Observation of Internal Structure of Edge MHD Modes in High Beta Plasmas on the Large Helical Device

WATANABE Fumitake[1)], OHDACHI Satoshi, TAKAGI Shohji, TOI Kazuo,
SAKAKIBARA Satoru, WATANABE Kiyomasa, MORITA Shigeru,
NARIHARA Kazumichi, TANAKA Kenji, YAMAZAKI Kozo[1)]
and LHD Experimental Group

[1)]Department of Energy Engineering and Science, Nagoya University, Nagoya 464-8603, Japan
National Institute for Fusion Science, Toki 509-5292, Japan

(Received 6 September 2005 / Accepted 17 November 2005)

Edge MHD modes are excited with an appreciable amplitude by the rise of the edge pressure gradient in the Large Helical Device (LHD), where the related rational surfaces are located near the last closed flux surface (LCFS). Internal structure of these edge MHD modes in high beta plasmas was measured by using a set of soft X-ray (SX) diode arrays. The relative amplitude of SX fluctuations related to these MHD modes increases rapidly toward the LCFS. The phase relation among SX fluctuation signals obtained by the SX-diode array clearly indicates the poloidal mode structure.

Keywords:
edge MHD mode, high beta plasma, soft X-ray fluctuation, LHD, rational surface

In the Large Helical Device (LHD), increase in the plasma beta (i.e., the ratio of volume-averaged plasma pressure to the toroidal magnetic pressure) causes appreciable excitement in MHD modes of m/n = 1/1, 3/4, 2/3 and 1/2 (m and n are poloidal and toroidal mode numbers, respectively) near the plasma edge region of the magnetic hill [1]. These edge MHD modes sometimes interrupt the increase in the stored energy in high beta regime. In particular, the edge MHD modes are suddenly destabilized immediately after the L-H transition which leads to the formation of edge transport barrier having a steep pressure gradient [1,2]. To clarify the characteristics of edge MHD modes and minimize the effects on plasma confinement, measurements of the internal structure, growth rate and so on are crucially required.

In the LHD, we have employed seven sets of a 20-channel soft-X-ray (SX) detector array in order to measure the internal structure of the edge MHD modes. SX emission measurement is applicable for the study of MHD instabilities in high beta plasmas without any limitations in magnetic field and density, although the path integral effect should be taken into account. An example of these SX detector array systems is shown in Fig. 1. This system is installed inside the vacuum vessel in the vertically elongated section of the LHD. The detector array is a silicon PIN photodiode array which consists of 20 ch active areas arranged in one dimension and was developed by Hamamatsu Photonics. A beryllium foil of 8 μm or 15 μm thickness is attached to the front of the system to shut out visible and vacuum ultra violet emissions.

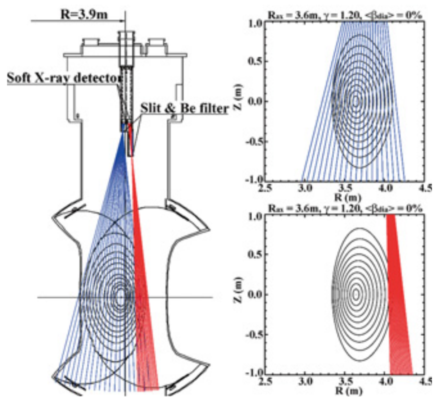

Fig. 1 SX detector array system in the LHD. 40 lines of sight by two SX-ray detector arrays are drawn.

The viewing sight of the detector system is adjusted through a collimator slit, as shown in Fig. 1.

A typical time evolution of high beta hydrogen plasma heated by NBI heating is shown in Fig. 2. The condition of discharge is as follows, where the magnetic axis position of the vacuum field R_{ax} = 3.6 m, the toroidal magnetic field strength B_t = 0.5 T and an index of the aspect ratio of the last closed magnetic surface γ = 1.2. In this discharge, the volume-averaged beta value obtained from diamagnetic measurement reaches up to $\langle\beta_{dia}\rangle$ ~ 2.5% by the ramping of line averaged electron density. In the latter half of the discharge where $\langle\beta_{dia}\rangle$ exceeds about 2%, the H_α signal exhibits fluctuations and

author's e-mail: fmtk-w@nifs.ac.jp

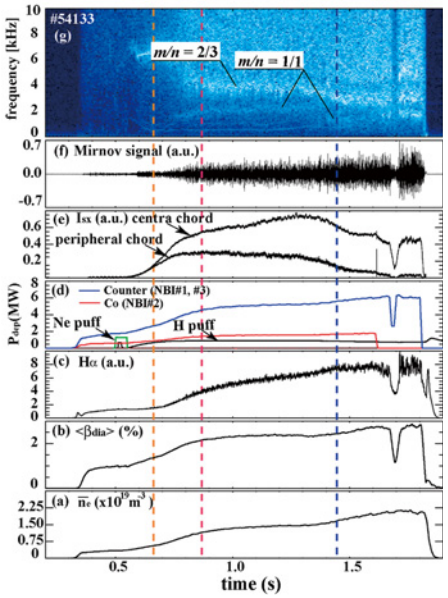

Fig. 2 Time evolution of a high β discharge; (a) line-average electron density $\bar{n}_e$, (b) volume averaged value $\langle\beta_{dia}\rangle$, (c) H_α emission, (d) NBI deposition powers and gas puff pulse, (e) SX signals at peripheral and central chords, (f) magnetic probe signal and (g) contour plot of magnetic fluctuation amplitude.

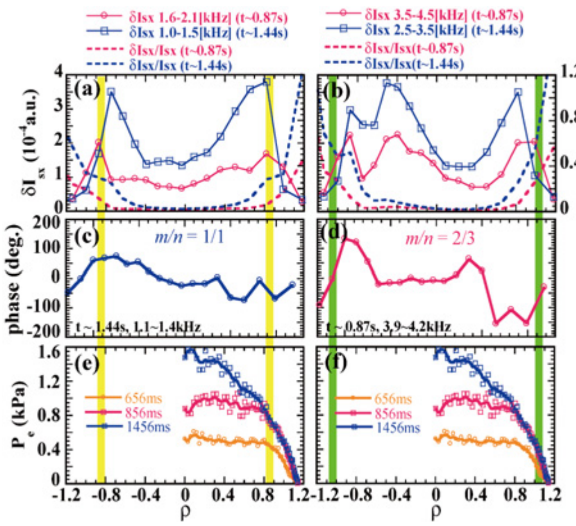

Fig. 3 Radial profile of SX fluctuation amplitude (δI_{sx}), relative amplitude ($\delta I_{sx}/I_{sx}$) for edge MHD modes (m/n = 1/1 and 2/3), phase difference between SX channels and electron pressure using data of Thomson scattering and FIR interferometer. Yellow and green thick lines stand for the rational surfaces of $\iota/2\pi$ = 1 and 3/2, respectively.

frequent bursts. In the spectrogram of magnetic probe signal shown in Fig. 2(g), the m/n = 2/3 and 1/1 coherent modes are clearly identified in the frequency range of 3–5 kHz and 1–2 kHz, respectively. The rational surfaces of these edge MHD modes are located in the plasma edge region ($\langle r\rangle/\langle a\rangle = \rho >$ 0.8).

Figures 3(a) and 3(b) show the radial profile of SX fluctuation amplitude δI_{sx} and relative amplitude $\delta I_{sx}/I_{sx}$ having high coherence with the observed m/n = 1/1 and 2/3 magnetic fluctuations. The SX fluctuation δI_{sx} is derived by numerical filtering around the frequency range of high coherence, and is averaged over a time window of 20 ms. The relative amplitudes $\delta I_{sx}/I_{sx}$ of both m/n = 1/1 and m/n = 2/3 modes rapidly increase in the edge region with the increase in the pressure gradient at the respective rational surfaces (Figs. 3(e) and 3(f)). The peak of δI_{sx} for the respective modes locates slightly inside the region of the rational surface, which is caused by the path integral effect of SX signals. Moreover, the δI_{sx} of the m/n = 2/3 mode has a peak in the plasma's central region (Fig. 3(b)). This is also attributed to the path integral effect. The relative amplitude of the m/n = 2/3 mode decreases more rapidly toward the plasma center than that of the m/n = 1/1 mode. This is consistent with the radial dependence of the eigenfunction having different m numbers, although $\delta I_{sx}/I_{sx}$ or even $\delta I_{sx}/|\nabla I_{sx}|$ does not necessarily correspond to an eigenfunction of the MHD mode because of the path integral effect.

The phase relation among SX fluctuation signals obtained by a SX array will give information regarding the m-number. As shown in Figs. 3(c) and 3(d), the phase difference between SX channels in inboard and outboard plasma edges is roughly ~2π for m/n = 2/3, i.e., the m-number is even, and is ~π for m/n = 1/1, i.e., the m-number is odd. They are consistent with the m-numbers determined by using the magnetic probes.

In conclusion, the edge MHD modes in high beta plasmas were clearly detected by SX detector arrays as well as by magnetic probes. The relative amplitude $\delta I_{sx}/I_{sx}$ of edge MHD modes such as m/n = 2/3 and 1/1 increases rapidly toward the plasma edge, which clearly indicates a characteristic of edge modes. The radial variation of $\delta I_{sx}/I_{sx}$ depends on the m-number. In order to clarify the characteristics of edge MHD modes and their impact on plasma confinement, we need a detailed comparison between experimental data such as SX data and theoretical results on edge MHD modes obtained by MHD stability codes for three-dimensional plasma such as the CAS3D3 code [3,4].

The authors acknowledge members of the LHD technical group for their support. This work was supported in part by the LHD project budget (No. NIFS05ULHH508). It was also supported in part by the Grant-in-Aid for Exploratory Research from MEXT, No. 16656287.

[1] K. Toi *et al.*, Nucl. Fusion **44**, 217 (2004).
[2] K. Toi *et al.*, Phys. Plasma **12**, 020701-1 (2005).
[3] C. Nührenberg, Phys. Plasma **6**, 137(1999).
[4] N. Nakajima, 20th IAEA Energy Conf., Villamoura, TH/56 (2004).