Development of an Array System of Soft X-ray Detectors with Large Sensitive Area on the Large Helical Device*)

Xiaodi DU[1)], Satoshi OHDACHI[1,2)], Kazuo TOI[2,3)] and LHD Experiment Group

[1)]*Department of Fusion Science, The Graduate University for Advanced Studies, 322-6 Oroshi-cho, Toki 509-5292, Japan*

[2)]*National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan*

[3)]*Department of Energy Science and Engineering, Nagoya University, Furo-cho, Nagoya 464-8603, Japan*

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A new 17-channel soft X-ray diagnostic system was developed for a study of magnetohydrodynamics (MHD) fluctuations and installed on the Large Helical Device (LHD). The Absolute X-ray Ultraviolet Photodiodes (AXUV diode) with a large sensitivity area 10 mm × 10 mm were adopted as the detectors. The sightlines were designed to cover the whole plasma with 3.8 cm space separation and the expected radial resolution was 7 cm at the equatorial plane of LHD. The toroidally elongated pin hole (25 mm × 7 mm) was used to increase the signal to noise ratio and a Be foil of 15 μm in thickness was used to shut the visible light. The detector array was placed inside the vertically elongated section of the LHD vacuum vessel, being shielded by an aluminum box. In the experimental campaign of LHD, this fiscal year 2011, various kinds of MHD fluctuations excited in core and edge plasma regions have clearly been detected by this newly installed diagnostic system. The characteristic behaviors of the ELM activity in H-mode plasmas and the “Fishbone”-like instabilities induced by the perpendicular neutral beam injection (NBI) were derived from the soft X-ray data.

Keywords: AXUV detector, soft x-ray diagnostic, ELMs, “fishbone”-like instability

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1. Introduction

In toroidal plasmas, the Soft X-ray (SX) range emission mainly consists of the combination of the bremsstrahlung, line and recombination radiations. The soft X-ray diagnostic system is one of the most popular diagnostics in the tokamak and helical devices. Much information can be derived from SX emission. The electron temperature can be deduced from the energy spectrum. The impurity content can be studied from the intensity of the line emission. Magnetohydrodynamics (MHD) instabilities would cause the deformation of the magnetic flux surfaces. Since the iso-radiation surface of the SX emission can be a good estimate of the flux surface, we can study the internal structure of the MHD activities from the SX emission [1].

On LHD, 20-channel soft X-ray diode array systems were used at several positions [2]. In order to improve signal to noise ratio with a reasonable spatial resolution, a new absolute X-ray ultraviolet diode having a larger detection area was selected as the detector. The detailed description of this new system is given in section II. Various kinds of MHD fluctuations are observed by this new system. Several examples are given in Section III. Future improvement and physics research targets of this system are presented in the summary.

author's e-mail: Du.xiaodi@lhd.nifs.ac.jp

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2. New Soft X-ray System

The absolute X-ray ultraviolet photodiodes (AXUV-100 model) with the 5.6 times larger sensitive area (10 mm × 10 mm) than old system [2], which are made by International Radiation Detectors, Inc., are adopted as the new detectors. The detectors have an effective silicon thickness of 100 microns. The sensitivity of the detector is shown in Fig. 1 (blue curve) The detector is sensitive to the photon energy up to 30 keV. Specifically, the high response

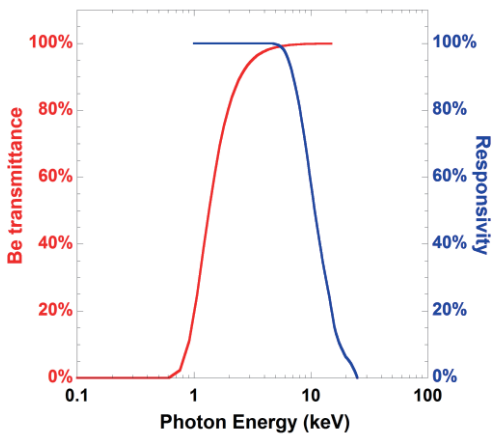

Fig. 1 Responsivity of AXUV photodiodes with 100 microns effective Si thickness (blue curve) and the transmittance coefficient for 15 μm Be foil filter (red curve).

range is from 1 keV to 6 keV. A beryllium foil of 15 µm thickness is arranged before the pinhole to shut down the visible light and vacuum ultraviolet emissions. The transmission coefficient is shown in Fig. 1 (red curve) It also determines the lowest coming photon energy, around 1.5 keV.

When the photons enter the detector, the current is induced. In the pre-amplifier, it's transferred to the voltage signal and then pre-amplified inside the vacuum vessel.

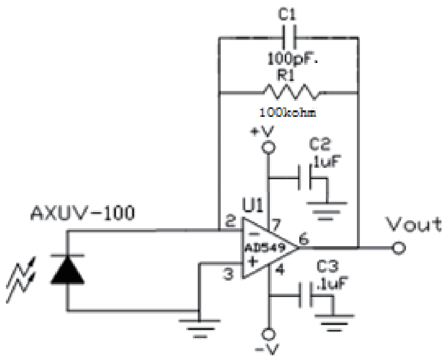

Fig. 2 The circuit of the preamplifier.

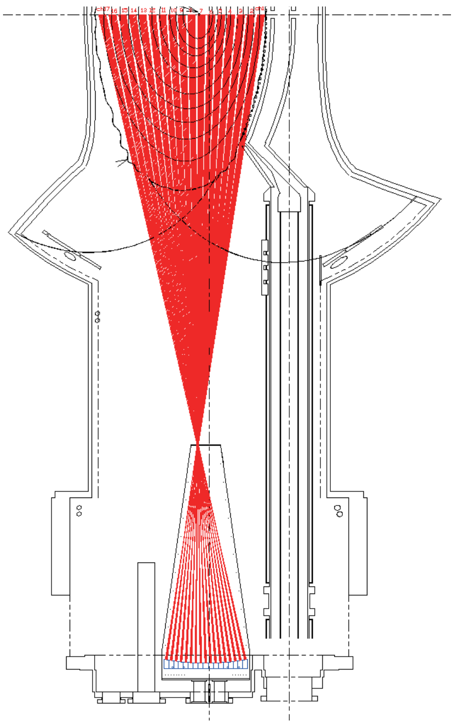

Fig. 3 The sightline view of the new SXR system.

The circuit is shown in Fig. 2. In the circuit, the resistivity to convert current to voltage is chosen as 100 kΩ. The effective capacitance is estimated as 100 pF. Then the upper limit of the frequency response $f_c = 1/2\pi R_1 C_1$ is about 16 kHz. At present, low frequency MHD modes less than 10 kHz can be detected by this new SX array system.

The sightlines, which were shown in Fig. 3, are designed to cover the whole vertical elongated poloidal cross section of the plasma with 3.8 cm space separation at the equatorial plane of an LHD plasma. A trapezoid shaped aluminum box 1.6 m in height is designed to support and shield the detector. A pinhole (25 mm × 7 mm) is opened on the top of the box to give the image of the plasma.

Here, the performance of the new detector system is roughly estimated under the arrangement of Fig. 4. Consider the radiation from the plasma with a distance s from the pinhole. The emission from the area $[a \times (s/t)] \times [b \times (s/t)]$ enters the detector. The length $a(b)$ and $c(d)$ denote the size of the detector and pinhole in the radial (toroidal) direction, respectively. The distance from the detector to the pinhole and from the pinhole to the plasma is denoted as t and s. The solid angle where the emission enters the pinhole is in proportional to $(c \times d)/(4\pi s^2)$. Since the total emission is a line integral of the emission over the sight line, the value $(abcd)/(4\pi t^2)$ can be used as a good measure of the brightness of the system. Radial and toroidal resolution of the system is also roughly estimated as the $c \times [(s + t)/t]$ and $d \times [(s + t)/t]$ respectively. The characteristics of the new and old systems are summarized in Table 1.

This new detector system can expect at least 10 times larger signal than the old system. In order to further improve the signal to noise ratio in the complicated electromagnetic environment of the experimental hall, condensers

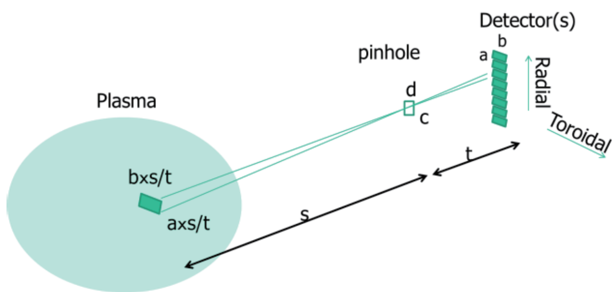

Fig. 4 Arrangement of the detector.

Table 1 Comparison of the old and the new SX detector system.

	a (mm)	b (mm)	c (mm)	d (mm)	t (m)	s (m)	Bright-ness	Δr (mm)	$R\Delta\phi$ (mm)
OLD	12	1.5	9	5	0.9	4.274	**79.58**	51.74	28.74
New	10	10	25	7	1.15	2.4	**1053.01**	77.17	21.61

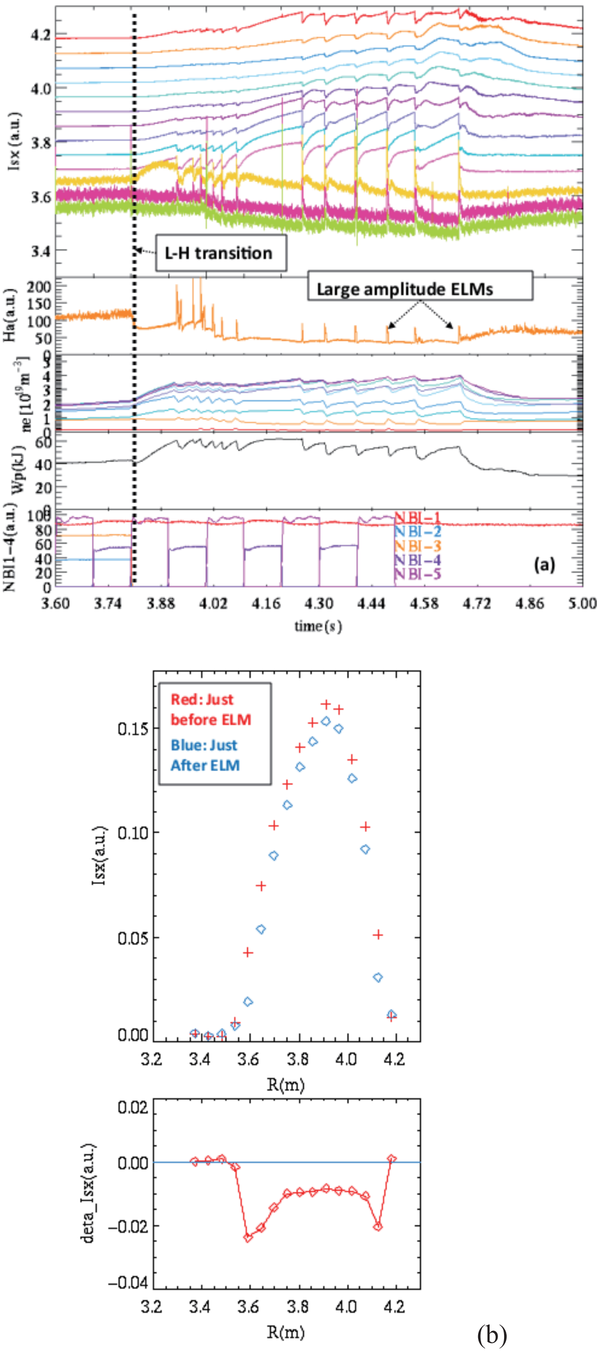

Fig. 5 (a) Time evolution of the plasma parameters when the large amplitude ELMs appear. From top to bottom, the time evolution of the SX emission, Hα emission, line integrated density, stored energy and NBI heating timing are shown together. Colors stand for different channels from outboard side (top) to inboard side (bottom). (b) Top: the SX emission profile just before (red) and after (blue) one ELM. Bottom: the profile of the SX emission change just before and after the ELM events.

with large capacitance (6.8 mF) are inserted in the power supply to mitigate the large impulse noise from the turn-on or turn-off of the NBI power supply. After using the condenser, the noise level around 10 kHz is reduced by a factor of 10.

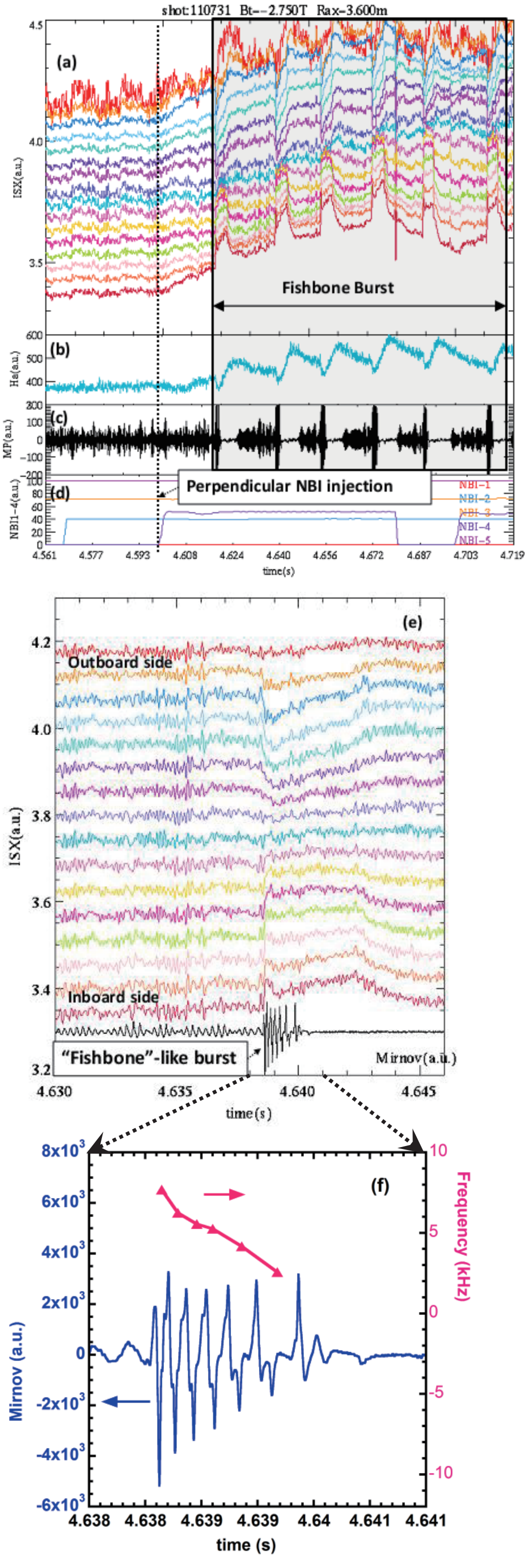

Fig. 6 The waveforms of the typical "fishbone"-like bursts on LHD. (a) The time evolution of the SX emission. (b) The time evolution of the H emission. (c) Time evolution of Mirnov probe signal. (d) Timing of the neutral beam injection. Parallel injection: NBI1-3; perpendicular injection: NBI 4-5. (e) Expanded view of one "Fishbone"-like burst event. Colors stand for the different SX channels from Outboard side (top) to inboard side (bottom) (f) Expanded view of the frequency chirping down during one "Fishbone"-like burst event.

3. "Snapshots" of the Experimental Results

In recent experimental campaign (2011), various kinds of MHD instabilities are observed. In this section, edge localized mode (ELM) activities observed in the H-mode plasmas and "Fishbone"-like activities are discussed.

Large amplitude ELMs are excited on LHD at the outward-shifted configuration [3]. One example is shown in Fig. 5 (a). The magnetic configuration is $Rax = 3.9$ m, $Bt = -0.9$ T, gamma = 1.19, $Bq = 100\%$, which means the magnetic axis position of the vacuum field, the strength of the toroidal magnetic field, the helical coil pitch parameter and the quadruple field components of the poloidal coils respectively [4]. The vertical black dashed line indicates the low to high confinement transition (L-H transition). In the top plot of the Fig. 5 (a), the sudden increase of the SX emission (light yellow curve) in the edge region indicates the formation of the edge transport barrier ETB [5].

The SX emission profile just before and after the ELM event is shown in Fig. 5 (b). Taking into account of the line-integration effect, this profile change indicates the large loss of the edge plasma without the large loss of the core plasma just after the ELM crash.

During the perpendicular neutral beam injection into the high ion temperature trial experiment, repetitive "fishbone"-like instabilities were observed at the configuration of $Rax = 3.6$ m, $Bt = -2.75$ T, gamma = 1.254, $Bq = 100\%$ (Fig. 6). From the magnetic measurements, the instabilities have $m/n = 1/1$ mode structure, where m/n denotes the poloidal/toroidal mode number respectively. The rapid frequency chirping down, from an initial value of $f \sim 8$ kHz to the final value of $f = 2$ kHz in 1.5 ms was shown in Fig. 6 (f). At each fishbone burst, the new SX system has the spike-like response. At the same time, the Halpha signal is also coincidently modulated by the burst. The detail expansion of one fishbone burst is shown in Fig. 6 (e). The inboard side channels suddenly increase and the outboard side channels decrease. This sudden change of the SX emission profile by each fishbone-like event can be explained by sudden decrease in energetic ion pressure produced by perpendicular NBI.

4. Summary and Future Work

A new SX system have been developed and installed on LHD. We showed two typical cases in various kinds of the MHD activities which are observed by the new system, such as sawtooth-like activities, ELM activities and "Fishbone"-like instabilities. In the future, the pre-amplifier will be designed to raise the cut-off frequency limit. The system will have ability to research the fluctuations up to 100 kHz for the observation of the Alfvén Eigenmodes (for example TAE mode). Further reduction of the noise is also important work.

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