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Computed Tomography of Soft-Xray on a Reversed-Field Pinch Device, TPE-RX

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1. Introduction Computed tomography (CT) analysis of soft X-ray (SXR) emission on a reversed-field pinch (RFP) device, TPE-RX (R/a = 1.72/0.45 m), is presented. Two arrays of a silicon surface barrier detector (SBD) have been installed on TPE-RX. This system has been used under several operation conditions. We report these experimental results. TPE-RX is one of the largest Reversed Field Pinch (RFP) devices, with a major radius, R, of 1.71 m and a minor radius, a, of 0.45 m. The RFP device can confine hot plasma in a relatively low applied external magnetic field. The toroidal magnetic field at the plasma edge is in the opposite direction to the toroidal magnetic field at the plasma core. The main component of the magnetic field at the plasma edge is that in the poloidal direction, and the toroidal magnetic field is sgnificantly smaller than the poloidal magnetic field. The ratio of the poloidal magnetic field at the plasma edge to the surface-averaged toroidal field is defined as a pinch parameter: $\Theta \equiv B_p(a)/\langle B_t \rangle$. Here, B_p is the poloidal magnetic field, B_t is the toroidal magnetic field, and $\langle\ \rangle$ indicates averaging over the plasma surface. The ratio of the toroidal magnetic field at the plasma edge, $B_t(a)$ to $\langle B_t \rangle$, is defined as a reversal parameter, $F \equiv B_t(a)/\langle B_t \rangle$. In the standard discharge of TPE-RX, Θ is approximately 1.5 and F is approximately -0.10. Almost all of the confining magnetic field is generated by the plasma current itself. The configuration of the RFP plasma is sustained by the dynamo effect due to magnetic fluctuation. However, this magnetic fluctuation affects the plasma confinement. SXR emission from the plasma depends mainly on the plasma electron density and the electron temperature. Hot-core structures connected with the magnetic fluctuation have been observed in RFP devices. [1,2] The quasi-single-helical (QSH) state, in which one mode of the tearing mode grows and the mode spectrum has a narrow peak, is sometimes observed. The hot core structure becomes bean shaped, similar to the magnetic island structure of the QSH state. In TPE-RX, the SXR-CT system was installed in 2003, and SXR emission has been observed using this system. Hot core structures connected with the magnetic fluctuation have also been observed. In the standard discharge of the TPE-RX, the toroidal mode spectrum of the magnetic fluctuation spreads in a wide range. A circular hot core is observed under standard discharge conditions. A bean-shaped hot core is also observed when the single tearing mode grows. In this case, the toroidal mode spectrum of the magnetic fluctuation has a narrow peak. The fluctuation in SBD signals corresponding to the MHD dynamics is also observed, and the results are presented in this paper. The SXR-CT system and the magnetic measurement systems are presented in section 2, and the experimental conditions and results are presented in section 3. The discussions are presented in section 4.

2. SBD array and magnetic measurement system We installed two arrays of SBD in the same toroidal section as the detectors for the SXR emissions (Fig. 1). One of the SBD arrays consists of twelve SBDs. These SBDs are installed at the vertical ports, and the observation lines are vertical lines as shown by the green lines in Fig. 1. The other SBD array is a fan-shaped array as shown by the red lines in Fig. 1, and consists of eleven SBDs. This array is installed at the horizontal port that is on the outer board side. The Fourier-Bessel model is used for tomographic inversion of SXR emissions. The number of expansions is limited to m=1 & l=6 or m=2 & l=3 for this SXR imaging system, by the number of SBDs. Two of the magnetic measurement system [3] are also used for the measurement of the magnetic fluctuations, for the study of the correlation between SXR emission and the MHD phenomenon. One consists of sixteen flux-loop coils installed around a vacuum vessel. These coils give the m=0 mode of toroidal magnetic fluctuations, and allow a toroidal mode number as high as n=8. The second one consists of sixty-four pick up coils installed at the inner and the outer board sides of the horizontal plane. These coils give the m=1 mode of toroidal magnetic fluctuations, and allow a toroidal mode number as high as n=16.

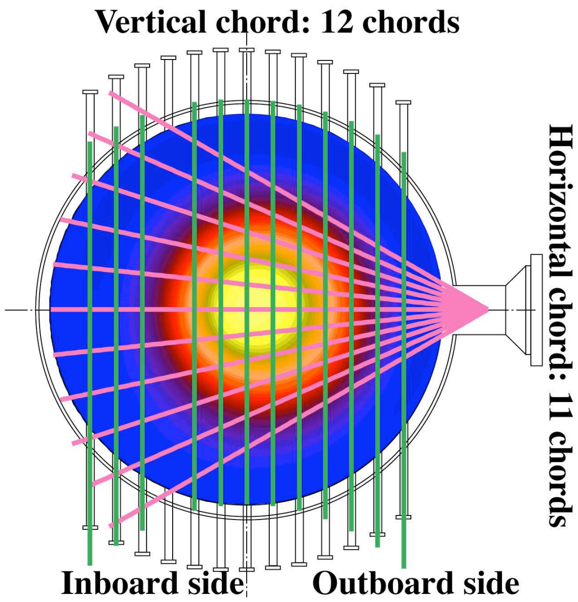

Figure 1. Experimental set up of SBD-CT system. Vertical array consists of twelve SBDs and horizontal array consists of eleven SBDs.

3. Experimental conditions and results Fig. 2 shows the temporal behaviors of the typical experimental parameters. Plasma current and Θ at the flat top phase are about 200kA and about 1.6, respectively, as shown in Fig. 2(a). Fig. 2(b) shows the F and SBD signal at the center chord of the vertical array. F at the flat top phase is about -0.2 in this case. Fluctuations exist in the F and SBD signals. We discuss these fluctuations in the next section.

Fig. 3 shows typical brightness profiles obtained by the SXR measurement system at t=31.7 ms; Fig. 3(a) shows the brightness profiles observed by the vertical array and Fig. 3(b) shows the brightness profiles observed by the horizontal array. The black lines and symbols in Fig. 3 are the normalized experimental results. Before the tomographic inversion, the experimental data are interpolated and extrapolated using a spline function, and these brightness profiles are normalized by the radial integrated value. The blue lines and symbols show the brightness after tomographic inversion. The number of expansions is m=1 & l=3 for this case. The tomographic image of the emissivity is shown in Fig. 1(a), and a circular hot core is observed. The toroidal mode spectrum of the m=1 magnetic fluctuation spreads in a wide range in this case. When one toroidal mode of the m=1 magnetic fluctuation grows as shown in Fig. 4(a), a bean-shaped hot core is also observed (Fig. 4(b)). It is predicted that a closed magnetic surface can be obtained in such a QSH state. [4]

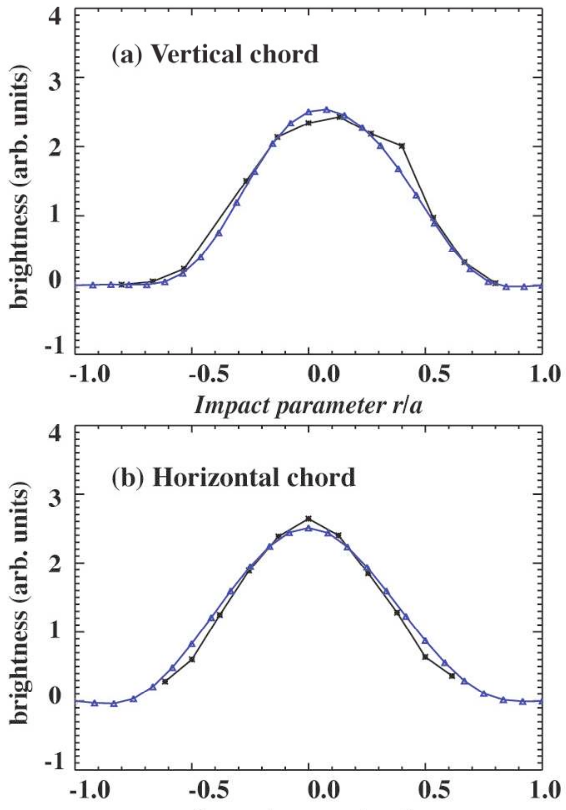

Figure 3. Brightness profiles of vertical chord (a) and horizontal chord (b). Black lines and symbols show the experimental results and blue lines and symbols show the brightness after tomographic invertion.

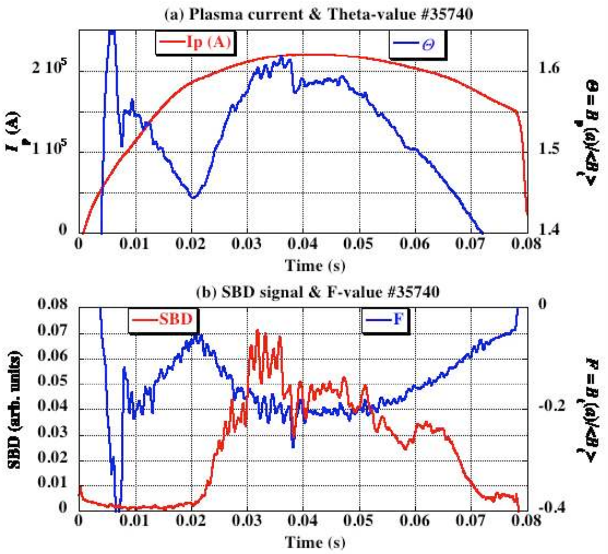

Figure 2. (a): Typical waveforms of the plasma curent (red) and of pinch parameter Θ (blue). (b): SBD signal at the center chord of vertical array (red) and reversal parameter F (blue).

4. Discussions The emissivity profiles corresponding to the m=1 mode of the magnetic fluctuation are obtained by the SXR-CT system. The fluctuation of SBD signals is also observed as shown in Fig. 2(b). A band-pass filter in which the frequency range is from 200 Hz to 10 kHz is used for the SBD signals and the m=0 magnetic fluctuations in order to neglect the slow component. Fig. 5(a) shows the SBD signal observed at the center chord and Fig. 5(b) shows the RMS of the m=0 magnetic fluctuation. When the RMS of the m=0 magnetic fluctuation increases, the SBD signal decreases. The SBD signal is well correlated with the RMS of the m=0 magnetic fluctuation, and this correlation is negative. Fig. 5(c) shows the RMS of the m=1 magnetic fluctuation which is small before t=35 ms, but the fluctuation level of the SBD signal is large. It is observed that there is no correlation between the fluctuation of the SBD signal and the m=1 magnetic fluctuation. The emissivity profile obtained by the CT is well correlated with the m=1 magnetic fluctuation. The fluctuation of the SBD signal is not correlated with the m=1 magnetic fluctuation, but with the m=0 magnetic fluctuation.

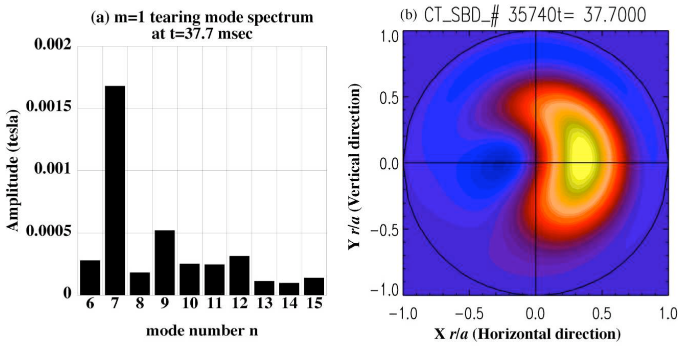

Figure 4. (a): Mode spectrum of m=1 toroidal magnetic fluctuation. The spectrum has a narrow peak at n=7. (b): Bean shaped hot core.

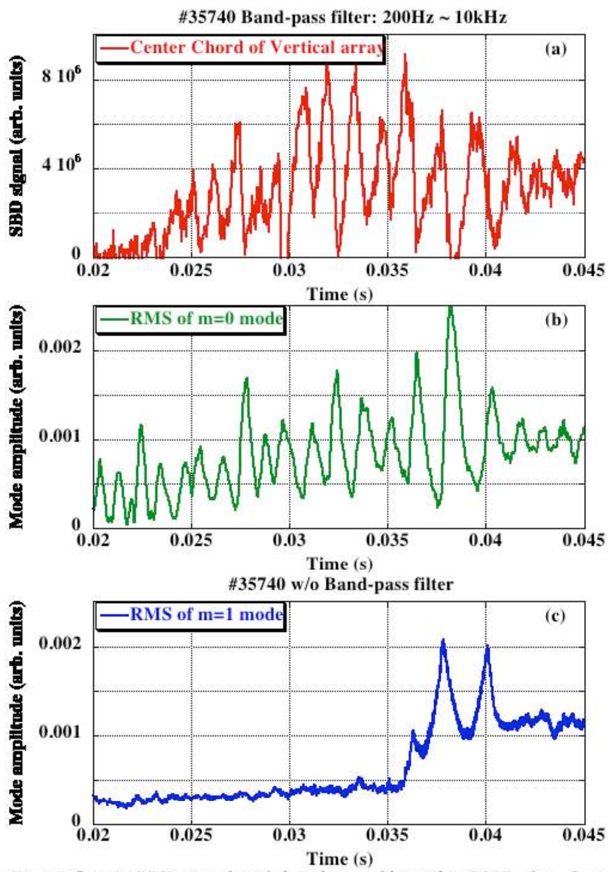

Figure 5. (a): SBD signal with band-pass filter. (b): RMS of m=0 magnetic fluctuation with band-pass filter. (c): RMS of m=1 magnetic fluctuation

5. Summary A SBD-CT system has been installed on TPE-RX, and SBD signals have been observed under several experimental conditions. The emissivity profiles of the SXR corresponding to the m=1 magnetic fluctuations have also been observed using the SBD-CT system. It is considered that the fluctuation in the SBD signal is correlated with the m=0 magnetic fluctuation.

References [1] P.Franz *et al.*, Soft X ray tomographic imaging in the RFX reversed field pinch, Nuclear Fusion **41**, 695 (2001) [2] L.Marrelli *et al.*, Quasi-single helicity spectra in the Madison Symmetric Torus, Physics of Plasmas **9**, 2868 (2002) [3] Y. Yagi et al., Fusion Eng. Des. **46**, (1999) 47. [4] H. Koguchi, Y. Maejima, Y. Hirano, Y. Yagi, T. Shimada, H. Sakakita and S. Sekine, Journal of the Physical Society **69** (2000) No. 8, August, 2375.