*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.125 (2006)*

Current profile estimation using Hard X-ray measurement along the top and bottom identical line of sight on TRIAM-1M

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A new technique to measure the current profile in lower hybrid current drive (LHCD) plasmas by using hard X-ray (HXR) energy spectrum measurement along the top and bottom identical line of sight (ILOS) is proposed. An angle between ILOS and the magnetic filed line is out of alignment from the perpendicular by the poloidal magnetic field. As the emission cross-section of HXR strongly depends on the angle to the drift direction of energetic electrons, that is the magnetic filed line, this disagreement of the angles makes significant difference between the signals of detectors located on the top and bottom. As the result, the poloidal magnetic field is able to be derived from the difference of the HXR emission along the top and bottom ILOS. The method was applied to the full LHCD plasmas on the TRIMA-1M tokamak and the plasma current around the magnetic axis was estimated.

Introduction

Current profile measurement in tokamaks is so important to understand plasma confinement as well as equilibrium [1-2]. The discovery of current hole in tokamaks is ascribed to be able to measure the reliable current profile [3]. The most popular way to measure the current profile by using MSE (Motional Stark Effect) has been developed. High power NBI (Neutral Beam Injection) and sophisticate detection of polarized light emitted from the atomic process are required to execute the way. Especially the high power NBI is crucial for the measurement. On TRIAM-1M, full non-inductive LHCD can be obtained. As no NBI are installed, the current profile in LHCD plasma does not have been obtained. Recently an internal transport barrier (ITB) is observed on TRIAM-1M [4]. As the current profile measurement is required to understand the physical mechanism of ITB, the current profile measurement in LHCD plasma is required.

The way to measure the current profile

A schematic view of the configuration to measure the current profile is shown in Fig. 1. As for the LHCD, the asymmetry of energetic electron distribution function makes plasma current. The HXR radiation along the top and bottom ILOS is the same, when poloidal magnetic field is zero, because the ILOS of the detectors is completely perpendicular to the toroidal magnetic filed. When the poloidal magnetic field is present, the angle between the ILOS and magnetic filed line is not perpendicular except the magnetic axis. The directions of the plasma current, the toroidal magnetic field, and the drift of energetic electron on TRIAM-1M are shown in Fig. 1.

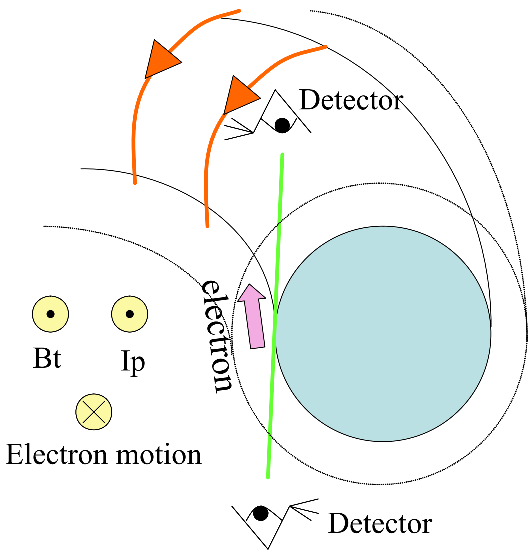

Fig. 1 Principle to measure a current profile in LHCD plasmas by using up-down asymmetry of HXR emission is illustrated.

The ILOS for the detector located at the inner top side in major radius from the magnetic axis leans to the coming drift direction of electrons. While the ILOS for the inner bottom side leans to the outgoing drift direction. In the case of the detectors located at the outer side, the situation is inverted. The emission crosssection of HXR strongly depends on the angle to the magnetic field [5], and the asymmetry of the electron distribution along the drift direction exists in the LHCD plasmas. As the results, the HXR radiation measured with the detectors located on the top side is distinct from that with ones located on the bottom side by the leaning of magnetic filed due to the poloidal field. Although the HXR emission significantly affects plasma density, Z_{eff}, and so on, these effects are well-cancelled by the division process of these top-bottom pair signals. Thus we can be estimated the magnetic pitch angle by using the HXR measurement.

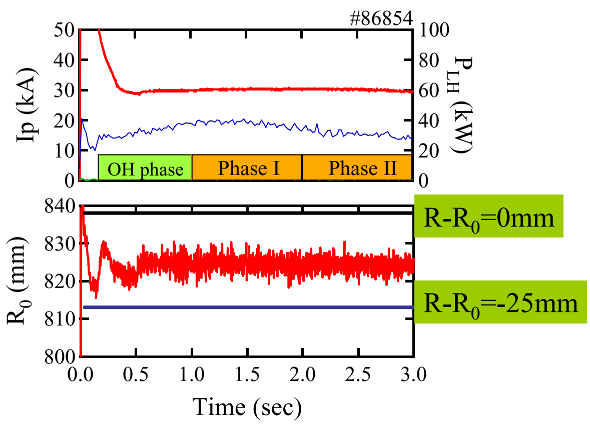

Fig. 2 Typical waveforms to measure the current profile are shown. Top figure shows the plasma current and the injected power. Oh phase corresponds to 0.2-1.0sec. Bottom figure shows the position of the current centre, R_0. The line of sight of detectors located on the positions in the bottom figure each other.

Experimental apparatus and results

The measurements were carried out in full non-inductive LHCD plasma on TRIAM-1M, where the two HXR detector systems were installed. One is a 7ch NaI scintillators detector array covered by lead to shield suborbital HXR, which is installed on the bottom side of TRIAM-1M and is able to move along the major radius shot by shot. Another is installed on the top side, which is an 1ch NaI scintillators detector moving along the major radius.

The observations were executed in LHCD plasma at $R\text{-}R_0=\pm 12.5$cm, where R_0 (=0.84m) shows the position of the centre of the plasma as shown in Fig. 2. Two detectors were set on the ILOS and were calibrated by a radio isotope. The final calibration was carried out by using the HXR emission from LHCD plasmas, based on a consideration that the signals from these detectors should be equated, when these two detectors set on the ILOS passing through the magnetic axis. Time trace of the ratios of these two detectors during full LHCD discharge is plotted in Fig. 3.

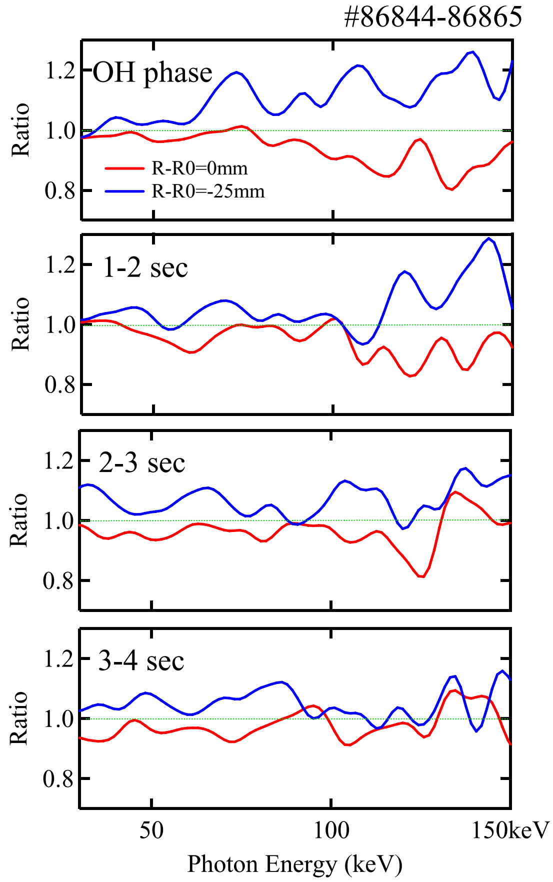

Fig. 3 Time trace of the ratio of HXR signal from the top detector to that from bottom one in the range of 40-150keV is plotted. Red line shows the ration at $R\text{-}R_0$=0mm and blue line shows that at $R\text{-}R_0$=-25mm, where the centre of the plasma is controlled at $R\text{-}R_0$=-12.5mm.

Each observed HXR energy spectrum was applied to a smoothing way. The clear difference was observed in the ohmic heating (OH) phase and it seems to be smaller with time. This suggests that the current profile becomes broad with time. This is no contradicts to a predicted current profile in LHCD plasmas. To estimate the current density quantitatively, a distribution function of energetic electrons should be assumed. We adopt the three temperature models [6] ($T_{//}$=100keV, T_P=50keV, T_B=50keV, f_{FB}=0.2, where $T_{//}$, T_P, T_B, and

f_{FB} show the temperature of the forward, perpendicular, backward directions, and the number ratio of backward-drifting electrons to forward-drifting ones, respectively. The calculation result is shown in Fig. 4. From this figure, the current including in r=12.5mm (a=110mm) corresponds to 15kA, which is the half of the total current. In this case, the predicted current profile is $j(r) = j0\left(1-(r/a)^2\right)^5$. This peaked profile eliminates with time and finally the current in the range of $|R - R_0| = 12.5mm$ becomes to be smaller than 4kA. This absolute value affects on the assumption of the electron distribution function and we may also estimate a distribution function by using these signals. It is a future work.

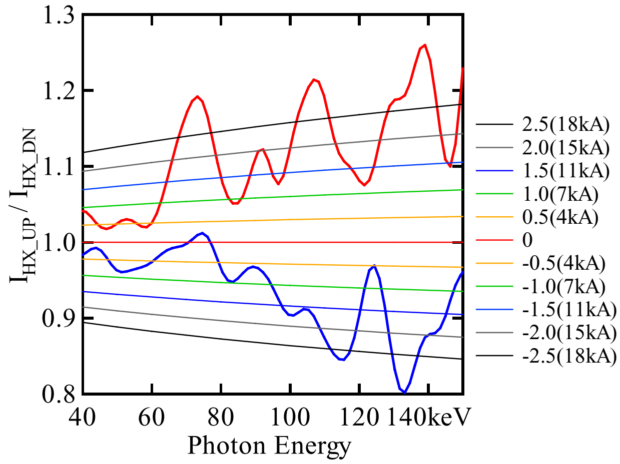

Fig. 4 The calculated up-down asymmetry of HXR based on the assumed distribution function in various current densities is plotted as the function of the photon energy with the experimental data in the OH phase.

Acknowledgment

This work was partially performed under the framework of joint-use research at RIAM Kyushu University and the bi-directional collaboration organized by NIFS. This work is partially supported by a Grant-in-Aid for Scientific Research from Ministry of Education, Science and Culture of Japan.

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