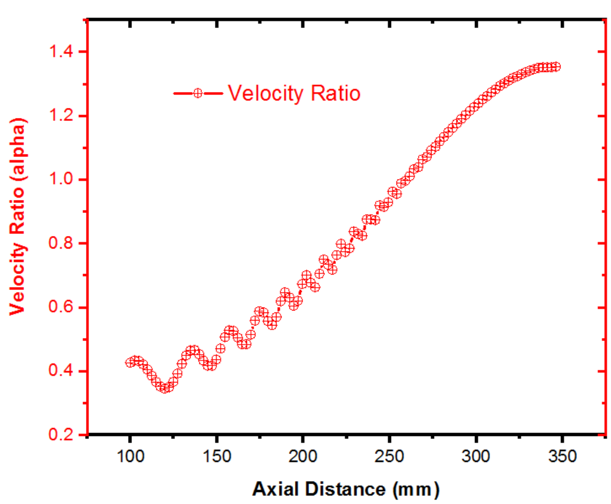

Fig. 4. Velocity Ratio vs Axial Distance upto Interaction Region

The optimized beam parameters such as velocity ratio and spread were obtained at the cavity center and the optimized value of those parameters are 1.35 and 3.3% respectively. The optimized operating parameters such as beam voltage, beam current and modulating anode voltage of MIG are 65kV, 5A and 29kV respectively. It was found that the simulated parameters are well under the permissible limit of design constraints.

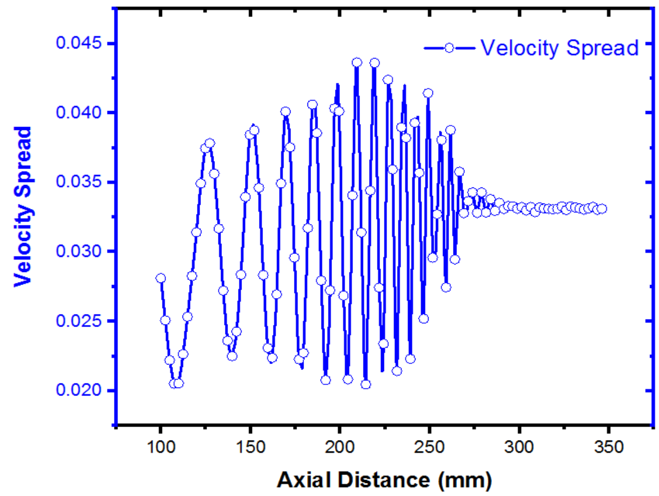

Fig. 5. Velocity Spread vs Axial Distance upto Interaction Region

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References

[1] M.V. Kartikeyan, E. Borie, and M. Thumm, "Gyrotrons – High power microwave and millimeter wave technology," Berlin-Heidelberg Springer-Verlag Germany, 2004.

[2] M. Thumm, State-of-the-Art of High Power Gyro-Devices and Free Electron Masers (Update 2008), Wissenschaftlishe Berichte, FZKA 7467, Karlsruhe, 2009.

[3] Alok Mishra, M. V. Kartikeyan, A.K. Sinha, A. Bera "Energy distribution of electrons from cathode in magnetron injection gun" 2018 IEEE International Vacuum Electronics Conference (IVEC), 24-26 April 2018.

[4] Alok Mishra, A. Bera, M. V. Kartikeyan. "Design of Diode Type Magnetron Injection Gun for 170GHz Gyrotron", 2019 44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), 2019.

[5] Jagadish C. Mudiganti, M. V. Kartikeyan, M. Thumm. "Design of magnetron injection guns — A 3D simulation approach", 2009 34th International Conference on Infrared, Millimeter, and Terahertz Waves, 2009.

[6] M. Thumm, State of the Art of High Power Gyro-Devices and Free Electron Masers. Karlsruhe, Germany: KIT, 2012.

[7] A. V. Gaponov-Grekhov and V. L. Granatstein, Application of High-Power Microwaves. Norwood, MA, USA: Artech House, 1994.

[8] Edgecombe CJ, editor. Gyrotron oscillators-their principles and practice. London: Taylor and Francis; 1993.

[9] A.Bera et al. "Development of 42-GHz, 200-kW Gyrotron for Indian Tokamak System Tested in the Regime of Short Pulselength" IEEE Transactions on Plasma Science, vol. 47, no. 10, October 2019.

[10] CST Microwave Studio Suite, Users Manual, 2019.

[11] M. V. Kartikeyan, Edith Borie, Oliver Drumm, Stefan Illy, Bernhard Piosczyk, and Manfred Thumm, "Design of a 42-GHz 200-kW Gyrotron Operating at the Second Harmonic" IEEE Transactions on Microwave Theory and Techniques, vol. 52, no. 2, February 2004.

[12] Shou Xi Xu, Pu Kun Liu, G. F. Liu, Z. H. Geng, Chao Hai Du, S. H. Shi, H. Wang, W. Gu, S. C. Zhang. "Design of a High-Harmonic Gyrotron With a Permanent Magnet System", IEEE Transactions on Electron Devices, 2013.