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Soft x-ray detector array system on the Large Helical Device

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Soft x-ray (SX) detector array systems are installed on the Large Helical Device (LHD). Two types of systems are in operation: An 80 ch array for detailed profile measurement and two sets of 40 ch array installed inside the vacuum vessel suitable for fluctuation studies. Recent results of the profile and fluctuation measurement with this system are discussed. © *2001 American Institute of Physics.* [DOI: 10.1063/1.1326006]

I. INTRODUCTION

Soft x-ray (SX) radiation from a fusion-relevant plasma has been used as a diagnostic tool for many purposes. Magnetohydrodynamic (MHD) instability study from the fluctuating components of SX radiations and the impurity transport study from the absolute intensity of SX radiation are significant applications. New SX detector array systems aimed at these themes were installed on the Large Helical Device (LHD). The LHD is a Heliotron-type device with the major radius $R=3.9\,\text{m}$ and the minor radius $\overline{a}=0.6\,\text{m}$.[1]

Two types of systems are in operation: (1) an 80 ch array for detailed profile measurement equipped with an adjustable beryllium (Be) filter system located on a bottom port (3.5 L) of the LHD. and (2) two 40 ch arrays with Be foil 15 μm thick installed inside the vacuum vessel at top ports (3.5 U and 6.5 U), which are suitable for fluctuation study.[2] In both systems, a linear array of silicon PIN photodiode is employed as the detector, which was developed by Kyoto University and Hamamatsu Photonics.[3] This detector contains 20 elements. Each element has a $12\times1.5\ \text{mm}^2$ active area and is separated by a center-to-center spacing of 2.25 mm. Since all the elements are made on the same silicon wafer, the sensitivity of each channel is quite similar; the dispersion of relative sensitivity is within 5%. The upper limit of the frequency response is about 300 kHz. The system is sensitive to the photons from 1 to 30 keV. The lower limit is determined by the thickness of the Be absorber foil and the upper limit is determined by the thickness of the depression layer of this detector. For the profile measurement system (1) (see Fig. 1) an exchangeable Be filter mechanism has been developed. The filters are driven by an ultrasonic motor which can be operated under large stray magnetic field (~100 G) there. We can choose one out of seven filters (7.5–80 μm) shot by shot.

Photodiodes are negatively biased with -15 V and the currents induced by the SX lights are preamplified in the vacuum. The output signals are buffered outside, transferred to the data acquisition room, and recorded there with 14 bit ADCs. Here, we should cover a wide range of time scales in LHD experiments; from the fluctuation studies such as TAE modes[4] (frequency range is about several hundreds of kHz) to the measurements at steady state/long-pulse experiments (typical duration of a discharge is 60 s). We adopt a flexible CAMAC module developed by a Japanese company.[5] The sampling rate can be selected from 1 kHz to 2 MHz. Programmable low-pass filters for the anti-aliasing (half the frequency of the sampling rate) and programmable amplifiers ($\times1$, $\times2$, $\times5$, $\times10$) for each channel are also built in. It can accept an input, a so-called ''Event trigger,'' with which the sampling frequency can be changed to the higher one *ad hoc*. Using this function, we can record rapid events which may happen occasionally in long-pulse experiments.

II. EXPERIMENTAL RESULTS

Here we introduce two topics, which we are studying with this detector array system. One is the Shafranov shift measurements and the other is the measurement of MHD instabilities observed in the edge region of LHD plasma.

A. Measurement of Shafranov shifts

Determination of the plasma equilibrium is an old-fashioned theme. However, it is not so easy to determine it in helical systems by a SX detector array system. The density profile is usually very flat or even hollow. Thereby, the SX radiation profiles tend to become flat or hollow ones as well. It is difficult to determine the center position of the radiation under these conditions using line-integrated measurements. We have developed a simple method to reconstruct the SX radiation profile.[6] The concept of this method is the following. If the position and the shape of each magnetic surface are given beforehand, it is easy to calculate the reconstructed radiation profile from the line-integrated data assuming the constant radiation on the magnetic flux surfaces. We try to move the radial position of each magnetic surface in order to make reconstruction best-fitted to the measured profile, whereas the shape of each surface is kept in constant. We developed a computer code which seeks the minimum error in the fitting calculations by moving the parameters (R_{ax} and R_{offset}) which represent the Shafranov shift of plasmas [see Fig. 2(a)], where R_{ax} represents the movement at the center and R_{offset} represents the whole movement of the plasma, respectively. After minimizing the errors, we can determine

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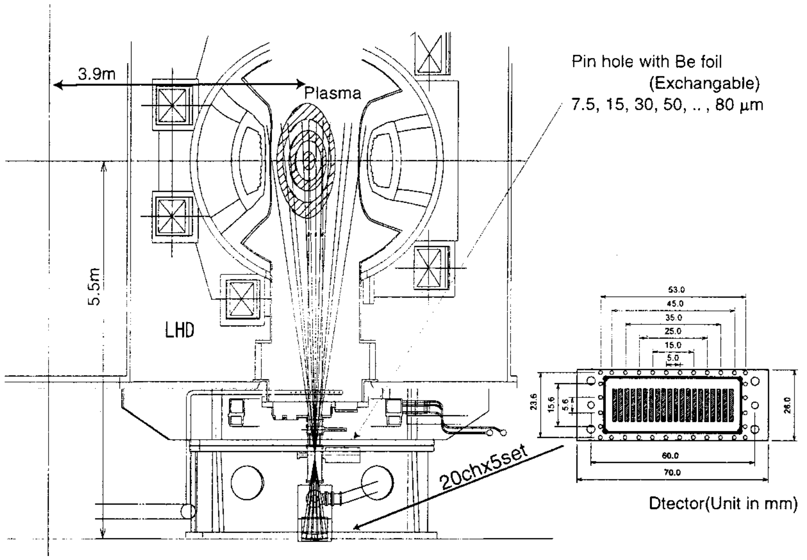

FIG. 1. A SX detector array system on 3.5 L port.

the magnetic axis position (R_{ax}) and the reconstructed radiation profile simultaneously.[6] Figure 3 shows the measured position of the magnetic axis R_{ax} as a function of the averaged toroidal beta β_t of the plasma. The shift derived from SX measurements is compared with that calculated by equilibrium code VMEC. Data from the discharges with the vacuum magnetic axis position=3.75 m (Ref. 1) and 3.6 m are shown together. The comparison with the equilibrium code is in good agreement within the error bars of the measurement.

B. Detection of MHD activities

Among several possible configurations of LHD, the magnetic configurations with the magnetic axis R_{ax}=3.6 m is found to be the favorable one for achieving the best plasma performance. However, it is predicted that this configuration with standard pressure profile might be unstable against Mercier modes even if the β_t is fairly low. Though coherent magnetic activities are observed experimentally, the amplitude is very small, so that an obvious effect on plasma confinement has not been found.[7] To clarify this contradiction is one of the most important issues related to MHD instabilities in the present LHD experiments.

Standard tomographic reconstruction using large numbers of sight lines is practically difficult in LHD, that is, the space for detectors which surround the plasma at a constant interval is strongly limited due to the large helical coil winding. Here, we evaluate the mode structure using our system which observes the plasma cross section in one direction. Low-frequency (~2–3 kHz) SX fluctuations correlate well

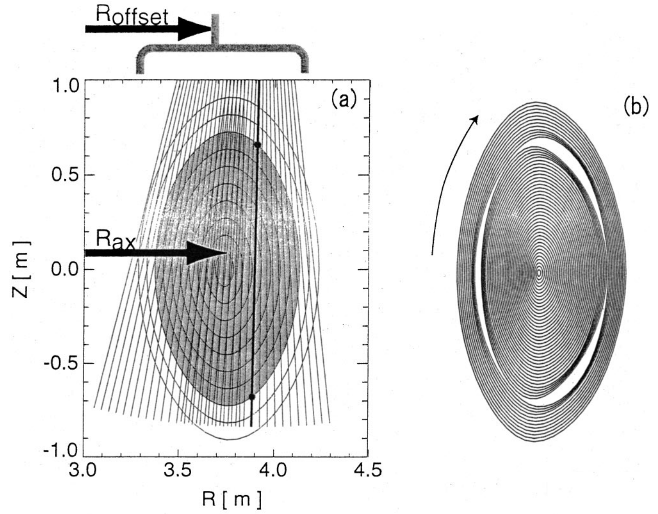

FIG. 2. Assumed magnetic surface and the sight lines are shown in (a). In the calculation, two parameters to move the flux surface are used. R_{offset} is the parameter for the whole movement of the flux surfaces and R_{ax} is the parameter for the magnetic axis position. For the MHD instabilities, deformed flux surfaces (b) are used to imitate the island structure with the poloidal mode number $m=3$ at the normalized radius ρ=0.75.

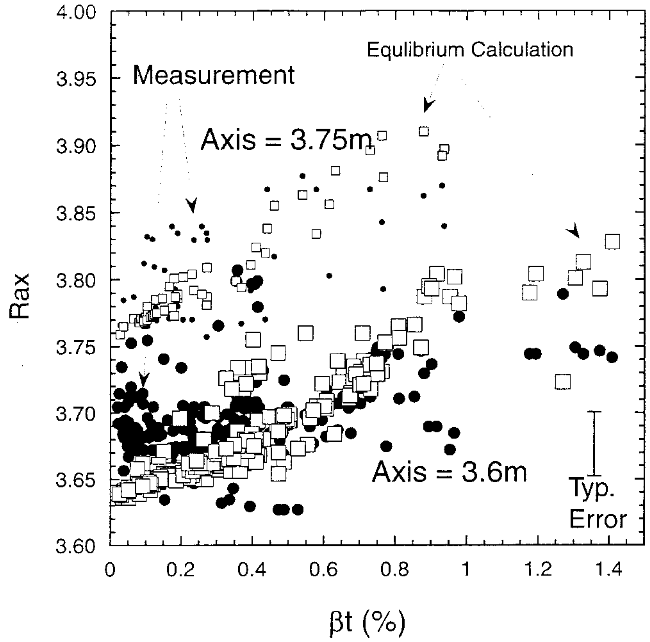

FIG. 3. Shifts of the magnetic axis as a function of averaged beta β_t. Measurements are plotted with rectangles and simulations are plotted with circles. Data from R_{ax}=3.6 m discharges (large plot) and from R_{ax}=3.75 m discharges (small plot) are shown as well.

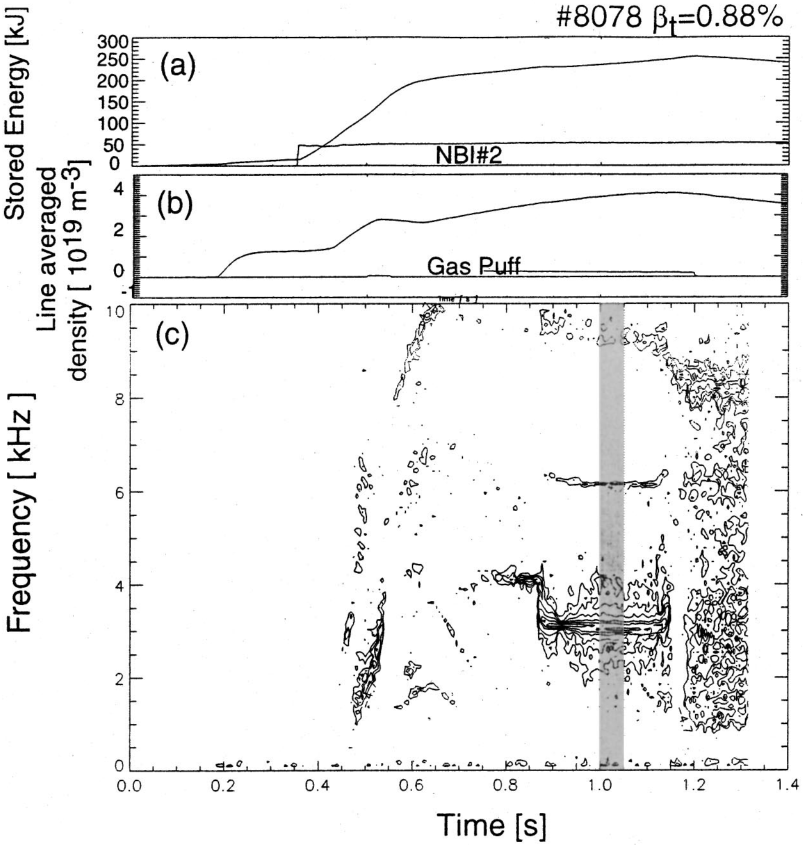

FIG. 4. Time evolution of the stored energy (a), the line averaged electron density (b), and the amplitude of the magnetic fluctuations as functions of the time and the frequency (c) are shown.

with the magnetic probe signals[2,8] selected as the target of this analysis. Neon gas puffing from the request of the charge exchange recombination spectroscopy measurements enhances the SX radiation near the edge region. This leads to clear correlation between magnetic fluctuations and SX radiation compared with the usual plasma without neon puffing. Figure 4(c) shows a contour plot of the amplitude of the magnetic fluctuations as functions of the time and the frequency. A large-amplitude coherent mode with a frequency of about 3 kHz is clearly seen, of which the mode is destabilized at $t=0.9\,\mathrm{s}$.

Evaluation of the mode structure is done by comparison of the measurements with simulations based on the reconstruction method described in the previous subsection. In the reconstruction method the magnetic surfaces are deformed with a certain poloidal mode number m [Fig. 2(b)] in order to simulate the mode structure. Then, the deformed magnetic surface is rotated poloidally in the simulation code. The amplitude and the cross phase of SX detector signals are calculated by this simulations and compared with the experimental results. Experimental results of the SX fluctuation amplitudes and the cross phase with the magnetic fluctuations are shown in Figs. 5(b) and 5(c). The radial pattern of the phase suggests that it is caused by an even mode. From the mode analysis of the magnetic probe signals. The toroidal mode number is determined to be $n=2$. Therefore, the most plausible candidate explaining the SX fluctuation profile is the $m=2/n=2$ mode localized near the $\iota/2\pi=1$ surface. The simulation results with this condition ($m=2$, at $\iota/2\pi=1$) are drawn in thick lines in Figs. 5(b) and 5(c) and they agree well with the experimental data. The instabilities are then specified to be $m=2/n=2$ modes localized at the $\iota/2\pi\sim1$ rational surface. The mode is predicted to be the pressure-driven mode, e.g., resistive interchange modes.[8]

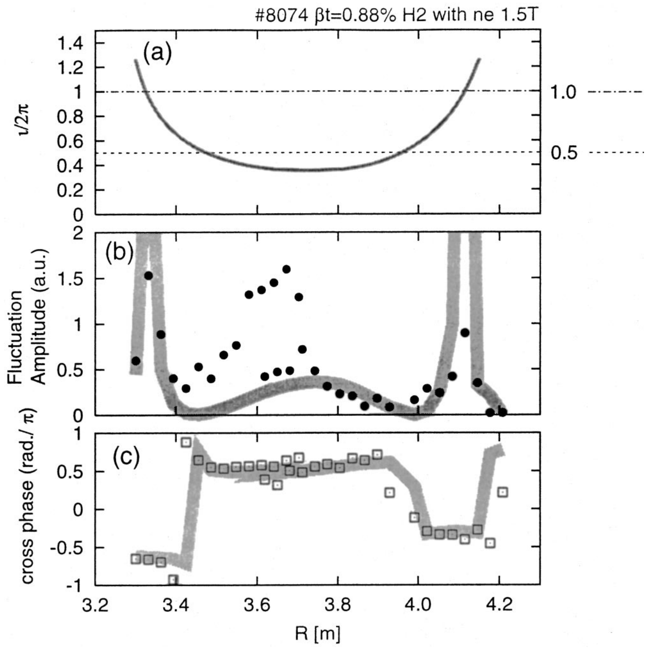

FIG. 5. Radial profile of the rotational transform profile (a), the fluctuation amplitude (b), and the relative phase of the fluctuations (c). Broad lines in the graph show the simulated result assuming $m=2/n=2$ at $\iota/2\pi=1$ rational surface.

III. CONCLUSION

The SX detector array has been installed on the LHD successfully. We have studied several phenomena, including magnetic axis measurement and determination of the radial structure of the MHD instabilities. We have measured only on vertically elongated sections until now. The extension of this system is also planned. We will install a new array (40 ch) in a horizontally elongated section. Moreover, a tangentially viewing SX camera with a fast CCD camera will be installed for studying a detailed two-dimensional structure of the fluctuations in the next experimental campaign of LHD (from September 2000 to March 2001).[9]

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