ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 1, Issue 2, November 2012

Design Optimization of Un-Depressed Collector through Magnetic Field and Thermal Studies

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***Abstract*— In this paper the authors have presented the design optimization of undepressed collector through magnetic field and thermal studies. The number of magnet coils and its position are optimized for maximum uniform beam spreading. Oxygen free high conductivity copper (OFHC) is used for study material. The effect of thermal load on collector wall and its geometry is analyzed. The collector geometry with cooling duct is finalized after thermal and structural analyses. The codes, EGUN and ANSYS are used for these analyses.**

***Index Terms*— Gyrotron, Collector, Thermal Analysis.**

I. INTRODUCTION

The gyrotron oscillator, sometimes referred to as the “electron cyclotron resonance maser” or “gyro-monotron”, is a high-power high-frequency source of coherent electromagnetic radiation [1]-[3]. The name now refers to a class of devices including both oscillators and amplifiers. It consists of a magnetron injection gun (MIG), which generates an annular electron beam which is focused into an open cavity resonator along an axial magnetic field, produced by a superconducting magnet. In the cavity, the RF field interacts with the cyclotron motion of the electrons in the beam and converts the transverse kinetic energy into an RF beam which may then be internally converted into a Gaussian beam [4]. The spent electron beam leaves the cavity and propagates to the collector where it is collected. When the beam strikes on the collector surface it needs spreading because, when the high energy beam strikes at the collector surface it generates heat. Due to heating effect, the portion starts melting, so for this reason beam is spreaded and the energy of beam is distributed up to certain region instead of collecting at one portion.

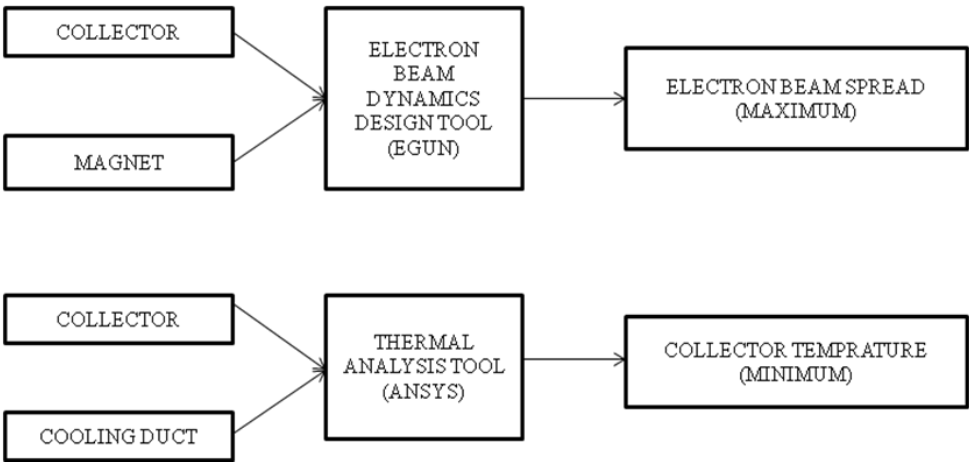

Fig. 1: The Approach Followed For Design of Collector System

Due to excessive heating on the surface of collector, it needs cooling. Cooling is of two types conventional cooling and unconventional cooling. In conventional cooling water is circulated due to its heat transfer capability. Thus as discussed above, the collector system consists of electron beam, collector, coolant, cooling duct and solenoid coils. Thus, to design the complete collector system, it may be divided in two parts as shown in Fig. 1. This paper is

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divided in different sections and focused on final design optimization of undepressed collector for 42 GHz, 200kW gyrotron, through magnetic field and thermal studies. The other components of 200 kW gyrotron are already designed [5], [6]. In the second section, the trajectory analysis with uniform spread through different magnet coils positions is presented. The length and the radius of the collector have been optimized by the analysis of the electron trajectory through EGUN simulation [7]. The third section describes the thermal simulation, fluid analysis and design of cooling duct. The fourth section is committed to a mechanical analysis and finalization of collector geometry. The ANSYS code is used for the thermal and the structural analyses.

II. TRAJECTORY ANALYSIS THROUGH MAGNETIC FIELD

Analysis related to electron beam spread is important for design of electron beam collector [8]. The analysis finally leads to the optimization of geometrical parameters of electron beam collector. The analysis of electron beam collector is carried out to optimize the collector dimensions and to achieve the maximum electron velocity spread on collector surface through magnetic field optimization. This is achieved with the use of simulation software of the electron beam i.e. EGUN. The simulation is carried out using 30 beamlets with the real energy distribution of the beam. Initially, the electron beam energy is 650 kW and after the beam wave interaction, 200 kW RF power is taken out of the window. The rest 450 kW power is remained with the electron beam and dissipated on the inner surface of the collector. The magnetic field plays a very important role in the optimization of the length and the radius of the collector. The magnitude and position of the magnetic field effects the beam spread on the collector surface. Thus, the EGUN code is used to study the uniformity and spreading of beam over the collector surface under the influence of the magnetic field.. To achieve the technical constraints, the collector dimensions and the magnetic field distribution in the collector region are changed accordingly. Figs. 2-4 shows the magnetic coils position & beam spread on the surface of collector with different electron beam spreads. Fig. 3 shows that the maximum uniformity is achieved for the beam spread equal to 332 mm in comparison to 393 mm beam spread, which is shown in fig.4. This is achieved by three magnet coils with 12 layers placed at different position around the collector. Nonlinear taper and RF window should be compatible with the dimensions of collector which are optimized as 85 mm diameter and 800 mm long.

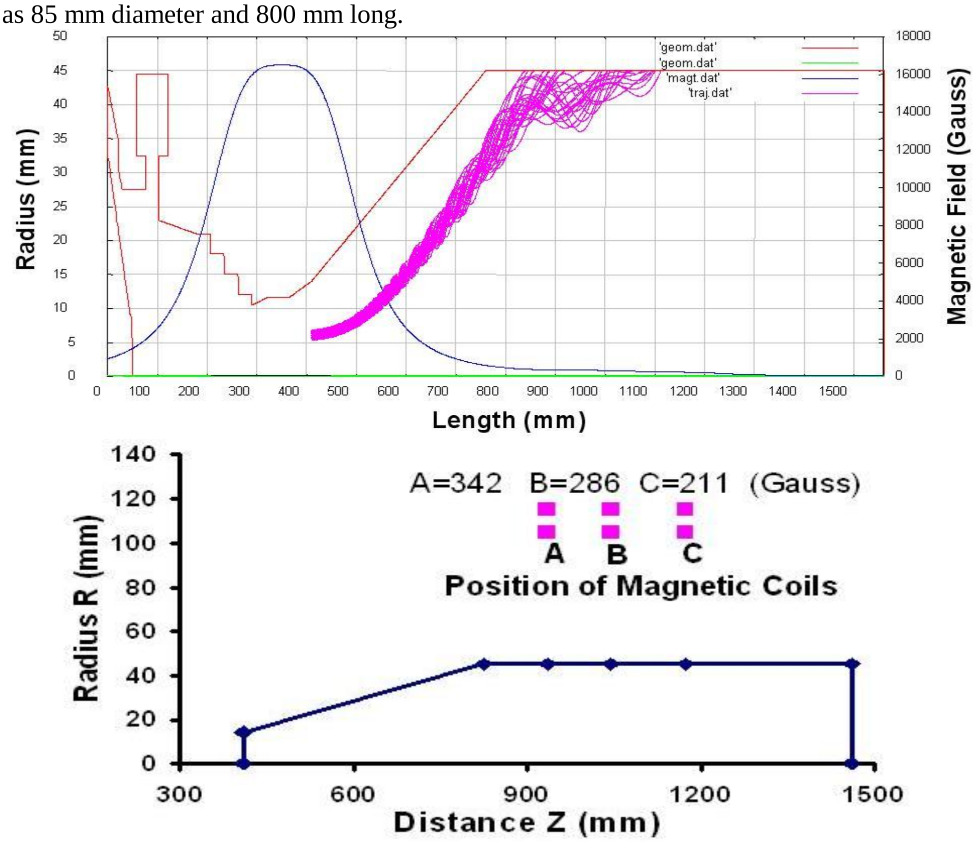

Fig. 2: Magnetic Coils Position & Beam Spread On The Surface Of Collector. Collector Length – 800 Mm; Collector Radius- 45 Mm; Non-Linear Tapered Length- 350 Mm; Electron Beam Spread- 272 Mm; Wall Loss-0.617 Kw/Cm^2.

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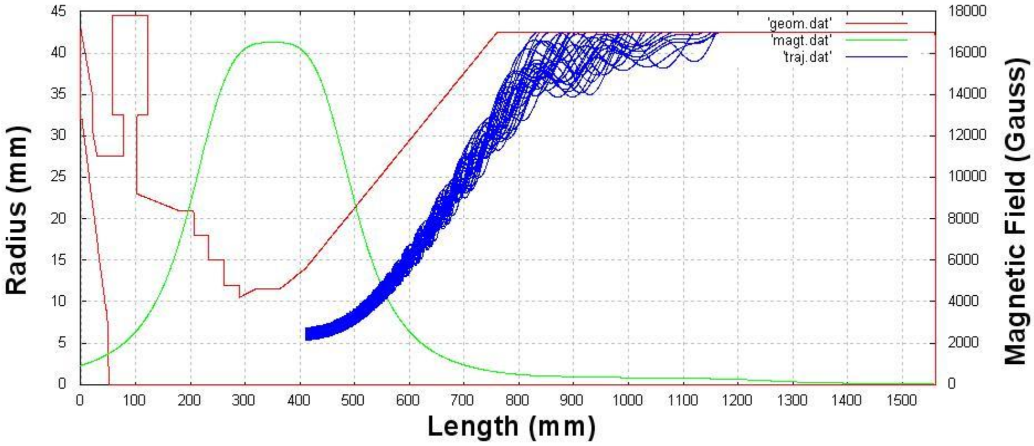


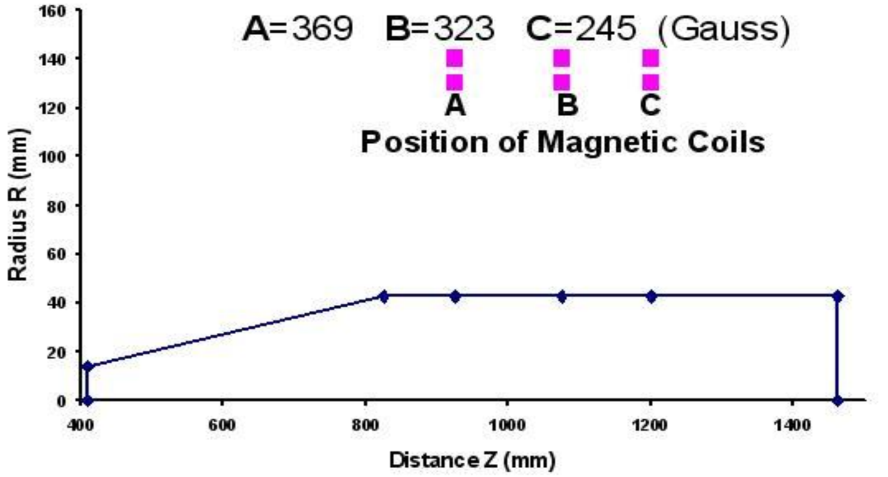
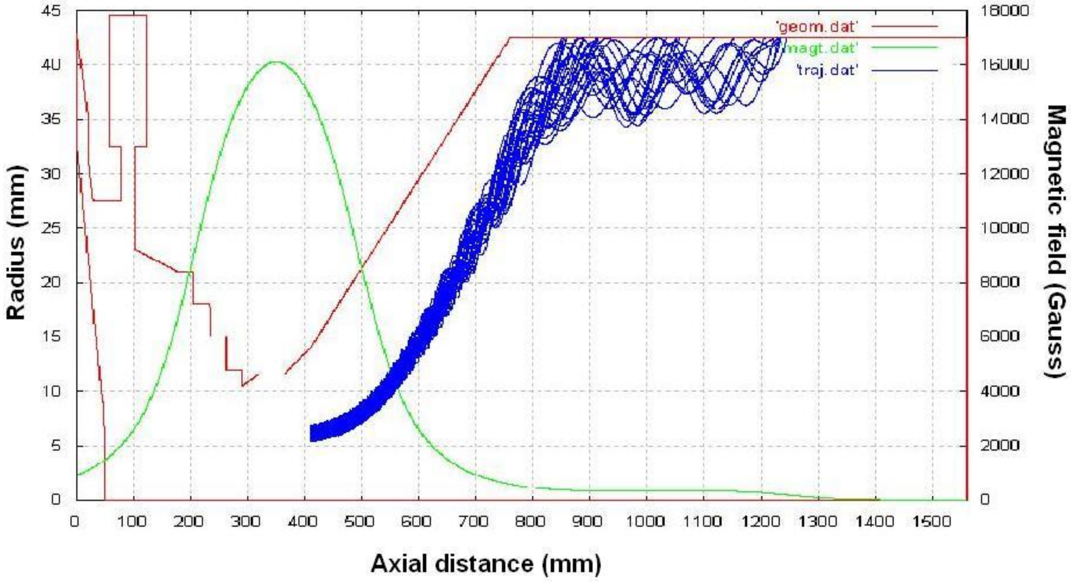


Fig. 3: Magnetic Coils Position & Beam Spread On The Surface Of Collector. Collector Length: 800 Mm; Collector Radius- 42.5 Mm; Non-Linear Tapered Length: 350 Mm; Electron Beam Spread: 332 Mm; Wall Loss: 0.507 Kw/Cm^2.



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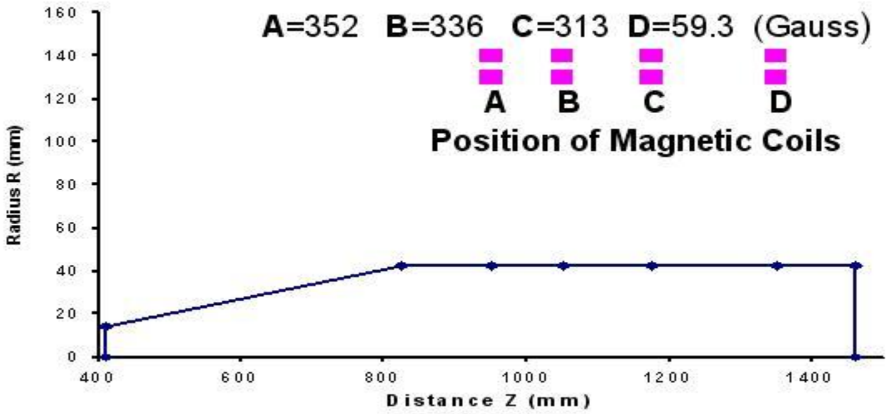

Fig. 4: Magnetic Coils Position & Beam Spread On The Surface Of Collector. Collector Length: 800 Mm; Collector Radius: 42.5 Mm; Non-Linear Tapered Length- 350 Mm; Electron Beam Spread: 393 Mm; Wall Loss: 0.429 Kw/Cm^2.

III. THERMAL AND FLUID ANALYSES

For the thermal study of collector, the finite element analysis code ANSYS is used [9]. ANSYS is finite element software which can be used for structural, thermal and fluid analyses. The oxygen free high conductivity (OFHC) copper is used as the collector material and DI water as a coolant for the cooling system for the collector of 42 GHz, 200 kW gyrotron. The calculated average wall loss is 0.507 kW/cm^2, which is within the technical limits for the optimized collector geometry [10]. The heat flux of 0.507 kW/cm^2 is applied at the specific area of the inner surface of the undepressed collector for the case of uniform electron beam spread, app. 332 mm and the heat dissipation equal to 450 kW. Fig. 5 shows the contour plot of collector temperature distribution for the axial groove collector at the applied heat flux and the heat film coefficient is 2.5x10^5 W/m^2.K for the hydraulic diameter, 4.5mm. The maximum temperature is 370 K on the inner surface of the collector and 295.7 K on the edge of the collector outer surface. In fluid analysis, the effect of different flow rates of coolant on the temperature of the collector outer surface has been studied. Fluid analysis is also an important study for optimisation of water flow rate and hydraulic diameter. Fig. 6 and 7 show the inner and outer temperature of collector with water flow rate for 450 kW and 650 kW power dissipations. Here water temperature is 293 K and the hydraulic diameter is 4.5 mm. From these figures, it can be concluded that the inner and outer temperatures continuously decrease with increase in water flow rate. The inner and outer temperatures also depend on the hydraulic diameter.

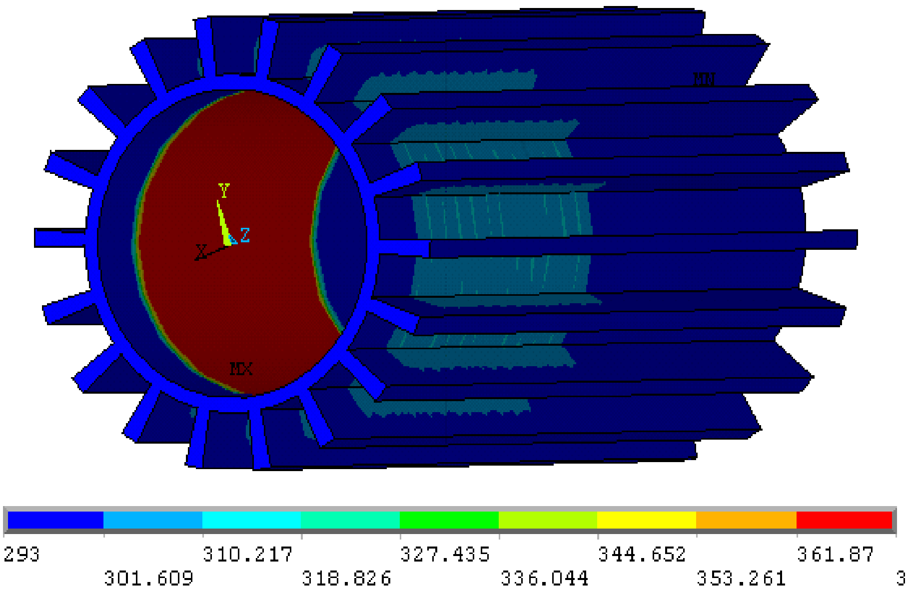

Fig. 5: Temperature Distribution for Axial Groove Collector (Groove Height=16 Mm, Groove Width=4 Mm, No. Of Axial Grooves=18, Space Between Two Grooves=16.5º)

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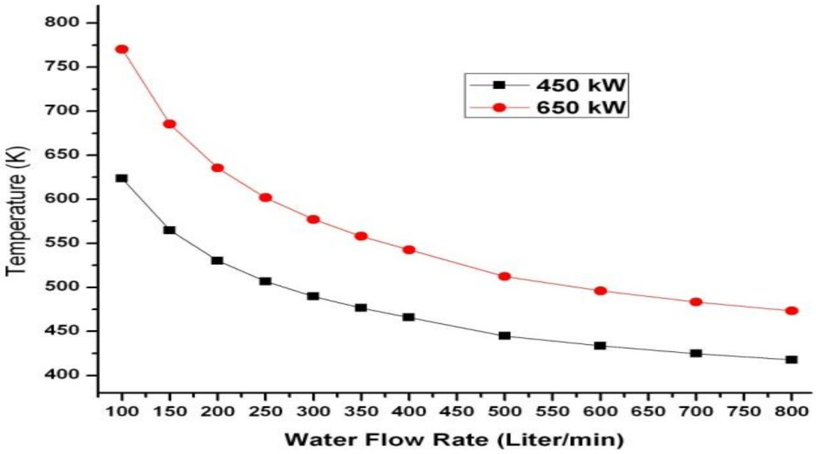

Fig. 6: Effect of Collector Inner Surface Temperature with Water Flow Rate for Different Power Dissipation

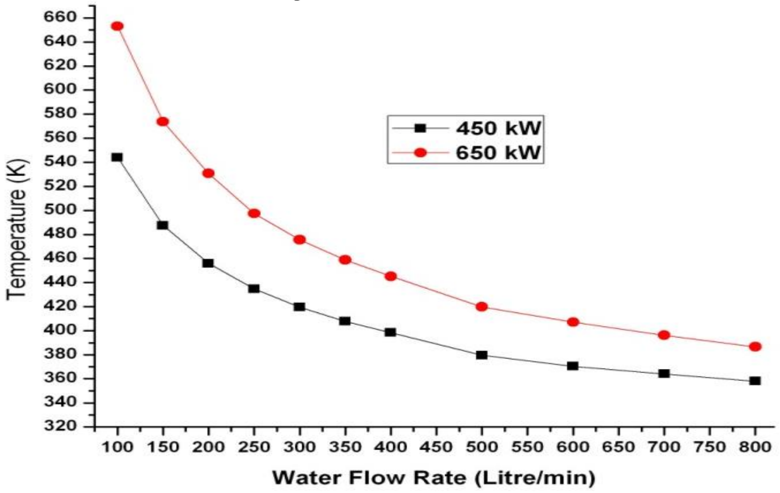

Fig. 7: Effect of Collector Outer Surface Temperature with Water Flow Rate for Different Power Dissipation

IV. STRUCTURAL ANALYSIS

After the thermal and fluid analysis, the structural analysis is very important for finalization of collector geometry and also to see the effect of structural deformation on beam spread. The temperature data and collector geometry obtained from the thermal simulation is used as the input for the structural analysis of the gyrotron collector [11]. Fig. 8 shows the radial thermal expansion of the axial groove collector for the temperature difference of 76 K. The maximum expansion 0.05 mm is very small of the collector geometry in the radial direction due to temperature difference. From Fig. 8, it is clear that the expansion of the collector surface occurs only in the radial direction and the change in axial direction is almost negligible.

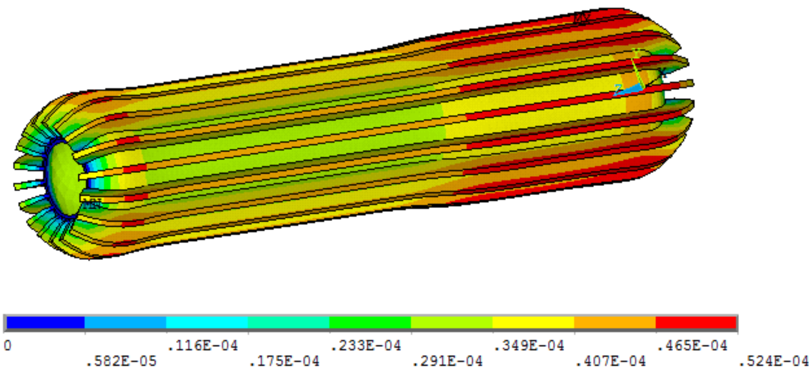

Fig 8: Structural Deformation for 450kw Power Dissipation, 800 L/M Water Flow Rate and 332 Mm Spread

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On the basis of the electrical, thermal and structural design of electron beam collector the optimized parameters for electron beam collector and collector cooling system for 42 GHz, 200 kW gyrotron are shown in Table I.

Table I: Optimized Collector Geometry and Cooling Parameters

Collector Radius (mm)	**42.5**
Collector Length (mm)	**800**
Length of electron beam spread on collector surface (mm)	**330**
Collector thickness (mm)	**20**
No. of axial grooves	**18**
groove width (mm)	**4**
groove height (mm)	**16**
Hydraulic diameter (mm)	**4**
Water flow rate (l/m)	**800**
Water temperature (K)	**288 - 298**

V. CONCLUSION

The electrical design of electron beam collector for application in 200 kW, 42 GHz gyrotron for the maximum uniform electron beam spread has been presented in this paper. For the electron beam analysis as well as optimization of collector geometry, an actively available commercial software EGUN was used as per requirement. The maximum uniform beam spread is 332 mm and optimized collector diameter and length are 85 mm, 800 mm respectively. The thermal, fluid and structural analyses are also carried of electron beam collector and ANSYS code is used for this simulation. The inner and outer temperatures of collector continuously decrease with increase in water flow rate. The maximum expansion of the collector geometry in the radial direction is very small i.e. 0.05 mm and the effect of this expansion on spread of spent electron beam is negligible. This work will be used in the fabrication of gyrotron collector with cooling duct. The thermal and structural analysis will be help to decide the tolerance limit of the geometry dimension.

ACKNOWLEDGMENT

We are pleased to acknowledge the support of Dr. Chandra Shekhar, Director, CEERI Pilani and Dr. S N Joshi, Project Co-coordinator of gyrotron activity. The authors also wish to thank for encouragement of this work and indebted to team members of gyrotron for helpful discussion.

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