§11. Physics Study on 3-D Helical Equilibrium Plasmas with 2-D Imaging Diagnostics

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The measurement of bremsstrahlung soft X-ray (SXR) radiation is one of the useful passive methods for diagnosing high-temperature plasmas, because contours of the SXR emissivity correspond to magnetic surfaces of the plasmas. SXR imaging has been applied to high-temperature toroidal plasma experiments for the study of pressure fluctuations either in the core or at the periphery[1]. The reversed field pinch (RFP) is a high-temperature and high-beta toroidal plasma. In the RFP, studies on the behavior of magnetic islands due to the tearing modes are quite important, because the RFP configuration is self-organized and sustained by nonlinear interaction of the tearing modes, which lead to magnetic chaos. One of the important issues of this study is the development of three dimensional (3-D) SXR measurement system, which will be applied for physics study on 3-D helical equilibrium on LHD.

Consecutive imaging measurement has been a useful tool for understanding the plasma dynamics and instabilities. Therefore, we have developed an SXR imaging diagnostic system that uses multiple pin-hole SXR cameras together with high-speed cameras to record the time evolution of the SXR images from the tangential and vertical directions simultaneously for studying the dynamic structures of 3-D SXR emissivity. Using this system, we expect to be able to discuss the 3-D dynamics of MHD instabilities. In this report, we describe the design and configuration of the vertical SXR imaging system [2].

A schematic drawing of the vertical imaging system is shown in Fig. 1. The solid lines and a dashed line represent the limits and the sight line of the center of the visual field, respectively. This SXR imaging system uses an MCP to record a higher-resolution distribution of the two-dimensional (2-D) luminosity on a phosphor plate. The energy efficiency of the MCP is nearly constant in the wavelength range of SXR from the RELAX plasma[3], and a linear relationship between the number of electrons ejected from the MCP and the luminosity on the phosphor plate has been confirmed. The projected images depend strongly on the equilibrium magnetic field. It is difficult to clarifying the correlation between the filament structure associated with a high toroidal mode number n and a projected tangential image. In this sense, the vertical imaging system mitigates the shortcomings of the tangential system.

In the vertical system, an indium tin oxide based phosphor plate is employed to cover the shortfall in the luminosity in images caused by the short sight line. The

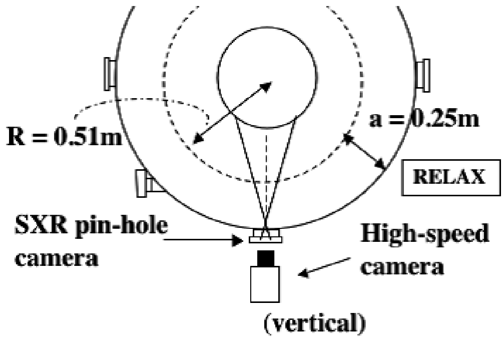

Fig. 1: Arrangement of the SXR pin-hole camera and the high-speed camera. Solid lines and dashed line represent the limits and the sight line of the center of the visual field, respectively.

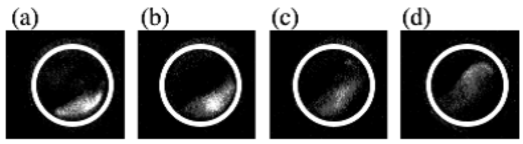

Fig. 2: Subtracted images of emissivity structure obtained from vertical port in RELAX at (a) 933 μs, (b) 940 μs, (c) 947 μs, and (d) 953 μs. Images were obtained by subtracting an SXR image from another obtained 6.6 μs later.

2-D luminosity distributions corresponding to the integrated SXR emissivity are measured with a high-speed camera (Photoron FASTCAM SA-4) with an image size of 264 $\times$ 96 pixels array and a 12-bit dynamic range. Nevertheless, the SXR image is produced only in a limited area on the pixel array: 70 $\times$ 70 pixels.

Raw images of SXR emission contain both equilibrium and fluctuating components. To illustrate the fluctuating component clearly, we applied a subtraction technique that enhances the difference between successive images, thus showing only the changes in the interval between images. Figure 2 shows subtracted images of the emissivity structure obtained from the vertical port in RELAX with a time resolution of 150 kfps. A zonal structure moves to the upper or left direction with time. By comparing the obtained experimental images during a single mode dominant phase with simulated SXR images calculated assuming a rotating helical configuration, we find that the evolution of the experimental SXR image suggests a rotating helical SXR emissivity.

1) S. Ohdachi, et al., Plasma Fusion Res. **2**, S1016 (2007)

2) A. Sanpei *et al.*, accepted for publication on Plasma Fusion Res. **7**, (2012).

3) S. Masamune *et al.*, J. Phys. Soc. Jpn. **76** (No.12) (2007) 123501.