Feasibility Study of Collective Thomson Scattering in LHD Plasma Using a 400 GHz Frequency Gyrotron

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***Abstract*— Feasibility of collective Thomson scattering (CTS) is examined for LHD high density plasmas. A 400 GHz gyrotron is used as a probe source. Calculations of ray trace through high density plasma and scattering power spectra are carried out. Necessary specifications of the gyrotron for LHD-CTS is estimated.**

I. Introduction And Background

HIGH density plasma with more than 10^{20} m^{-3} has been produced in a large helical devise (LHD). Collective Thomson scattering (CTS) is one of strong diagnostics of ion temperature for high-density fusion plasmas. To date, CTS has not been fully utilized because of the difficulties in achieving sufficient signal-to-noise ratios and appropriate scattering angles. To overcome these conditions, use of a low-frequency wave is favorable. However, a lower limit of frequency is set because of wave refraction in the high-density plasmas, wave reflection due to upper hybrid cut-off and background noise due to electron cyclotron emission. From the points of view, frequency higher than, at least, 300 GHz is appropriate for the CTS probe beam in LHD. In university of Fukui, high-frequency gyrotrons have been developed [1]. One of them, a 400 GHz high-power pulse gyrotron is now being developed [2, 3]. Feasibility of the CTS measurement in LHD by using the 400 GHz Fukui-gyrotron is examined, based on ray tracing and scattering spectra calculations.

II. Results

As a target of CTS, high density plasma with the density 10^{20} m^{-3} and temperature 1 keV is chosen. Two available ports on the LHD vacuum vessel are chosen for injection and receiving antennas. For the present configuration, scattering angle θ_s is 104 degrees, which is large enough to obtain high spatial resolution. In Fig.1, fundamental and higher harmonic electron cyclotron frequencies (f_{ce}, $2f_{ce}$ ..), upper-hybrid one (f_{uh}) and plasma frequency (f_{pe}) are plotted along (a) the incident beam and (b) the beam scattered at the magnetic axis. R is the coordinate along the beams and R = 0 indicates the position of magnetic axis on each beam. Incident beam power is absorbed around cyclotron resonance points where wave frequency f agrees with fundamental or harmonic cyclotron frequencies ($f = nf_{ce}$). For scattered wave, strong cyclotron emission is superposed from around $f = nf_{ce}$. Since the absorption is weaker for higher harmonics with large n, it is preferable that the beam crosses only resonance points with $n > 3$. Then, the frequency

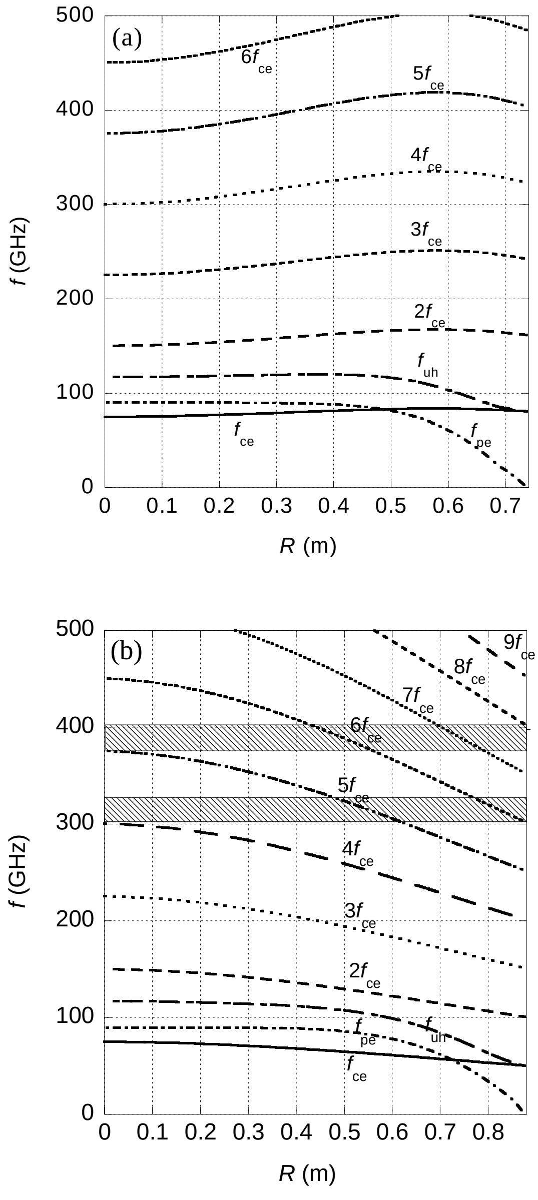

Figure 1*:* Cyclotron, upper-hybrid and plasma frequencies are plotted along (a) the incident wave and (b) a scattering wave. The hatched regions indicate frequency candidates for LHD-CTS.

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more than 300 GHz must be taken. To avoid cyclotron emission along scattering beam lines, the windows of frequency exist around 300 and 400 GHz. Thus, 300 or 400 GHz is frequency candidates as the LHD-CTS probe beam.

The beam radius is calculated assuming a Gaussian beam. Figure 2 indicates the beam radius relation between incident and scattering points. When beam radius is converged as w_0 = 1 cm at the scattering point, the incident radius w_{i} is 5 cm for 400 GHz. This value is not so large that the antenna size is reasonable to be installed.

Ray tracing calculations are carried out. A result is shown in Fig. 3. An incident probe wave with frequency of 400 GHz propagates through the high density plasma and reaches the center of plasma without refraction and reflection. Microwave of 300 GHz also almost straightly propagates. However, the wave with 168 GHz, which is the highest frequency among existing NIFS gyrotrons for electron heating, does not straightly propagate, and it is reflected due to upper-hybrid cut-off for X-mode injection in the high density plasma.

Scattering power spectra [4] observed at the receiving antenna are evaluated as

$$P_{\mathrm{s}} = P_{\mathrm{in}} N_{\mathrm{e}} r_{\mathrm{e}}^2 \Gamma S \Delta f \frac{\lambda_{\mathrm{i}}^2}{\sqrt{\pi} w_0 \sin\theta_{\mathrm{s}}}$$

where P_{in} is the gyrotron power, N_{e} is the density, r_{e} is the classical electron radius, Γ is the geometrical factor [5] and S is the spectral density function[4]. An example of power spectra is shown in Fig. 4, where P_{in} = 100 kW and w_0 = 1 cm are assumed. Solid and dashed lines indicate the scattering power spectra stemming from the motion of electrons collective with ions and the thermal motion of electrons, respectively. Thus, collective scattering is dominant and it can give us ion information through the CTS measurement. The calculated power per unit band frequency is about 1eV. For this value, a signal to noise ratio of 3 is expected, which is large enough to determine the ion temperature. Thus, 400 GHz, 100 kW gyrotron is one of favorable candidates of power source for LHD-CTS.

III. SUMMARY

Feasibility study was carried out for applying the Fukui 400 GHz to probe beam of CTS measurement for LHD high density plasma. It shows that 400GHz, 100 kW gyrotron is proper to obtain ion information through CTS measurements.

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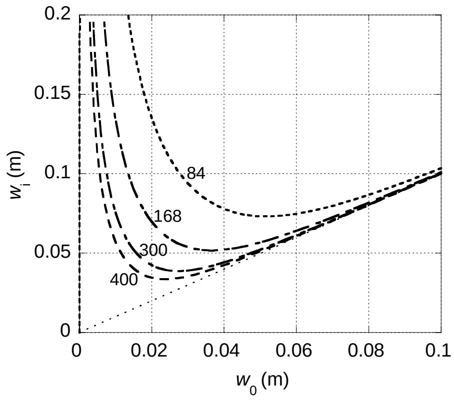

Figure 2: Relations between incident radius (w_{i}) and scattering radius (w_0) for incident beam with some different frequencies. Attached numbers represent wave frequencies (GHz).

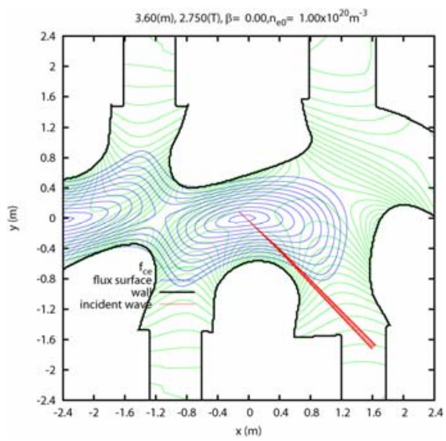

Figure 3: Calculation of ray tracing in LHD. Maximum density is 10^{20} m^{-3} and ray frequency is 400 GHz.

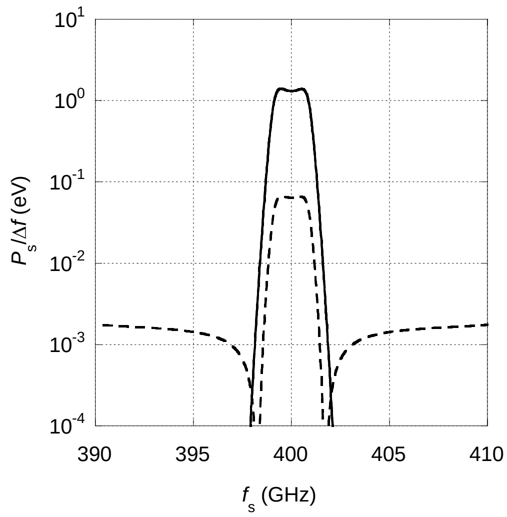

Figure 4: Scattering power spectrum in unit band frequency. Solid and dashed lines indicate the scattering power spectra stemming from the motion of electrons collective with ions and the thermal motion of electrons respectively.

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