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Soft X-ray measurement in IRE on the TST-2 spherical tokamak

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Internal Reconnection Event (IRE) is a characteristic relaxation phenomenon in STs (Sperical Tokamaks). To investigate the deformation of the plasma shape during IRE, four PIN diode arrays of 20 channels were installed on the TST-2@K (TST-2 at Kyushu University). Precursor of IRE was observed for several milli-seconds. The fluctuation was composed of two dominant components in frequency of 10kHz and 4kHz. The mode structure of 10kHz component is n/m=1/1 helical structure and 4kHz is n/m= 3/4. The overlap of modes (10kHz and 4kHz) was considered to be cause of IRE in TST-2 from the position and the growth of the modes.

Introduction

Spherical tokamak (ST) having aspect ratio A≤1.5 have been investigated as cost effective alternative to the tokamak fusion concept [1]. ST plasmas have some characteristic features, the avoidance of a characteristic relaxation phenomenon in ST, that is Internal Reconnection Event (IRE) [2], is one of the crucial issues to execute the stable operation. When IRE takes places, the large amount of magnetic energy stored in plasmas is converted to the kinetic energy of plasmas by magnetic reconnection process and then the stored thermal energy and particles in the core region is lost abruptly. According to the computer simulation [3], the plasma shape is deformed by the two modes (n/m=1/1 and n/m=2/2, where n, m represent toroidal and poloidal mode number, respectively) and the nonlinear-coupling between them causes 3-D deformation of the plasma during an IRE. Study of IRE is carried out also with ST devices, such as NSTX and MAST [4]. In this experiment, there is feature that n and m can be determined by measurement only Soft X-ray (SXR).

Experimental apparatus

The typical design parameters of Tokyo Spherical Tokamak (TST-2) are: major radius R=0.4m, minor radius a=0.25m, aspect ratio A~1.6, toroidal field B_t=0.2T and plasma parameters are: plasma current I_p~130kA, electron density n_e~$10^{19}m^{-3}$ and elongation κ~1.8 [5]. To investigate the 2-D deformation of the plasma shape during IREs, three PIN diode arrays of 20 channels (detected region 200eV~30keV) were installed in the same poloidal cross-section at 120 degree interval and an another PIN diode array is also installed on location 120 degree toroidal apart direction as shown in Fig.1.

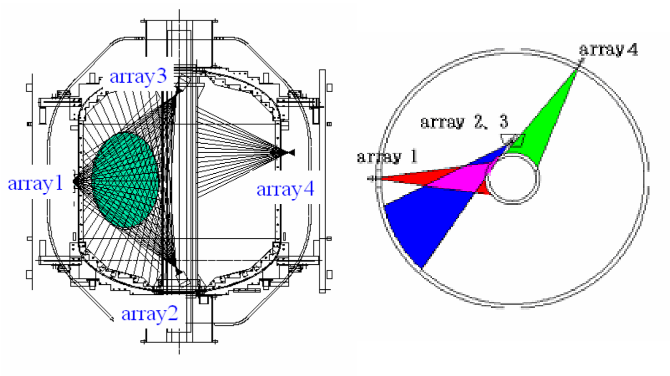

Fig.1: Left figure; poloidal cross diagram of the installation of each detector array and the line of sights of each detector. The ellipse represents a typical size of plasma. Right figure; troidal cross diagram, measured regions of each detector array are painted.

Experimental results

In Fig.2, the IRE occurred at about 35.8ms. A positive spike on the plasma current and a negative spike on loop voltage were observed on the IRE, and density decreases after the IRE. Precursor was observed during several milli-seconds before IREs. As shown in Fig.3(a), the frequency of SXR precursor was analyzed by fast Fourier transform (FFT) technique, and it turned out that the fluctuation had two dominant Fourier components (Fc) with 10kHz and 4kHz. Fc with 10kHz and 4kHz were existed sometimes independently without IREs. The presence of both components with 10kHz and 4kHz leads to IREs.

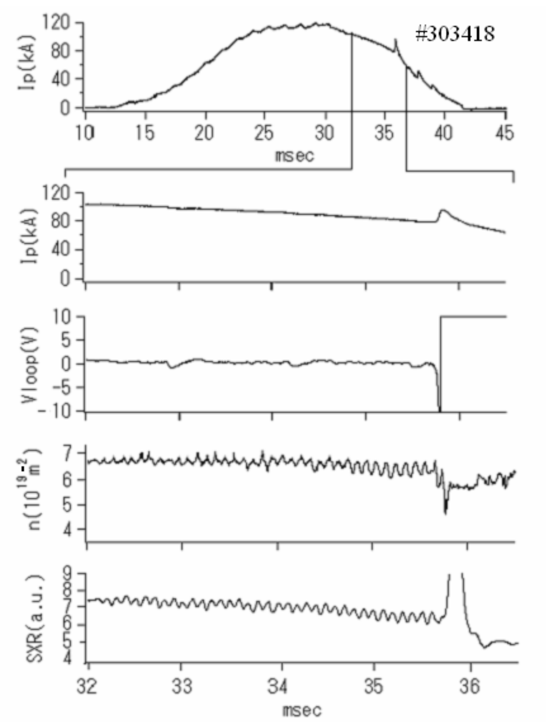

Fig.2: Plasma current, loop voltage, density and intensity of SXR when IRE occurred.

As for the Fc with 10kHz, magnetic fluctuation could be detected by magnetic pick-up coils installed on just inside of the wall and the mode structure is able to be identified as n/m= 1/1. The mode structure of the Fc with 10kHz is determined as the following. The time evolution of the Fc with 10kHz in array 1 and array4 at r/a=0.4 are shown in Fig.4(a). The phase difference of about 120 degree between two wave shows n=1. Fig.4(b) is shown the phase of the Fc with 10kHz. The phase difference of about 180 degree between peaks shows m=1.

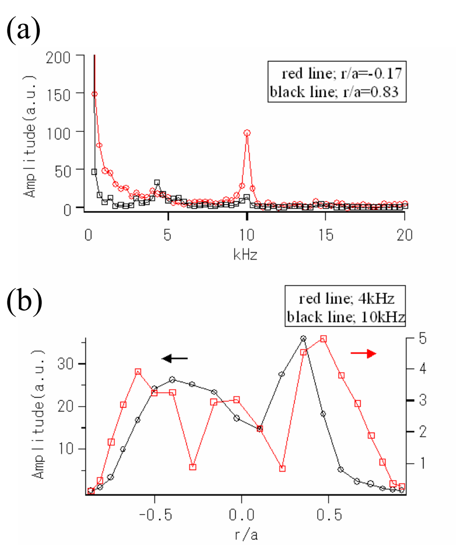

Fig.3: (a) The amplitude of frequency of precursor before IREs. Red and black lines are r/a=-0.17,0.83 in array2, where r is the length of perpendicular line from the center of plasma to the line of sight. (b) The amplitude of Fc with 10kHz and 4kHz of array1.

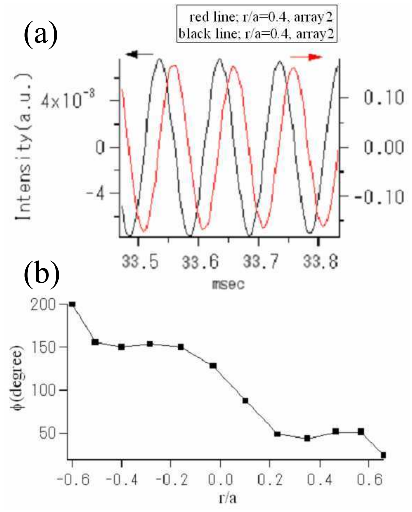

Fig.4: (a) The intensiy of Fc with 10kHz at r/a=0.4 of array1 and array4. (b) The phase of the Fc with 10kHz.

The Fc with 4kHz was not detected by magnetic pick-up coils, because m and n were large, and it was impossible to measure by magnetic pick-up coil. As shown Fig.5(a), there is no phase difference between array1 and array4. Therefore the m is considered to be 3. It can be expected that m number is high from rapid phase difference in division of array1 view. As shown in Fig.5(b), the poloidal number is m=4 because phase difference was about 180 degree between the two chords in array4 which are 45 degree apart in the poloidal direction. In addition m=4 is consistent with the amplitude profile with three peaks in array1 (Fig. 3(b)). Therefore the 4kHz fluctuation could be identified as n/m=3/4.

Fig.6 shows time evolutions of amplitude and radial peak position for both modes. There is no change of Fc with 4kHz and 10kHz, but as for amplitude, both Fc with 10kHz and 4kHz are grown (Fig.5(a),(b),(c)). The growth rate γ are; (a)8.9ms^{-1}, (b) 10.9ms^{-1}, (c) 3.7ms^{-1}. The growth of amplitude did not take place IRE. The position of peak of 10kHz was shifted outside until just before IRE. Therefore, it can be guessed that the cause of IRE is the overlap of two magnetic islands.

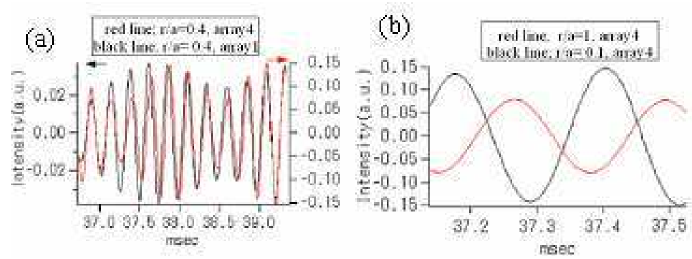

Fig.5: The intensity of Fc with 4kHz, (a) in array4 and array1 at r/a=0.4, (b) in array4 at r/a=1, 0.1

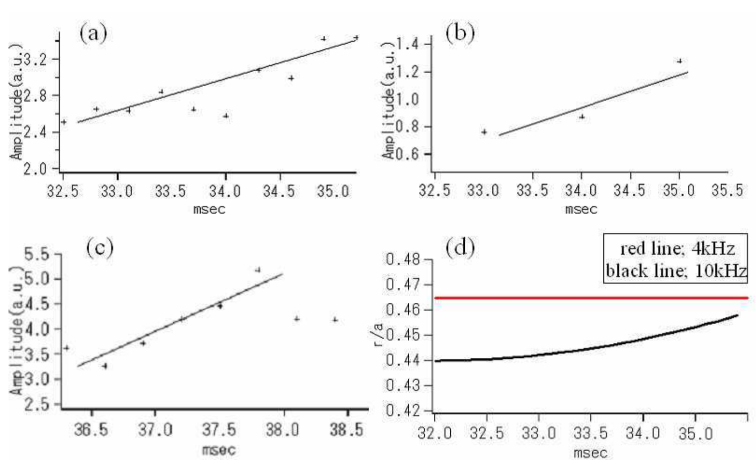

Figure 6. (a),(b) The time evolution of amplitude of Fc with 10kHz and 4kHz when IRE occurred. (c)The time evolution of Fc with 10kHz when IRE didn't occur. (d) The shift of peak; black line is 10kHz, red line is 4kHz.

Conclusion

Two modes (about 10kHz and 4kHz) exist before IRE. Only when two modes exist, IRE occurs. And these structures of precursor were identified. It turns out that about 10kHz mode structure is n/m=1/1, and about 4kHz mode structure is n/m=3/4. There is no change of frequency until precursor begins to take place and it results in IRE, but amplitude increases. The overlap of modes is considered to be the cause of IRE in TST-2 from the positional relation of Islands, and changes of amplitude.

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