Design of Triple- frequency Gyrotron

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Abstract: *This paper presents the electrical designs of interaction cavity and electron gun for triple frequency (170-, 140-, and 127.5 GHz) gyrotron.* $TE_{34,10}$, $TE_{21,11}$ *and* $TE_{22,9}$ *modes are selected as the operating mode for 170 GHz, 140 GHz and 127.5 GHz operation of the device, respectively. The design results show more than 1 MW power at all three frequencies.*

Keywords: Gyrotron, Electron Gun**,** interaction structure.

Introduction

Gyrotron is a high power, high frequency RF source prevalently used in the plasma heating and plasma diagnosis [1]. Two or more frequencies in millimeter wave band are used commonly for ECRH and start-up in the plasma fusion machines like, SST-1, ITER, ASDEX, etc. The ECRH RF system can be simplified if the single gyrotron device delivers MW power at two or more frequencies. Considering this advantage of multi-frequency gyrotron, the design work for triple-frequency (170 GHz, 140 GHz, and 127.5 GHz) is carried out and presented in this paper.

The design goals for the triple frequency 1 MW gyrotron are given in table 1. 170 GHz and 127.5 GHz are the popular ECRH frequencies in ITER, while 140 GHz is used in W-7X and ASDEX tokomak systems as the ECRH frequency.

Table 1. Design specifications and goals

Frequency (f)	170-, 140 - & 127.5 GHz
Output power (P_{out})	>1 MW
Harmonic (s)	1
Beam voltage (V_b)	77-83 kV
Beam current (I_b)	41-45 A
Interaction efficiency (η)	≈ 35 %

Cavity Design

The selected operating TE modes are excited in a single cavity at different frequencies by launching the electron beam at different radial positions. $TE_{34,10}$, $TE_{21,11}$ and $TE_{22,9}$ modes are selected as the operating modes for 170 GHz, 140 GHz and 127.5 GHz, respectively. The selected operating modes satisfy all the technical constraints. The electron beam is launched at the first radial maxima of the operating modes, which are 10.00 mm, 8.28 mm and 8.71 mm for 170 GHz, 140 GHz and 127.5 GHz, respectively. The cavity magnetic fields are optimized as 6.78 T, 5.56 T and 5.10 T corresponding to 170 GHz, 140 GHz and 127.5 GHz frequencies. The dimensions of interaction cavity are shown in Table 2.

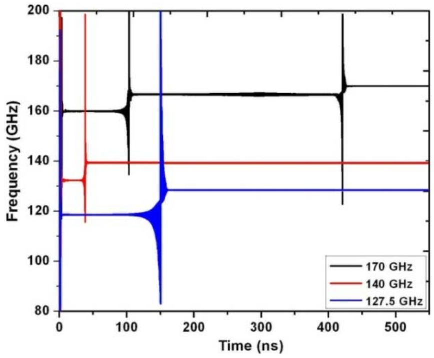

Figure 1. Temporal growth of frequency

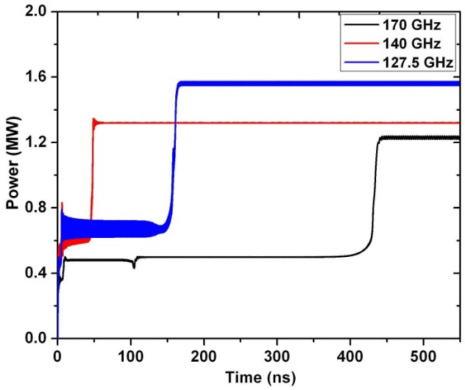

Fig. 2.Temporal growth of Power

Table 2. Optimized cavity geometry parameters

Parameters	Dimensions
Input taper length (L_1)	8 mm
Middle section length (L)	14 mm
Output taper length (L_2)	16 mm
Cavity radius (R_c)	20.95 mm
Input taper angle (θ_1)	2.8°
Output taper angle (θ_2)	3°

Particle-in-cell code is used for the interaction cavity design. Figs. 1-2 show the typical plots of frequency and power growth with respect to time. The beam wave interaction results confirm more than 1 MW power at 170 GHz, 140 GHz and 127.5 GHz frequencies.

Electron gun Design

A triode-type magnetically tunable magnetron injection gun (MT-MIG) is designed for 1-MW triple frequency (170-, 140-, and 127.5-GHz) gyrotron. The electron trajectory analysis has been carried out by using the trajectory code EGUN to optimize the electrode shapes and the beam parameters [3]. The dimensions and parameters for the trajectory simulation are shown in Table 3. The optimized MIG geometries with the electron beam and magnetic field profiles are shown in Fig. 3, Fig. 4 and Fig. 5 for 170-, 140-,127.5 GHz, respectively. The simulation results of MT-MIG show the utility and capability of such electron guns in multi frequency gyrotrons (table 4).

Table 3. Dimensions and parameters for trajectory simulation.

Value for Frequency (GHz)	**170**	**140**	**127.5**
Mean radius (mm)	52.8	52.8	52.8
Slant length (mm)	5.38	5.38	5.38
Cathode- anode gap (mm)	12	12	12
Slope angle of emitter	28^0	28^0	28^0
Magnetic field at cathode (T)	0.260	0.173	0.169
Magnetic compression ratio	25.08	32.13	30.17
Modulating anode voltage	58 kV	30 kV	29 kV

Table 4. Optimized electron parameters

Parameters	**170 GHz**	**140 GHz**	**127.5 GHz**
Transverse-to-axial beam velocity ratio (α)	1.37	1.29	1.3
Maximum transverse velocity spread	2.1 %	3.3 %	3 %
Beam radius (mm)	9.95	8.30	8.78

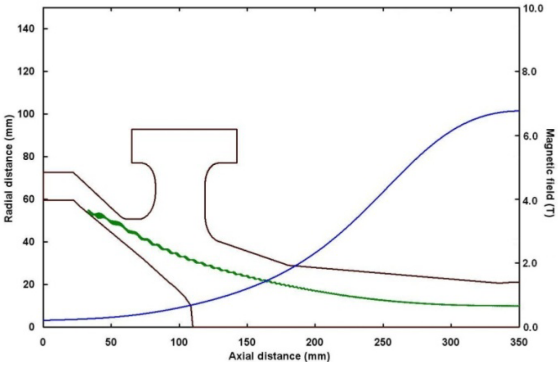

Figure 3. Electron beam profile with MIG for 170 GHz

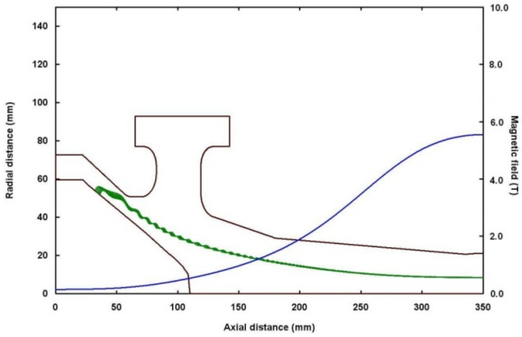

Figure 4. Electron beam profile with MIG for 140 GHz

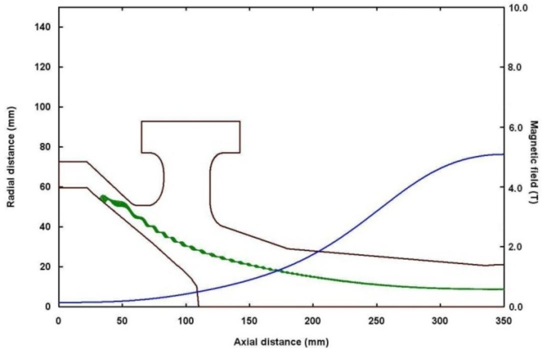

Figure 5. Electron beam profile with MIG geometry for 127.5 GHz

Conclusion

The beam-wave interaction simulation results confirms more than 1 MW power genration for all the three frequencies. The design of MT-MIG is also discussd to support the practical popssibilty of the device. The results confirm the possibilty of 1 MW or more power genration in such a wide frequency range for nuclear fusion applications.

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