Design of Electron Beam Collector for High Power, High Frequency RF Source

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Abstract

A 120 GHz gyrotron with 1 MW RF power and an electronic efficiency of 30% is designed. The beam voltage is 80 kV, the beam current is 40 A andt he operating mode is $TE_{22,6}$ and the gyrotron is designed for radial output power of 1.0 MW. Clearly, the spent electron beam has 2.2 MW power coming through input beam power after power growth in the device as waste power and that must be dissipated on the collector wall. To overcome the problem of thermal loading, the electrical design of single stage depressed collector with non-adiabatic magnetic field has been carried out. The water cooling duct has been modeled using multi-physics software. Further, the thermo-mechanical analysis is carried out to optimize the design tolerances.

Keywords: *RF source; Un-depressed Collector; Depressed Collector; Plasma Heating*

1. Introduction

Vacuum electronic sources have immense capabilities to meet high power applications. For example, high power, high frequency gyrotron produces few hundred kilowatt in continuous wave (CW)to megawatt in short pulse mode in millimeter and sub-millimeter ranges. Its applications include heating of fusion plasma, electron cyclotron resonance, materials processing, plasma diagnostic, stand-off detection and imaging of explosive and weapon, deep space and special satellite communication, atmospheric monitoring, new medical technology, etc [1]. Typically, 30-35% of beam energy is converted into RF power in a gyrotron and the remaining energy is deposited in the collector. Due to long pulse operation in a gyrotron, the high energy spent beam may cause metal fatigue in the inner collector wall. The high power gyrotron with the depressed collector reduces the power loading significantly [2-3]. By reducing the collector voltage with respect to the body, the unused translational kinetic energy of spent electron beam can be recovered. The energy recovery of the spent electron beam enhances the overall efficiency of the gyrotron. In that case, the presented thermal analysis was carried out for average power density of 0.510kW/cm^2 for 1 MW RF power. However, the maximum peak power density of 1.2 kW/cm^2 found in the case of undepressed collector may cause thermal problem during CW operation [4]. This thermal problem can be overcome both by the efficient cooling arrangement and by the single/ multi stage depressed collector. Here, for the sake of convenience and simplicity, the single stage depressed collector is considered for the study. The use of new materials for both collector and coolant to improve the performance of the gyrotron collector is also discussed.

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2. Electrical Design

The electrical design of the single stage depressed collector includes electrostatic as well as magneto static design achieved using ray tracing code [5-6]. To collect the spent electron beam without any back scattering, the potential difference between the collector and the body should be less than the minimal energy of the spent beam electrons. Other technical constraints of the depressed collector are (1) the efficiency should be greater than 60% and (2) the peak power density should be less than 1 kW/cm^2.

Initial design of the single stage depressed collector insulated from the grounded body of the device is carried out using 30 beamlets. A lot of iterations are carried out to fulfill the technical constraints. Figs. 1.1-1.3 show the initial results of beam spread over collector surface. Fig 1.4 shows the final electrical design of single stage cylindrical collector with spent electron beam trajectory for 120 GHz, 1 MW gyrotron. The collector length is 1400 mm and diameter is 300 mm, respectively. The depressed voltage, 44 kV is applied to reduce the deposited power from 2.2 MW to 1.44 MW. The design efficiency of the collector is 80 %. Four solenoid magnet systems are employed to achieve non-adiabatic condition and beam spread, 600 mm [7-10]. The beam conditioning system helps to achieve peak power density, 0.9 kW/cm^2. The beam trajectory analysis shows no backscattering of electron beam trajectory and the probability of secondary electron beam emission is 5%, which is further collected by collector electrode. The device efficiency is enhanced to 68.8%.

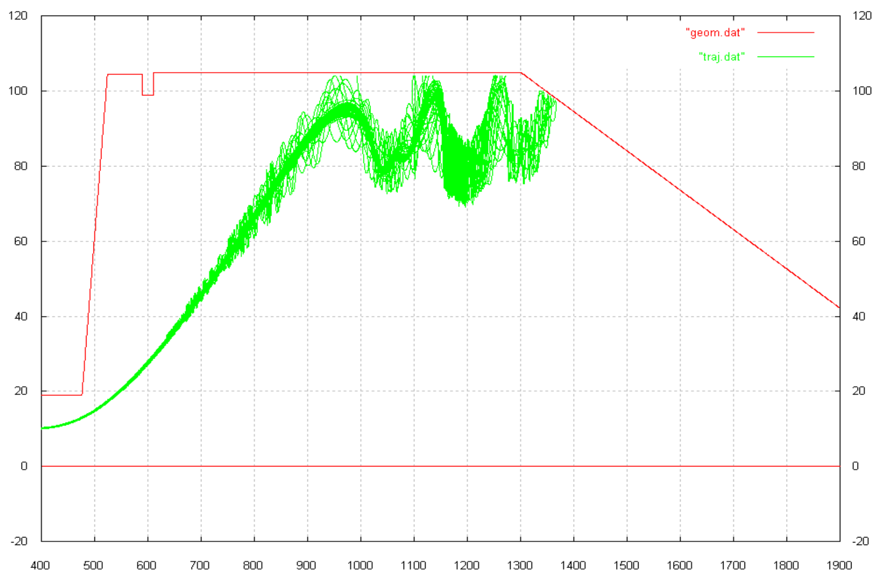

Fig. 1.1: Single stage cylindrical collector with electron beam trajectory at non-adiabatic decompression magnetic field (Depression voltage=75 keV, magnets=3 magnets with 2 layers each, input radius (mm) = 115, output radius (mm) = 125, magnet positions (mm): 1054, 1194, 1312, magnetic field (Gauss): 1225,1575,1575, spread length (mm) =500)

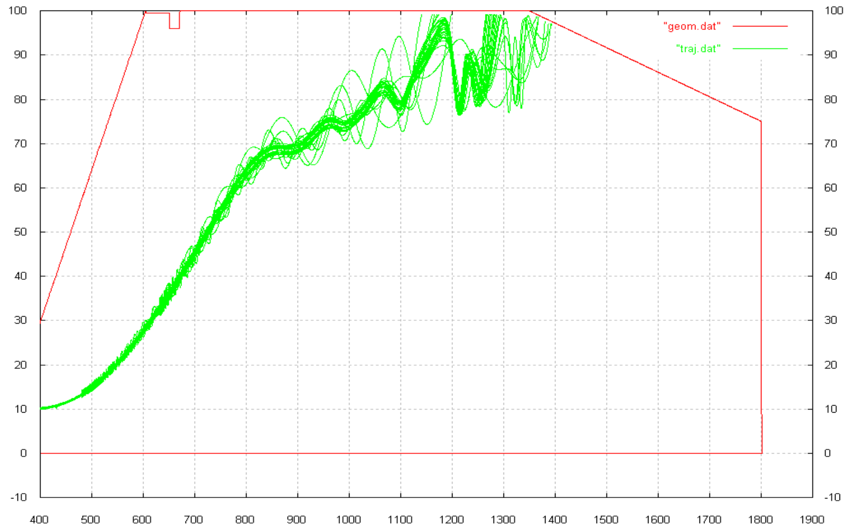

Fig. 1.2: Single stage cylindrical collector with electron beam trajectory at non-adiabatic decompression magnetic field (Depression voltage=75 keV, magnets=6Magnets with 2 layers each, input radius (mm) = 115, output radius(mm) = 125, magnet positions (mm):900, 1000, 1100,1225, 1325, 1425, magnetic field (Gauss): 930, 930, 930, 1225, 1225, 720, spread length (mm) =250)

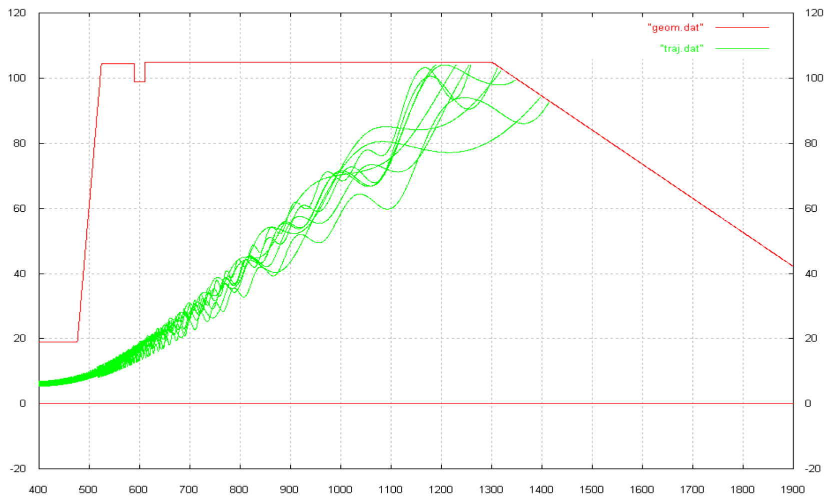

Fig. 1.3: Single stage cylindrical collector with electron beam trajectory at non-adiabatic decompression magnetic field (Depression voltage=20keV, magnets=3 magnets with 2 layers each, input radius (mm) = 115, output radius(mm) = 125,magnet positions (mm):1054, 1194, 1312, magnetic field (Gauss): 315, 200, 285, spread length (mm) =220)

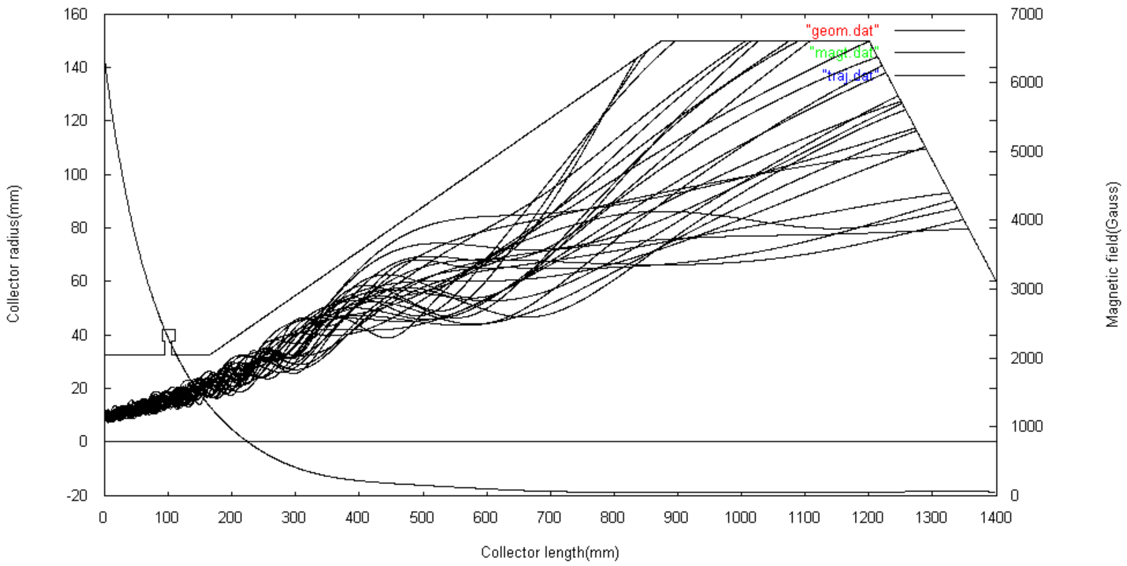

Fig. 1.4: Single stage cylindrical collector with electron beam trajectory at non-adiabatic decompression magnetic field

3. Conclusion

This manuscript presents the design analysis of the single stage depressed collector with cooling system for 120 GHz, 1MW gyrotron. The cylindrical collector is simple in design and relatively robust in nature. The simulated electron beam trajectories indicate that the overall efficiency will be enhanced by the factor of two. The thermo-mechanical analysis optimizes the desired heat film co-efficient and time of operation. Based upon these analyses, the designs of depressed collector of 120 GHz, 1MW gyrotrons have been optimized and thus fabrication based upon the designs finalized here would be taken up in due course of time.

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