Phase Alignments between MHD Modes Followed by Minor Collapses on TST-2

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MHD instabilities followed by minor collapses in the TST-2 plasma are studied. Precursors with toroidal mode numbers $n = 1$ and $n = 2$ localized in the plasma's core become phase aligned so that their mode amplitudes strengthen each other at a certain spatial point. During phase alignment, the total mode amplitude on the soft X-ray radiation profile does not show significant change, and a minor collapse occurs but does not terminate the discharge. This behaviour is similar to the results during a non-linear growth phase in three-dimensional MHD simulations [N. Mizuguchi *et al.*, Phys. Plasmas **7**, 940 (2000)]. However, predicted pressure-driven modes are not confirmed in these experiments.

Keywords: IRE (Internal Reconnection Event), mode coupling, spherical tokamak, soft X-ray

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MHD instabilities accompanying plasma collapses have been investigated in many tokamak experiments. In particular, two coupling modes with m (poloidal mode number) = 1 and $m = 2$ followed by disruptions were identified by a two-dimensional soft X-ray radiation (SXR) profile and singular value decomposition (SVD) method in WT-3 [1]. The phase relationship between the two modes is constant and is sustained for some duration. It is possible to prevent plasma collapses by changing the rotation profile, as demonstrated in TEXTOR [2]. In both cases, however, the coupling modes remain for some time without showing any sudden disruptions. In spherical tokamaks (ST), internal reconnection events (IREs) are frequently observed in START [3], MAST [4], NSTX [5], and TST-2 [6]. Precursors with low toroidal mode numbers (n) are also frequently observed. An IRE accompanies a spike (increase) in the plasma current I_p due to a reduction in the internal inductance l_i (i.e., flattening of the current density profile), flattening of the pressure profile, and collapse of the SXR, density, and stored energy. Although IREs often trigger a major disruption (major IRE), the plasma frequently survives after the collapse (minor IRE). In MAST, a saturated tearing mode ($m/n = 2/1$) and sudden growth of the second precursor ($n = 2$) mode are observed just before the collapse (< 0.5 ms) [7]. Thus, we need to clarify the relationship between those precursors and compare the characteristics with tokamak experiments. IRE behaviour was studied theoretically by three-dimensional MHD simulations [8], which predicted that linear and non-linear growth of pressure-driven modes trigger plasma collapse, described as follows. During non-linear coupling of toroidal modes, toroidal phase alignment between low-n modes was observed, leading to a larger localized deformation of the plasma and a local steepening of the pressure profile. Due to the increased pressure gradient, high-n pressure-driven modes can grow, resulting in reconnection of the internal and external magnetic fields. Once reconnection happens, plasma (heat and particles) is expelled quickly from the core to the periphery along the reconnected field lines, because the parallel flow is much faster than the radial diffusion. In TST-2 [9], R_0 (major radius) $= 0.38$ m, a (minor radius) $= 0.25$ m, B_t (toroidal magnetic field) ≤ 0.3 T, and $I_p \simeq 0.1$ MA: IREs show $n = 1$ and $n = 2$ modes, and in many cases an increase in the ion temperature of impurities (such as OV and CIII) is observed, suggesting release of magnetic energy by magnetic reconnection [6, 10]. In this paper, we focus on the phase relationship between the precursor modes.

A tangential pin-hole camera with a 20-channel PIN-diode array is employed to measure the radial SXR profile in the region R_{tan} (tangency radius) = 0.15-0.63 m. The sensitive energy ranges from a few eV to 10 keV, and the frequency responses are up to about 100 kHz. In addition, eight-channel magnetic probes (n-coils) distributed along the toroidal direction

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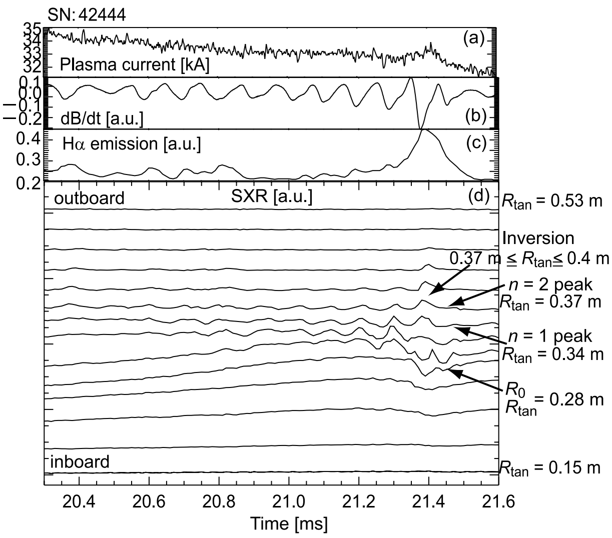

Fig. 1 Waveforms with an IRE. (a) I_p [kA] (plasma current), (b) dB/dt [a.u.] from the n-coil. (c) $H_\alpha$emission [a.u.] (d) SXR signals obtained by the tangential SXR camera.

$(0°, 30°, 90°, 112.5°, 127.5°, 180°, 220°)$ are used for understanding the toroidal mode structure. Figure 1 shows a trace of the typical IRE in an ohmic discharge. The plasma shows an inward shift to $R_0 \sim 0.28$ m and $a \sim 0.16$ m, determined from the SXR profile. I_p increases from $t = 21.3$ ms (a) and the n-coils show growth of magnetic fluctuations (b) and identify $n = 1$ ($\sim$ 10 kHz) and $n = 2$ ($\sim$ 20 kHz). H_α emission suggests plasma wall interactions, showing a rapid increase from $t = 21.3$ ms (c). The SXR profile shows that heat and particles are expelled from the core after the collapse at $t \sim 21.35$ ms (d). After that, an increase in the SXR signal propagates toward the outboard side. Each mode profile can be resolved by taking the corresponding frequency components. The $n = 1$ and $n = 2$ modes show peaks at ρ (normalized radius) ~ 0.4 ($R_{tan} = 0.34$ m) and $\rho \sim 0.6$ ($R_{tan} = 0.37$ m), respectively. However, both components overlap and interact with each other. The phase difference can be estimated by comparing the corresponding frequency components. At the inversion radius $0.6 \le \rho \le 0.8$ ($0.37\,\mathrm{m} \le R_{tan} \le 0.4\,\mathrm{m}$) where the SXR shows a collapse, the phase difference decreases until the collapse time. The positive peaks between the $n = 1$ and $n = 2$ modes do not show phase alignment until $t \sim 21.2$ ms (Fig. 2). However, after this time the positive peaks of the $n = 1$ and $n = 2$ modes become aligned, as indicated by arrows. This can be seen more clearly by plotting the phase difference between the peaks of the $n = 1$ and $n = 2$ modes, as shown by asterisks in Fig. 3. Since phase alignment occurs before the beginning of the collapse ($t \sim 21.35$ ms), this is believed to be the main cause of the collapse. In many other discharges, the phase difference also decreases towards zero within < 0.5 ms prior to the collapse. Some shots, such as SN42449 (plotted by triangles), show random phase variation, but finally the phase

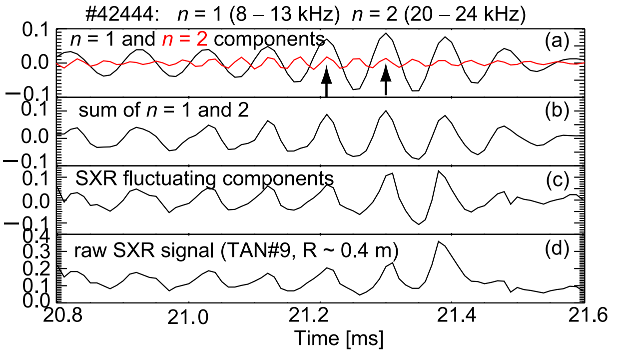

Fig. 2 Time evolution of $n = 1$ and $n = 2$ modes on SXR Ch. 9 ($R_{tan} = 0.4$ m). (a) $n = 1$ and $n = 2$ components of SXR signal [a.u.], (b) sum of the two modes, (c) fluctuating components of the SXR signal [a.u.], (d) raw SXR signal.

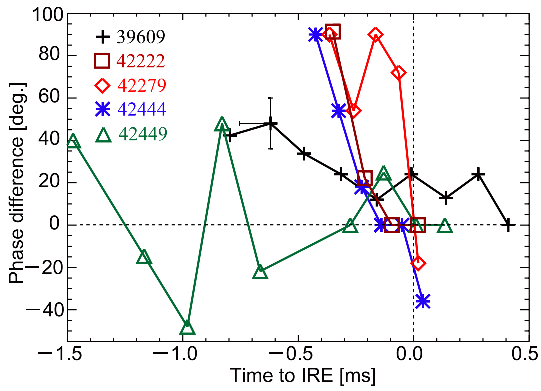

Fig. 3 Time evolutions of the phase difference between the positive peaks of $n = 1$ and $n = 2$ modes near the inversion radius extracted from SXR data in several discharges.

settles at the aligned state. In this case, there are chances to achieve the phase aligned state before $t = -0.3$ ms: however, no collapse occurs. It is likely that rotation shear between different mode positions prevents the couplings or that even if the phase is aligned, the total mode intensity is not enough to trigger collapses. It should be noted that the collapse timings have a slight uncertainty (< 0.1-0.15 ms) because the tangential SXR camera measures only one toroidal location. Since the plasma rotates toroidally, the real collapse time could be earlier than that determined from the SXR profile. Throughout such phase alignment, the total mode intensity tends to increase and enhance the localized deformation, triggering plasma collapses. This characteristic is similar to the MHD simulation, but we did not identify high-frequency modes, which are expected as high-n pressure-driven modes localized at the deformation area. We cannot conclude whether the pressure driven modes with high-n modes appear because limitation of the sampling rate of the digitizer (100 kHz) may prevent the measurements. In summary, precursor profiles followed by IREs on TST-2 are studied by the SXR profile and magnetic fluctuations. Many cases show phase alignment between $n = 1$ and $n = 2$ modes localized at the plasma core, which enhances localized deformation, triggering minor collapse.

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[1] S. Yoshimura *et al.*, Phys. Plasmas **9**, 3378 (2002).
[2] P.C. de Vries *et al.*, Plasma Phys. Control. Fusion **38**, 467 (1996).
[3] T.C. Hender *et al.*, Phys. Plasmas **39**, 1958 (1999).
[4] H. Tojo *et al.*, Plasma Fusion Res. **3**, S1605 (2008).
[5] I. Semenov *et al.*, Phys. Plasmas **10**, 664 (2003).
[6] H. Tojo *et al.*, Plasma Fusion Res. **2**, S1605 (2007).
[7] H. Tojo *et al.*, submitted to Plasma Phys. Control. Fusion (2008).
[8] N. Mizuguchi *et al.*, Phys. Plasmas **7**, 940 (2000).
[9] Y. Takase *et al.*, Nucl. Fusion **41**, 1543 (2001).
[10] A. Ejiri *et al.*, Nucl. Fusion **43**, 547 (2003).