Design of 42 GHz, 200 kW Gyrotron

Udaybir Singh, Uttam Goswami, Hasina Khatun, Nitin Kumar, N Shekhawat, Anil Kumar, V Yadav, MK Sharma, A Mishra, SK Sharma, MK Alaria, A Bera, RR Rao and AK Sinha
Gyrotron Laborotary, Microwave Tubes Area
Central Electronics Engineering Research Institute (CEERI)/Council of Scientific and Industrial Research (CSIR)
Pilani, Rajasthan, INDIA-333031
mka@ceeri.ernet.in and aksinha@ceeri.ernet.in

Abstract: *The design of 42 GHz, 200 kW Gyrotron has been carried out using in-house and commercially available software's. A triode type MIG has been designed using EGUN code and three in house developed codes MIGSYN, GINTMESH and MIGANS respectively. A weakly tapered interaction cavity has been designed to excite TE_{03} operation mode. A software GCAVSYN has been developed to synthesize the cavity geometry and selection of the operating mode. The cold cavity analysis was carried out using commercially available PIC code MAGIC. An axial output power above 200 kW has been obtained at the guiding magnetic field 1.60T-1.65T. The behavior of generated rf power in beam tunnel has been simulated using the CST Microwave Studio and Ansoft HFSS. The different lossy ceramics have been studied for reflection, transmission and absorption. A good agreement has been found in the simulated results from both the software. The design of collector has been optimized to achieve the maximum beam spread.*

Keywords: Gyrotron, Limiting current, Voltage depression, lossy ceramic**,** Start oscillation current.

Introduction

Gyrotron oscillators are high-power sources producing coherent cyclotron radiation in the millimeter and sub-millimeter regions [1]. A 42 GHz, 200 kW continous wave output power gyrotron is being to be developed for electron cyclotron resonance plasma heating for an Indian TOKAMAK system. A conceptual design of triode type magnetron injection gun (MIG) for a gyrotron operating at fundamental cyclotron frequency was presented in IVEC-08 [2]. A code MIGSYN has been developed to synthesize the gun geometry. Initial parameters like cathode radius, width of emitting surface, slant spacing between cathode, modulating anode, etc. have been evaluated through synthesis. MIG geometry has been modeled and simulated by using EGUN code. MIGANS code is used to find out different parameters like transverse to axial velocity ratio (α), velocity spread, larmour radius and beam radius. This gyrotron is operated at fundamental harmonic, required magnetic field for 42 GHz is around 1.65T and magnetic profile. Table 1 shows the optimized values of different parameters of the MIG. Figure 1 shows the optimised electron beam and magnetic field profiles of MIG.

Magnetic system has been finalized for magnetic profile with respect to its peak value (equal to 1.61 T) with tolerance of +/- 10% to make the system flexible to the maximum, warm bore radius equal to 62 mm keeping a gap of 3 mm between gyrotron dimension and magnetic system. The size of magnetic system was presently decided as 400 mm. Mode selection has been studied with the aim of minimizing mode competition and restricts the excitation of undesired mode in the cavity to obtain the desired power level. Two software codes GCAVSYN and GCAVSOC have been developed to synthesize cavity geometry and analysis for selection of modes. The parameters such as cavity radius, beam radius, limiting current, voltage depression and wall loss were obtained for different modes. After evaluating above parameters, TE_{03} mode has been selected as the operating mode. Gyrotron cavity geometry has been simulated and finally designed using the self-consistent particle-in-cell (PIC) simulation code MAGIC [3]. The non-linear tapered cavity model is based on design parameters for fundamental operation of 42 GHz, 200 kW gyrotron and dimensions described in Table 2. Figure 2 shows the output power profile w. r. t time achieves steady state after 100 ns of start operation. The calculated output power strongly depends upon guiding magnetic field of interaction cavity as shown in Figure 2. In this paper, the results of RF behavior of beam tunnel have been presented. Three lossy ceramics AlN-SiC, Al2O3-SiC, MgO-SiC are initially considered for beam tunnel simulation using CST-Microwave Studio and Ansoft HFSS software [4]. The length, input radius and output radius of beam tunnel is decided by EGUN software during the analysis of MIG, which is respectively 112mm, 21mm and 12mm. Ideally, zero transmission is required through the beam tunnel. The transmission of RF through beam tunnel depends on ceramic properties and tunnel geometry. Table 3 shows the comparison of results obtained from CST-MS and HFSS in terms of reflection, transmission and absorption. Based on available window and nonlinear taper dimensions, the dimension of the collector has been optimized to achieve the maximum beam spread. Figure 3 shows that beam spread on the surface of collector at 42.5 mm collector radius and 800 mm collector length, maximum spread achieved is 332 mm on the collector surface with a dissipation capability of <0.4 kW/cm^2.

Table 1 Designed parameters of MIG

Parameters	Value obtained
Cathode radius	22. 6 mm
Cathode angle	28^0
Slant length	7 mm
Modulating anode voltage	29 kV
Beam voltage	65 kV
Alpha (α)	1.26
Cathode- anode distance	9 mm
Beam current	10.3 A
Larmor radius	0.42 mm
Distance from cavity centre	330 mm
Cavity radius	11.57 mm
Magnetic field at interaction	1.61 Tesla

Table 2 Dimensions of the Interaction cavity

Dimensions	
Length $L_1/L_2/L_3$ (mm)	4.2λ/6.16λ/6.44λ
Taper angle $\theta_1/\theta_2/\theta_3$ (degree)	2º/0º/3º
Parabolic Smoothing D_1/D_2 (mm)	1.4λ/1.4λ
Cavity diameter Φ1/ Φ2 /Φ3 (mm)	2.93λ/3.23λ/3.92λ

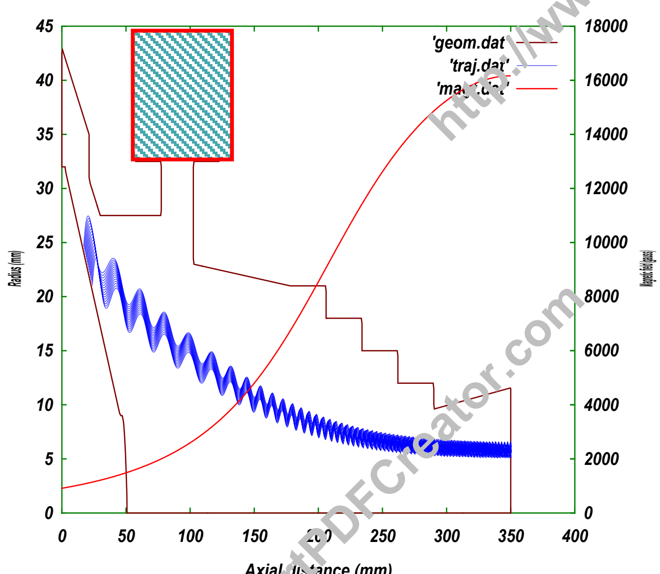

Figure1 MIG with optimised electron beam and magnetic field profiles

Table 3 Compression of CST-MS and HFSS

Material	Reflection coefficient		Absorption coefficient		Trans. coefficient
	CST	HFSS	CST	HFSS	HFSS /CST
Al_2O_3-SiC	0.108	0.071	0.891	0.928	0.001
AlN-SiC	0.123	0.095	0.876	0.904	0.001

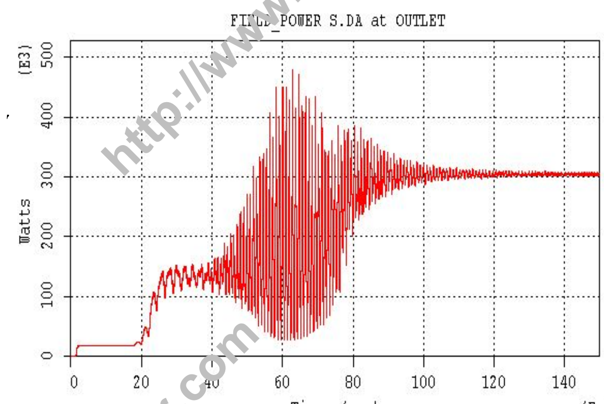

Figure 2 Output power w. r. t time at TE_{03} mode

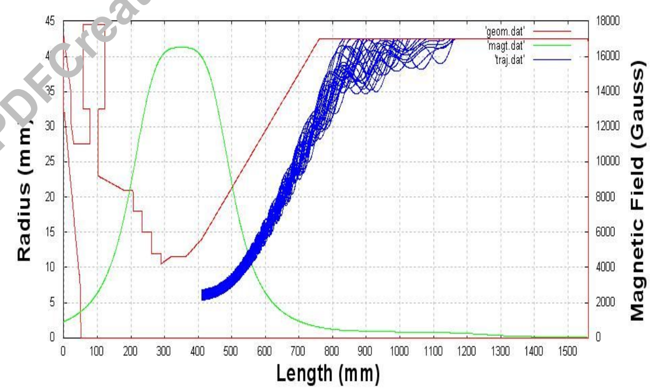

Figure 3 Beam spread on the surface of collector

Conclusion

The electrical design of all the prime and associated components for 42GHz, 200kW gyrotron has been completed using in house and commercial available software's. The total length of 42 GHz gyrotron is 2.2 m.

References

1. Greogory S Nusinovich, Introduction to the Physics of Gyrotron. Maryland: JHU, USA, 2004.
2. A Bera, U Singh, RR Rao and AK Sinha, "Design of MIG for 42 GHz, 200 kW Gyrotron"IVEC-2008, Monterey, USA
3. MAGIC User Manual: 2007 version of M agic 3D, ATK Mission Research, Washington.
4. Ansoft HFSS V.11, User Manual, Pittsburgh, PA