19PB-103

Hard X-ray Measurement on the TST-2 Spherical Tokamak Plasma Driven by Lower Hybrid Wave Power

低域混成波で駆動されたTST-2球状トカマクの硬X線計測

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Hard X-ray measurements are a method of estimating the fast electrons in RF plasmas. The measurements in the TST-2 spherical tokamak were performed for discharges with the injection of lower hybrid wave.There are two types of antenna for the RF injection; a grill antenna and a capacitively coupled combine antenna. Hard X-rays of the current driving direction (Co direction) and the anti-current drive direction (Ctr direction) were measured at the same time. It was found that the Co direction energy flux of hard X-rays is 10 times higher than the Ctr direction energy flux.

1. Introduction

The capability of plasma current start-up and ramp-up using lower hybrid wave in spherical tokamak (ST) has been investigated. Even in STs, lower hybrid wave (LHW) can be used for the plasma start-up phase if the plasma density is kept sufficiently low. Hard X-ray (HXR) measurements revealed that the fast electrons produced through the Landau damping of the LHW were responsible for the current drive [1].

Bremsstrahlung is emitted by electrons in the plasma, and HXRs imply the presence of fast electrons. Assuming that the fast electrons have a Maxwell distribution, it is possible to estimate the effective temperature of the fast electrons from the energy spectrum of HXR. X-ray measurements during LHW injection by using the grill antenna have been performed in the TST-2 [2]. Currently, X-ray is measured by using a capacitively coupled combine antenna (CCCA) [3]. Fast electrons exist to the Co direction, therefore It is examined that it is responsible for the current.

2. Measurement system

NaI scintillators and photomultiplier tubes (PMTs) are used for the HXR measurement. When a HXR enters the NaI scintillator, it emits visible light, and the number of photons is proportional to the HXR energy. In the PMT the visible light is converted to photo electrons and they are multiplied in the PMT. There are two same systems, they measure HXR of plasma center ($R_{tan} = 410$ mm) to Co and Ctr direction respectively.

The PMT and the NaI scintillator are covered by lead blocks and a lead collimator is placed in front of the scintillator. It is used to specify the direction of X-rays. Angular resolution of the lead collimator is Gaussian of $\sigma = 1.5°$. Therefore, solid angle is 3.516×10^{-4} sr. Here ^{57}Co (122 keV) is used as the source. Both measurement and simulation results are generally consistent (Fig.1.).

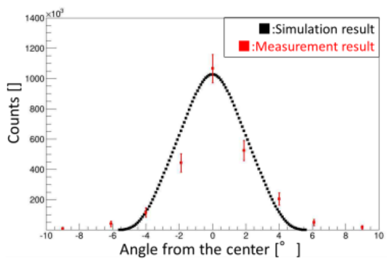

Fig.1. Angular resolution.

3. Measurement result

3.1 *Measurements of Co and Ctr directed HXRs*

Measurements of Co and Ctr directed HXRs were performed for the plasma with LHW injection. Maximum plasma current was 14 kA, and LHW power was 20 kW between 10 ms and 100ms.

Spectra of the energy flux are shown in Fig.2. Here, the data from 10 discharges with

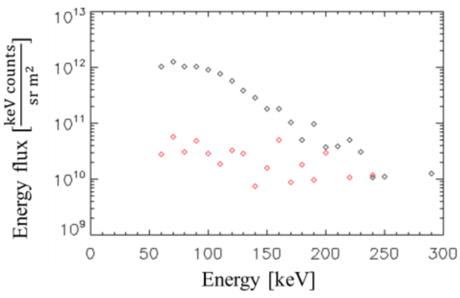

Fig.2. Spectra of the HXR energy flux for Co direction (black) and Ctr direction (red) for the case of CCCA.

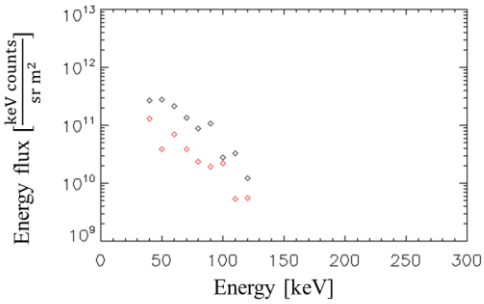

Fig.3. Spectra of the HXR energy flux for Co direction (black) and Ctr direction (red) by for the case of grill antenna.

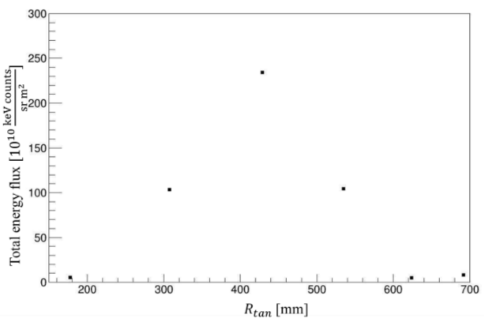

Fig.4. Radial total X-ray flux profile

high-reproducibility were accumulated. Energy flux is corrected by using the transmittance of glass, solid angle and the light receiving area. Energy flux spectrum shows an exponential distribution. Total energy flux for the Co direction is $8.080 \times 10^{12}\ \frac{\text{keV counts}}{\text{sr m}^2}$ that for Ctr direction is $4.354 \times 10^{11}\ \frac{\text{keV counts}}{\text{sr m}^2}$.

Similar measurements have been performed for LHW injection using a grill antenna (Fig. 3.). Waveforms of the plasmas were similar to the plasmas where CCCA was used, but the maximum plasma current for the grill antenna case was slightly lower (12 kA). . Total energy flux for the Co direction is $1.155 \times 10^{12}\ \frac{\text{keV counts}}{\text{sr m}^2}$ that for Ctr direction is $3.559 \times 10^{11}\ \frac{\text{keV counts}}{\text{sr m}^2}$.

The effective temperatures for the cases of the CCCA and the grill antenna were xx keV and yy keV, respetively. The total energy flux for the Co direction is 10 times higher than that for the Ctr direction for the case of the CCCA. The total energy flux for the Co direction is 3 times higher than that for the Ctr direction for the case of the grill antenna. Therefore, fast electrons with the Co direction by using CCCA were more dominant by using grill antenna. Bremsstrahlung is emitted Ctr direction from the fast electrons to the Co direction by relativistic effects. Therefore, fast electrons exist to the Co direction of much more than Ctr direction by using CCCA.

3.2 *Radial profile measurement of HXR*

HXR was measured for the six chord directions ($R_{tan} = 178, 308, 429, 535, 624, 692\ m$). The energy integrated HXR flux is shown in Fig.4. 5×6 as a function of the chord tangency radius. Here, the data from 30 discharges with high-reproducibility were accumulated. Assuming that the HXR emission has the toroidal symmetry the profile can be transformed to the emission profile by using Abelian conversion. The HXR emission at the outborad side ($R_{tan} = 624, 692\ mm$) is low. Because there is limiter at $R_{tan} = 585\ mm$. HXR emission near the plasma center ($R_{tan} = 429\ mm$) is high. Therefore, electrons are accelerated by LHW near the plasma center. Fast electrons exist to the Co direction, and

4. Summary

HXR measurements of LHW injected plasma has been performed. Fast electrons with the Co direction by using CCCA were more dominant by using grill antenna. Radial emission profile indicates that the fast electrons are concentrated near the plasma center.

Acknowledgments

This work is supported by Grants-in-Aid for Scientific Research (S) (21226021) of JSPS, Japan, The Second A3 Foresight Workshop on Spherical Torus, and by NIFS Collaborative Research Program NIFS14KOCR001.

References

[1] S. Bernabei, et al., Phys. Rev. Letters **47**, 1255 (1982)

[2] T. Wakatsuki, et al., Nucl. Fusion **54**, 093014 (2014)

[3] Y. Takase, et al., Nucl. Fusion **53**, 063006 (2013)