Eigen mode Analysis of Cylindrical Cavity for Millimeter& Submillimeter Gyrotrons

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Abstract: *In this paper Eigen mode analysis has been carried out using Ansoft HFSS for high frequency 120 GHz, 140 GHz, 170 GHz, 503GHz and 1000 GHz gyrotron cavity. Eigen mode analysis has an idea about the excitation of the operating modes in the cavity of the gyrotron and obtained the simulated eigen frequency and field pattern of the modes. The CPU time on Pentium-4, 2.99 GHz system with 4 GB RAM was less then 10 minutes for simulation a cavity in HFSS. The simulated results have also been compared with CST microwave studio.*

Keywords: Eigen mode; Periodic boundary; resonant cavity; Gyrotron

Introduction

Gyrotron is a high power microwave tube, which emits coherent radiation at approximately the electron cyclotron frequency or its harmonics. Gyrotron is widely used in plasma fusions, ECRH heating, Industrial heating and material processing. The need for high power, high frequency rf sources for the magnetic fusion research experiments has provided much of the impetus for the development of present day gyro oscillators. From the last three decades gyrotron oscillators have played a key role in magnetic fusion experiments. Magnetic confined plasma fusion is the most important application of gyrotron oscillator as a high power, high frequency rf source [1]. A 120 GHz to 170 GHz, 1MW Gyrotron is being developed for International Thermonuclear Experimental Reactor (ITER). The design of cavity resonator for gyrotron oscillators requires the knowledge of the RF field profile, resonator eigen frequencies, and the quality factor Q. In conventional gyrotron, the resonator cavity is usually a three-section smooth walled cylindrical cavity structure as shown in the Figure 1 [2].The input taper is a cut-off section, which prevents the back propagation of RF power to the electron gun. The beam wave interaction takes place mainly in the uniform middle section where the RF field reaches peak values. The up taper connects the cavity with the output wave-guide. The first taper should have opening below the cut-off diameter of RF mode so that the wave is totally reflected from this end. The diameter of the middle section is near cut-off so that even small changes lead to strong reflections, which result in an increase in the stored energy in the middle part that is the resonator. The diameter of third section is such that there is no reflection and the wave should propagate further. The shape of the cavity has to be chosen so that desired mode can be excited, energy exchange from the electron beam to the RF wave is high as possible and ohmic loss can be handled.

Eigen mode analysis

In Eigen mode analysis the resonance frequency of the structure has been obtained applying with periodic boundary conditions and studies the electric field pattern for different modes. The CPU time on pentium-4, 2.99 GHz system with 4 GB RAM has less then 10 minutes for simulation a cylindrical cavity in HFSS for 42 GHz. For high frequency 100 GHz and above frequency it is necessary to assigning the mesh refine operation in HFSS software [3]. So the mesh operations are optional and mesh refinement settings that provide HFSS with mesh construction guidance. This technique of guiding HFSS's mesh construction is referred to as seeding the mesh. The length-based mesh refinement and skin depth-based mesh refinement have been defined then CPU time of the solution has less then 10 minutes for simulation a cylindrical cavities in HFSS for 120 GHz to 1000 GHz. Table1 shows the design parameters for 120 GHz gyrotron cavity. The dimensions of the cylindrical cavities have been used: radius =18.1 mm, Length =16 mm for 120 GHz, radius =20.4 mm, Length =14 mm for 140 GHz and radius =1.95 mm, Length =10 mm for 1000 GHz in the simulation. Table 2 shows the length $L_1/L_2/L_3$ and angle $\theta 1/\theta_2/\theta_3$ of the different cavities. Based upon some typical selection criteria using in-house developed code $TE_{22,6}$, $TE_{28,7}$, $TE_{37,7}$, $TE_{5,5}$ and $TE_{6,12}$ modes have been selected as operating modes for 120 GHz, 140 GHz, 170 GHz ,503 GHz and 1000 GHz gyrotron cavities.

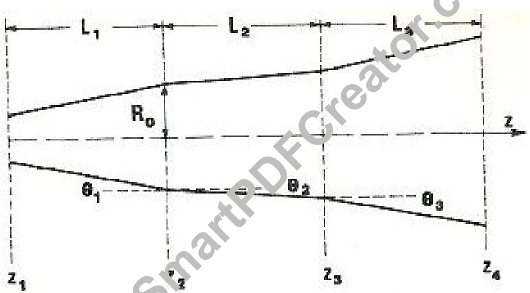

Figure1 Interaction structure for Gyrotron

Table 1 Design parameters for 120GHz gyrotron

S.N	Parameters	Values
1	Voltage depression	$\Delta V \leq 5$ kV
2.	Wall Loss	0.275 kW/cm^2
3.	Limiting current (I_L)	110 A
4.	Cavity radius	18.1 mm
5.	Alpha (α)	1.4
6.	Beam radius	10.0 mm
7.	Fresnel parameter	$C_F \geq 1$
8.	Beam voltage	80 kV
9.	Beam current	40 A

Table 2 Length and angle of different cavities

Cavity	Length $L_1/L_2/L_3$ (mm)	Angle $\theta_1/\theta_2/\theta_3$ (degree)
120GHz	22/16/12	2º/0º/3º
140 GHz	16/14/16	2.5º/0º/3.5º
1000GHz	5/10/5	5.5º/0º/22.3º

Modes of propagation	Using HFSS-Ansoft	Using CST Microwave studio
TE $_{13, 6}$	80.45	80.82
TE $_{18, 6}$	110.01	110.45
TE $_{22, 6}$	120.01	120.18
TE $_{28, 7}$	140.03	140.01
TE $_{37, 7}$	170.02	170.14
TE $_{5, 5}$	503.17	503.23
TE $_{6, 12}$	1000.12	1000.20

Table 3 The comparison of simulated frequencies for different modes

Results and discussion

Eigen mode analysis of the 120 GHz, 140 GHz, 170 GHz, 500 GHz and 1000 GHz gyrotron cavities have been carried out using Ansoft HFSS. Table 3 shows the comparison of the simulated frequencies of 100 GHz to 1000 GHz Gyrotron cavities for different modes using Ansoft HFSS and CST. The modes $TE_{18, 6}$, $TE_{22, 6}$, $TE_{28, 7}$, $TE_{37,7}$, $TE_{5,5}$ and $TE_{6,12}$ have been selected as operating modes for 110 GHz, 120 GHz, 140 GHz, 170 GHz, 503 GHz and 1000 GHz gyrotron cavities. Figure 2 shows the $TE_{22, 6}$ mode at 120 GHz. Figures 3 and 4 shows the $TE_{37,7}$ and $TE_{6,12}$ modes at 170 GHz and 1000 GHz respectively. In the HFSS the specification of modes are not displayed so, the different modes are calculated by observing the corresponding field patterns. These modes have also been compared with CST microwave studio.

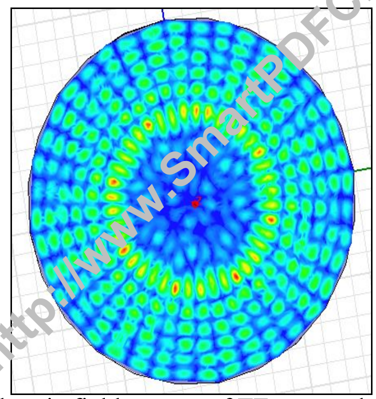

Figure 2 Electric field pattern of TE $_{22, 6}$ mode at 120 GHz

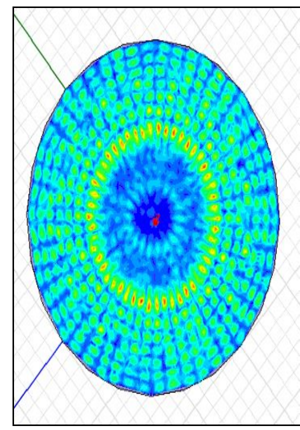

Figure 3 Electric field pattern of TE $_{37, 7}$ mode at 170 GHz

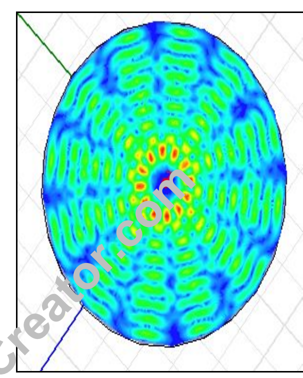

Figure 4 Electric field pattern of TE $_{6, 12}$ mode at 1000GHz

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