Design of interaction cavity for 120 GHz, 1 MW Gyrotron

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Abstract: *A weakly tapered interaction cavity has been designed to excite $TE_{22,6}$ operating mode at the fundamental harmonic number for 120 GHz, 1 MW gyrotron. A MATLAB code has been developed to synthesize cavity geometry and selection of operating mode. The cold cavity analysis and the beam-wave interaction were carried out using the commercially available PIC code MAGIC. The output power above 1 MW has been achieved at guiding cavity magnetic field 4.82 T.*

Keywords: Gyrotron; interaction cavity; limiting current; voltage depression; wall loss.

Introduction

Gyrotron oscillators are high-power sources which produce coherent cyclotron radiation in the millimeter and sub millimeter wave regions. A 120 GHz, 1 MW output power gyrotron is being to be developed for the electron cyclotron resonance heating (ECRH) for the Indian TOKAMAK system. Initial MIG parameters have been finalized for 120 GHz gyrotron by EGUN simulation code. For the high power, high frequency gyrotron, higher order modes are chosen to reduce the ohmic wall loss. At higher order mode and large cavity volume, the mode density increases sharply [1]-[2]. The mode selection has been carefully studied with the aim of minimizing mode competition and restricting the excitation of undesired modes in the cavity as well as to obtain a desired power level [3]. A MATLAB code has been developed to synthesize the cavity geometry and analyze the mode selection. The parameters such as cavity radius, beam radius, limiting current, voltage depression and wall loss were obtained for different modes [4]. After evaluating above parameters, few higher order modes have been selected. Further on the basis of other parameters like start oscillation current and coupling coefficient, $TE_{22,6}$ is selected as the optimized operating mode.

The gyrotron cavity geometry has been modeled, simulated and finally designed using the self-consistent particle-in-cell (PIC) code MAGIC [5]. In this paper a detail design of the interaction cavity of 120 GHz gyrotron is presented. The simulation results show the output power 1.141 MW at the operating frequency 120.35 GHz with the interaction efficiency more than 35%.

Cavity Design

For the operation in the $TE_{22,6}$ mode, the cavity radius and the beam radius have been calculated for the operating frequency 120 GHz [6]. Input taper and output taper geometry have been optimized by MAGIC simulation.

Table 1. Design parameters of weakly tapered interaction cavity for 120 GHz, 1 MW gyrotron.

Frequency	120 GHz
Output power	1 MW
Beam voltage	80 kV
Beam current	40 A
Modulating anode voltage	40 kV
Cavity Radius	18.16 mm
Beam radius	10.08 mm
Length of uniform section of cavity	17 mm
Operating mode	$TE_{22,6}$
Velocity ratio	1.5
Magnetic field	4.82 T
Estimated wall loss	0.5 kW/cm^2

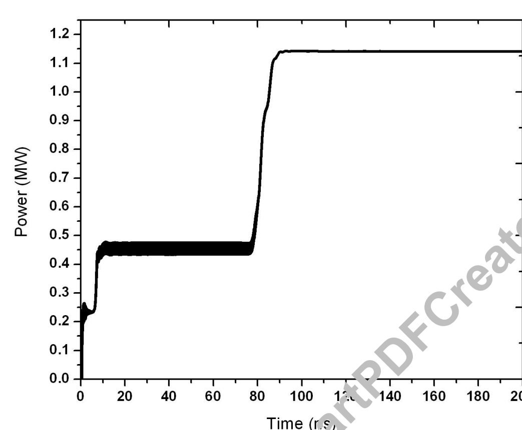

Fig. 1. Output power with respect to time for gyrotron oscillator operates at $TE_{22,6}$ mode.

The design parameters for the fundamental operation of 120 GHz, 1 MW gyrotron is given in Table I. 3-dimensional MAGIC code has been used for analyzing the asymmetric $TE_{22,6}$ mode and beam wave interaction.
An electron beam posses all the desire beam properties has been launched at the first radial maxima of the input taper entrance for beam wave interaction simulation. The beam interacts with the normalized RF field profile while propagate across the cavity and terminates on the other end wall. The code is run using the Maxwell CENTERED algorithm at confined magnetic field. The cold cavity analysis illustrates the eigenmode, the eigenfrequency and the electric field profile for the operating mode $TE_{22,6}$.

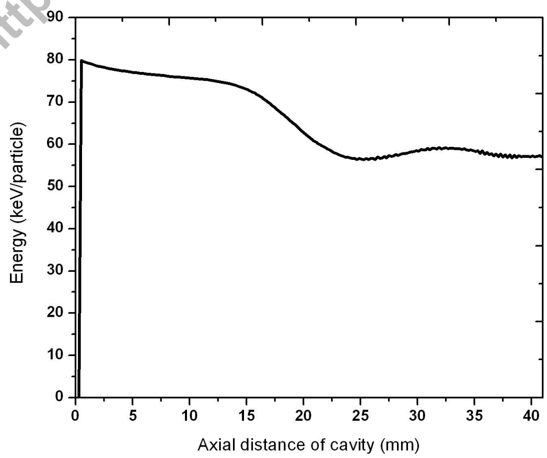

Fig. 2. Profile of electron energy in the cavity for a $TE_{22,6}$ mode.

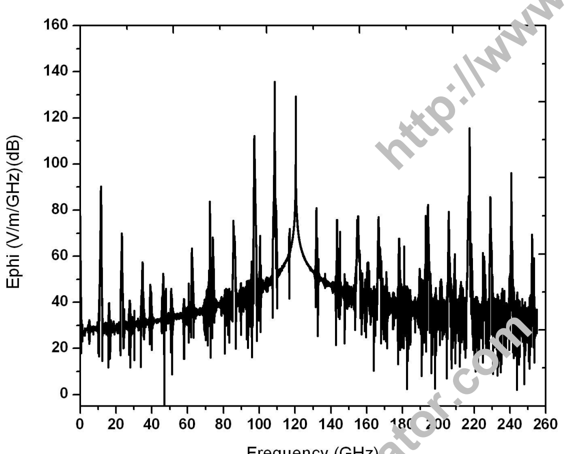

Fig. 3. Frequency spectrum for the $TE_{22,6}$ mode gyrotron.

The axial distribution of the wave electric field in the tapered cavity resembling the Gaussian profile. Figure 1 shows output power profile with respect to time, achieving the steady state after 100 ns of the start operation. Figure 2 shows the electron beam energy profile with the cavity axial distance. The figure shows the beam wave interaction in the cavity. The maximum energy of the electrons is transferred to the rf at the cavity center. From the frequency spectrum (Figure. 3), it is clear that the frequency of 120.35 GHz is excited with maximum gain. Although the frequency of 108.59 GHz is also exciting, but this frequency is far away from the operating magnetic field. Around 120.35 GHz, no other higher frequency is exciting.

Conclusion

$TE_{22,6}$ mode is chosen as operating mode for 120GHz, 1MW gyrotron. Simulated results show that the output power is 1.141 MW at confined magnetic field of 4.82 T, beam voltage 80 kV and beam current 40A. The interaction efficiency is more than 35%.

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