§12. Measurement of Fast Ion Velocity Distribution Function by Collective Thomson Scattering Diagnostic in the Large Helical Device

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Fast ion confinement is major concern in fusion plasmas as well as bulk ion one. One of possible methods for diagnosing confined bulk and fast ions is to use a collective Thomson scattering (CTS) technique with a millimeter wave and mega-watt power. As other options, the fuel ratio of D/H, the ion temperature, and the flow velocity have also reported in TEXTOR and ASDEX-Upgrade using this method. We have recently reported major progresses on the data analysis[1)] of the CTS diagnostic in the Large Helical Device (LHD).

In the 18th LHD experimental campaign, we have measured CTS spectrums by a broadband receiver and a high frequency resolved fast digitizer. Based on the past experience of CTS diagnostic development, hardware improvements have been carried out. The major points are listed below;

(a) The port location of the receiver beam is moved from 1.5L to 2O-L.
(b) The mirror control system for 2O-L is upgraded.
(c) 154GHz receiver system has been developed.

The aim of item (a) is to extend the field of view for receiver beam with simpler geometry (resonances and cutoff layers on the beam pass in 3D geometry). It covers the wide detection area from perpendicular to parallel velocity on the velocity space.

The in-situ beam alignment is important to check the scattering volume. The item (b) enables us to scan the scattering volume during a shot.

For the fast ion diagnostic, the probe and receiver beams are positioned at $\rho \sim 0.5$. The typical CTS spectrum is shown in Fig. 1. The fluctuation vector $\boldsymbol{k}^{\delta}$ is directed to the angle with 102 degrees to the magnetic field. With this scattering geometry, the CTS spectrum is relatively sensitive to the parallel directed fast ions. Different parallel injections of NBs, which are co and counter Bt direction, can induce asymmetry of spectrum due to the difference of fast ion density of co and counter beams. In this context, the observed asymmetry in the CTS spectrum in Fig. 1 can be explained by the difference of the fast ions of NB1 (co. injected) and NB2 (counter injected). However the estimated fast ion density is higher than 1% of the bulk ion density. This is likely to be an over estimated value. The bulk ion temperature from the CTS spectrum broadening in the bulk component is ~ 1 keV. The more careful analysis is needed to validate the bulk and fast ion diagnostic.

The fueling ratio of D/H is important parameter to control confined plasmas for fusion power output. When $\boldsymbol{k}^{\delta}$ is directed perpendicularly to the magnetic field, the ion Bernstein wave (IBW) is superimposed onto the CTS spectrum as ion cyclotron harmonics. Fig. 2 shows the measured CTS spectrum that satisfies $\boldsymbol{k}_{\parallel}^{\delta} \sim 0$ with the scattering volume at (R, T, Z) = (3.9, 0, 0.1). When Z = 0.2, the IBWs are not observed as the theory predicts. The harmonic waves have the frequency interval of 21-24 MHz. The observed frequency does not agree with the ion cyclotron harmonics of 40 MHz for hydrogen. The discrepancy will be studied by the parameter scan in the forthcoming campaign.

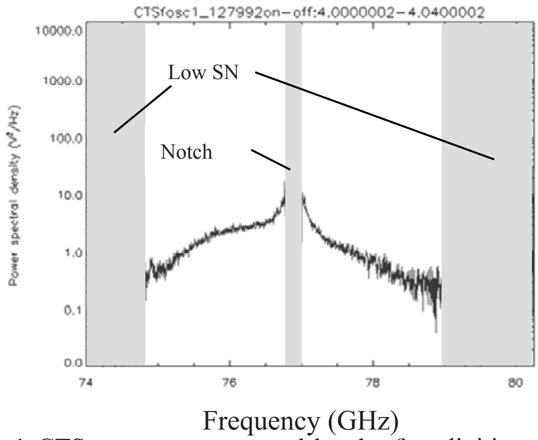

Fig. 1 CTS spectrum measured by the fast digitizer. The scattering volume is located at $\rho \sim 0.5$. The asymmetry with respect to 77GHz probe beam in the CTS spectrum is observed.

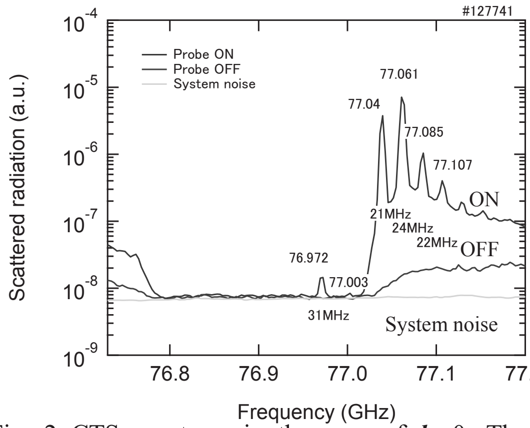

Fig. 2 CTS spectrum in the case of $\boldsymbol{k}_{\parallel}$~0. The excited harmonic waves are observed.

1) Nishiura, M., Kubo, S., Tanaka, K. *et al.* : Nucl. Fusion **54**(2014) 023006.