STUDIES OF GAMMA 10 ECRH CHARACTERISTICS FROM THE SOFT X-RAY MEASUREMENT

Hideaki IIZUMI, Ryutaro MINAMI, Tsuyoshi IMAI, Tsuyoshi KARIYA, Hitomi AOKI, Hideyuki KONDOU, Mao OTA and GAMMA 10 Group

Plasma Research Center, University of Tsukuba, Tsukuba, Ibaraki, 305-8577, Japan
Email Address: iizumi_hideaki@prc.tsukuba.ac.jp

We examined the difference of the heating characteristic by the injection condition of the ECRH from the measurement of the soft X-rays representing the electron temperature. The line integrated intensity of soft X-ray (I_sX_L) in X-mode ECRH (the best absorption) increased to 5.8 times of that without ECRH and 3.4 times in O-mode (the worst absorption). The MCP signal ratio of the different absorbers (P_e2/P_e1.5) increased from 0.43 before ECRH to 0.56 during ECRH of X-mode and from 0.47 to 0.52 in O-mode. It is confirmed the electron heating by ECRH qualitatively in both cases. However the ion stored energy decreased in O-mode ECRH. This results show that it is important to maximize the first pass RF absorption at the resonance layer on axis for the efficient electron heating and avoidance of the confinement degradation of plasma.

I. INTRODUCTION

In tandem mirror GAMMA10, the electron temperature is far lower than the ion temperature because the plasma is generated and maintained by the IC heating. It is considered that there is large energy transfer from the high temperature ions to the low temperature electrons (the electron drag), and the rise of the ion temperature is limited. It is necessary to confine the high temperature ions for a long time for the nuclear fusion achievement. It is very important to suppress the energy transfer from the high temperature ions.

For suppressing the electron drag, the electron heating is done by the Electron Cyclotron Resonance Heating (ECRH) in the central cell that is the main plasma confinement region. For that purpose, it is necessary to clarify the physical phenomena and the characteristics of ECRH in the various ECRH injection conditions and optimize ECRH for the electron heating and the confinement of plasma.

The soft X-rays (SX) are radiated with the electron information by the bremsstrahlung of EC heated electrons. It is thought that the characteristics of ECRH can be clarified from the SX measurements. Fig.1 shows the overall view of the GAMMA 10 and the positions of the ECRH and the SX detector.

II. THE SOFT X-RAY MEASUREMENT

The SX measurement is employed for investigating the effect of ECRH in the central cell. The micro channel plate (MCP) is used for the detector of the SX measurement. The MCP is composed of a lot of channels that is the secondary electron multiplier and installed at the upper side of the central cell. Fig.2 shows the pattern diagram of installed the MCP. The MCP investigate the time evolutions of the integrated SX intensity and has radial resolution of about 1.8 cm because it employs the separated MCP and the collimator.

The electron temperature could be estimated from
the ratio of the signals obtained with different absorbers in front of the MCP. Because the detected intensity is different according to the absorber, and the ratio depends on the electron temperature.\textsuperscript{1} This detected intensity of SX is the local value. But in the experiments, the obtained SX intensity is the amount of the line integration in view of detector. In this paper, because local value is not accurately evaluated, the change of electron temperature is evaluated qualitatively by the ratio of the integrated SX intensity (Pe\textsuperscript{2}/Pe\textsuperscript{1.5}) obtained with different absorbers. The used absorber is Py\textsuperscript{0.72}µm + Pe\textsuperscript{1.5}µm (Pe\textsuperscript{1.5}) and Py\textsuperscript{0.72}µm + Pe\textsuperscript{2.0}µm (Pe\textsuperscript{2}).

III.EXPERIMENTAL RESULTS

As expected from the ECRH scheme in GAMMA 10, the best absorption in plasma was obtained in X-mode polarization and hence the ECRH is oblique injection from the strong magnetic field. We compare it with O-mode that absorption at the resonance layer on axis is considered to be worst. The injected ECRH polarization is controlled by the polarizers.\textsuperscript{2} The ECRH is injected into plasma from 160ms to 180ms in these experiments. Fig.3 shows the time evolutions of the diamagnetism (DM) and the line integrated SX intensity (IsxL) in X-mode. Similarly, Fig.4 shows it in O-mode. We compare the results in 170ms (during ECRH) and the results in 158ms (before ECRH). The IsxL in X-mode ECRH increased to 5.8 times of that without ECRH and 3.4 times in O-mode. The MCP signal ratio of the different absorbers (Pe\textsuperscript{2}/Pe\textsuperscript{1.5}) increased from 0.43 before ECRH to 0.56 during ECRH of X-mode and from 0.47 to 0.52 in O-mode. As this signal ratio (Pe\textsuperscript{2}/Pe\textsuperscript{1.5}) relates the electron temperature, it is thought that the electron is heated in both cases. In X-mode, the electron heating is more efficient than O-mode.

However, in O-mode, the DM that is proportional to the ion stored energy decreased to 0.78 times of that without ECRH. Theoretically, the electron drag should decrease since the electron temperature increases during ECRH, which should increase in the ion stored energy. But, the ion stored energy decreased in O-mode.

We also found interesting results on the radial dis-
The radial distribution of the $I_{\text{ssL}}$ during the ECRH in Pe1.5 absorber. In X-mode, axisymmetric distributions are observed with both absorbers. However, off-axis distributions shifted to south are observed with both absorbers in O-mode. In other words, it can be considered that the heating is non-axisymmetric in O-mode. There is a possibility of the electrical potential distribution is non-axisymmetric. As a result, it can be considered that the ion loss increased due to the neoclassical diffusion, and DM decreased. As another possibility why DM decreases is considered out gas from the limiter due to the plasma contacts with the limiter which enhances the CX loss.

### IV. SUMMARY

In this study, the electron heating by ECRH in the various conditions has been confirmed by the SX measurement. The $I_{\text{ssL}}$ in X-mode ECRH (the best absorption) increased to 5.8 times of that without ECRH and 3.4 times in O-mode (the worst absorption). The MCP signal ratio of the different absorbers (Pe2/Pe1.5) increased from 0.43 before ECRH to 0.56 during ECRH of X-mode and from 0.47 to 0.52 in O-mode. It is found the electron heating by ECRH qualitatively in both cases. However the ion stored energy decreased in O-mode ECRH. This indicates that when the absorption at the resonance layer on axis is lower, the confinement of ions deteriorates. As a conclusion, it is important to maximize the first pass RF absorption at the resonance layer on axis for the efficient electron heating and avoidance of the confinement degradation of plasma.

We are going to measure the SX from the multiple angles to obtain more position information in the next campaign. We also plan to obtain the electron temperature and the electron velocity distribution by SX, and compare with Thomson $T_e$ to clarify the characteristics of ECRH.

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### References
