# The three-dimensional particle-in-cell simulation analysis of cavity of high power subterahertz pulsed gyrotron

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## ABSTRACT

**High power sub-terahertz pulsed gyrotrons for Collective Thomson Scattering (CTS) diagnostics of fusion plasmas are being developed . The typical target parameters are: output power of 100~200 kW, operation frequency of 300 GHz, and pulsed length > 10 us. In order to support experimental development, numerical simulations were carried out by using Particle-In-Cell (PIC) code MAGIC. The oscillation mode of the electromagnetic radiation was selected as $TE_{15,2}$, for which the beam parameters and cavity dimensions were determined accordingly. The simulation results have showed maximum power of 144 kW at oscillation frequency of 292.80 GHz, with oscillation efficiency of 22.15%.**

## Keywords

**high-frequency, gyrotron, collective Thomson scattering, sub-terahertz, simulation, MAGIC, $TE_{15,2}$ mode**

## 1 INTRODUCTION

Gyrotrons are a high power electromagnetic wave oscillator. The operation of the gyrotron is based on the phenomena called electron cyclotron maser instability[1]. The electromagnetic wave stimulates the azimuthal and phase bunching in the helically moving electrons. The bunched helical moving electrons enhance the electromagnetic wave by the coherent bremsstrahlung-type radiation. Recently, high frequency gyrotrons has been studied for Collective Thomson Scattering (CTS) [2-4] diagnostics on fusion plasmas. CTS is a method for evaluating the ion velocity distribution function and offers the capability to measure the fast ion distribution in magnetically confined plasmas.

The scattering measurement for the plasma by the electromagnetic wave which used a gyrotron is applied for the detailed measurement of the density fluctuation. When the electromagnetic wave is incident in the plasma, electron swarm oscillates in the plasma. Then, oscillated electron causes the re-radiation of the electromagnetic wave. The scattering measurement of the plasma is the technique to measure density fluctuation of particle by observing the frequency spectrum of the re-radiated electromagnetic wave. In the plasma, the electron swarm fluctuates as blocking off the ion cluster. The wave number area a in which the scatter spectrum of electron is determined by the density fluctuation of ion. The temperature and density of ion are measured by CTS measurement in the plasma.

As the probe beam source for CTS, the development of the 1) $CO_2$ laser and 2) the gyrotron for the plasma heating and the electric current drive[6-8] has been carried forward. However, because the wavelength of the 1) is short, the measurement of the high resolution is difficult. On the other hand, 2) enables the high resolution measurement. But, it is rather a lower frequency than the $CO_2$ laser. Therefore, the electron cyclotron resonance absorption and the mighty cyclotron radiation noise occur. To solve these problems, we have studied to develop the sub-terahertz high power pulsed gyrotron which is appropriate to a light source for CTS. The development goal is the output power of 100~200kW, fundamental frequency of 300GHz.

## 2 SUB-TERAHERTZ HIGH-POWER GYRO-TRON

The gyrotrons is the electromagnetic wave oscillator which uses the effect of the electron cyclotron resonance maser. The kinetic energy of the electron beam is changed into the electromagnetic wave energy. In the cavity, an external magnetic field is applied to the axial direction. Thus, the electron beam turns in the spiral. The velocity of the electron beam has a turn component and a progress component. The ratio of the tarn rate and the progression rate of electron are called a pitch factor [8-9].

The oscillation mode of the electromagnetic wave is determined by the electron beam radius and the applied magnetic field in the cavity. The energy conversion efficiency of the electromagnetic wave depends on the cyclotron frequency and the pitch factor. Hence, the design of the cavity is very important to develop the high efficiency gyrotron.

At the 300GHz fundamental harmonic gyrotron, the oscillation of $TE_{15,2}$ mode is chosen as the candidacy mode. However, when the oscillation mode becomes a high order, the oscillation output and the oscillation efficiency decrease [10]. This is due to mode competition. Also, because the high frequency gyrotron needs a high magnetic field, it's not able to develop easily. Thus, It is difficult to develop the gyrotron only by the experimental evaluation. In order to solve this problems, numerical simulation studies were performed by using three-dimensional (3-D) particle-in-cell (PIC) code "MAGIC" [11-13].

## 3 SIMULATION METHODE

### 3.1 SIMULATION MODEL

The sub-terahertz high-power pulsed gyrotron was designed by MAGIC. Figure 1 shows a simulation model. Table 1 shows a design-parameter.The electron beam condition is the beam current of 10A, the beam voltage of 65kV and the pitch factor of 1.2. Also, the external magnetic field is 11.45T.

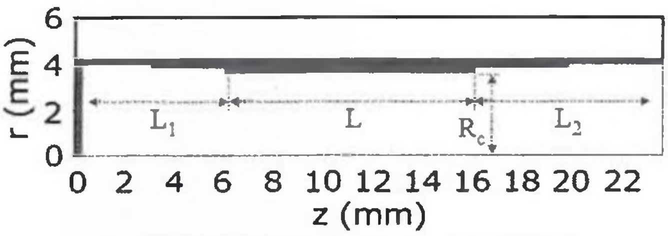


Fig.1 Simulation model of $TE_{15,2}$ mode cavity

Table 1. Design parameter for 293GHz gyrotron

| | $TE_{15,2}$ |
|---|---|
| Cavity Length (L) | 10mm |
| Input Taper Length ($L_1$) | 6mm |
| Output Taper Length ($L_2$) | 7mm |
| Cavity Radius ($R_c$) | 3.6mm |
| Taper Angle (θ) | 6° |
| Beam Radius ($R_b$) | 2.6mm |
| Beam Current ($I_b$) | 10A |
| Beam Voltage ($V_b$) | 65kV |
| Pitch Factor (α) | 1.2 |
| Magnetic Field (B) | 11.45T |

### 3.2 Boundary condition

Figure 2 shows the boundary condition of the simulation model. The waveguide is a perfect conductor. In the cavity, it is a vacuum state. Port is set in the right end. It is able to prevent a reflection of the electromagnetic wave. Absorber is set in the left end. It is able to absorb the electromagnetic wave. The current of the short pulse is generated in Driver region. The remaining noise is measured in Area.

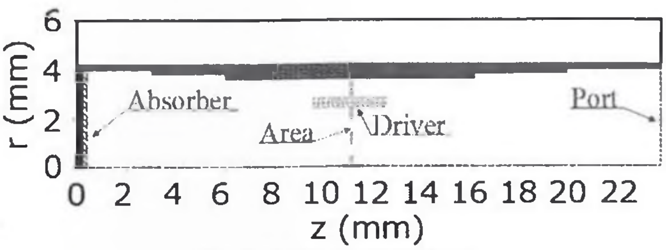


Fig.2 Boundary condition

### 3.3 COLD TEST

Cold test was carried out to specify the resonant frequency in the cavity. It enables to confirm the oscillation of the electromagnetic wave which has a peculiar resonant mode. In the cavity, it was specified by inputting the electromagnetic wave of single pulse in the cavity and analyzing remaining noise.

### 3.4 HOT TEST

Hot test was carried out to specify the oscillation frequency and the RF output power in the interaction cavity. The helical moving electron beam is incident in the cavity. The electron beam and the electromagnetic wave cause an interaction.Thus, electromagnetic wave is oscillated. And, they are measured in Port (Fig.2).

## 4 SIMULATION RESULT AND DISCUSSION

### 4.1 COLD TEST RESULT

The electric field component of the electromagnetic wave was measured in Area (Fig.2). Figure 3 show the frequency spectrum
of the electromagnetic wave of $TE_{15,2}$ mode. The frequency spectrum was computed by FFT (Fast-Fourier Transformation) of the measured electric field shape. In cold test results of $TE_{15,2}$ mode, the resonant frequency of 292.80GHz was confirmed among a multitude of the frequencies.

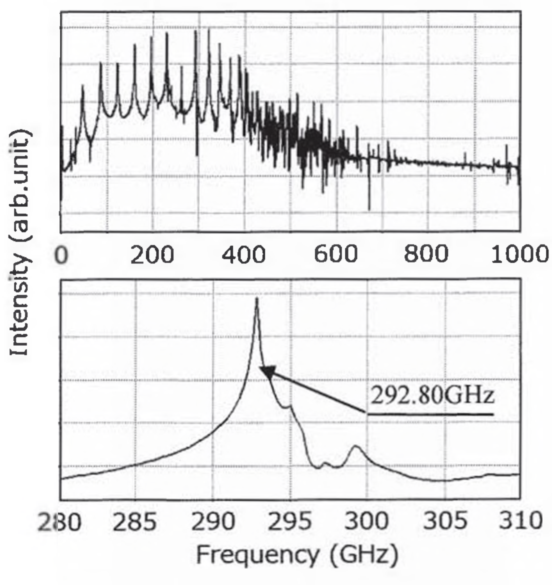
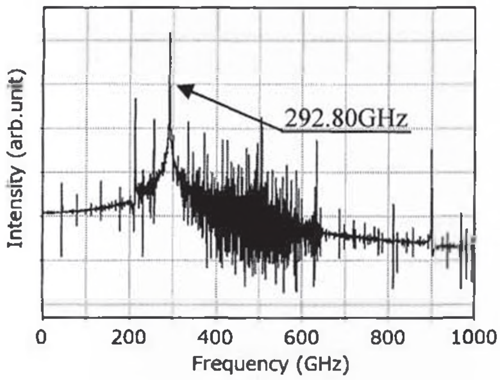


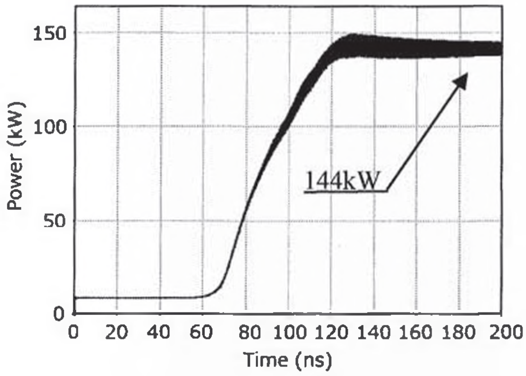
Fig.3 Frequency spectrum of $TE_{15,2}$ mode in the interaction cavity

### 4.2 HOT TEST RESULT

Figure 4 shows the frequency spectrum and the RF output power of the electromagnetic wave of $TE_{15,2}$ mode. The simulation results show the output power of 144kW, operating frequency of 292.80GHz and interaction efficiency of 22.15%.




(a)Frequency spectrum




(b)RF output power

Fig.4 Hot test result of $TE_{15,2}$ mode

## 6 CONCLUSION

High power sub-terahertz pulsed gyrotrons for CTS diagnostics of fusion plasmas are being developed. In order to support experimental development, the numerical simulations of high power sub-terahertz pulsed gyrotron for CTS was carried out by using three dimensional particle-in-cell (PIC) code, "MAGIC". The cold test and the hot test were carried out. In the cold test, the resonant frequency was 292.8GHz in the cavity. The oscillation of $TE_{15,2}$ mode was confirmed. In the hot test, when the beam voltage, beam current and the external magnetic field was 65kV, 10A and 11.45T respectively, the RF output power and the interaction efficiency was each 144kW and 22.15%. Also, the oscillation frequency is 292.8GHz.

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