

Triggering Instability of Sawtooth Crash in NBI-Heated Plasmas of CHS Heliotron/Torsatron

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The triggering instability of the annular crash observed in NBI-heated plasmas of the CHS heliotron/torsatron is investigated. Two types of $m \sim 2/n = 1$ magnetic fluctuations, fishbone-like burst mode and low frequency ideal/resistive interchange mode, respectively, grow just before the crash. Time evolution of the amplitude and phase inversion radius of these modes indicate that the low frequency interchange mode is the main triggering instability of the sawtooth crash in CHS.

Keywords:

CHS, sawtooth, annular crash, fishbone-like burst mode, interchange mode

Sawtooth oscillation, a typical magnetohydrodynamic (MHD) phenomenon, is well known in tokamak and helical plasmas. Though a large number of investigations have been conducted to explain crash phenomena, some open questions and inconsistencies between experiments and theories [1] remain. One important issue is the abruptness of the growth of fluctuations that lead to crashes. This is often called the "magnetic trigger". Investigation of magnetic triggers is important to reveal crash mechanisms.

In the Compact Helical System (CHS) heliotron/torsatron, sawtooth oscillations are often observed in inward-shifted ($R_{ax} = 0.92$ m) plasmas heated by neutral-beam-injection (NBI) [2,3]. Typical plasma parameters of such an experiment are: toroidal field $B_\phi \leq 1.5$ T, plasma beta $\langle \beta_{dia} \rangle \approx 0.1\text{--}0.4\%$, and plasma current $I_p \approx 5\text{--}15$ kA. The sawtooth oscillations in CHS show the following characteristic features: (1) the instabilities are associated with the $q = 2$ (q is the safety factor) surface located at $r/a \approx 0.5$, and (2) the instabilities lead to plasma collapse only in a narrow annular region [4]. The characteristics of crashes in CHS are similar to those of the $q = 2$ off-axis sawteeth observed in negative shear

(NS) tokamaks having a non-monotonic q profile [5]. Two types of magnetic fluctuations grow just before the crash in this discharge condition. One is a high frequency fishbone-like burst mode (FB) excited by energetic ions in the frequency range of 10–30 kHz, and the other is a low frequency mode (LF) of 2–8 kHz, which is thought to be an ideal or a resistive interchange instability [6,7]. Both modes have $m \sim 2/n = 1$ (m and n : poloidal and toroidal mode number) mode structure. Most probable instabilities triggering the sawtooth crash are ideal/resistive interchange modes in helical plasmas. On the other hand, observations on ASDEX-Upgrade show that fishbone instability leads to a redistribution of electron temperature and impurity density, which features are similar in form and magnitude to those of sawtooth crash [8]. Identifying which mode is the main triggering instability in CHS is of interest.

Figure 1 shows typical time traces of soft X-ray (SX) signals at two radial positions, just inside and just outside the sawtooth-inversion radius, for one period of the sawtooth oscillations in CHS plasmas, together with magnetic fluctuations of FB and LF modes. The crash occurs at $t \approx 127.8$ ms, and is indicated by a vertical

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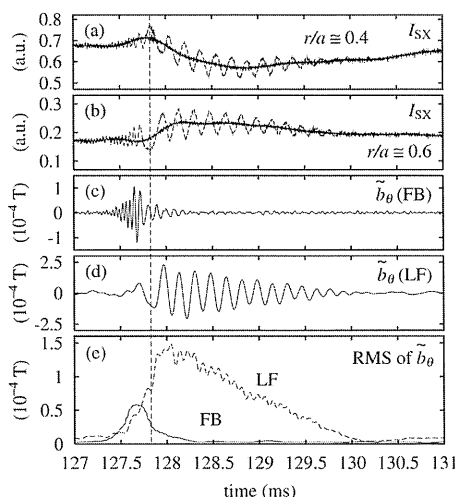


Fig. 1 Time traces during the annular crash in CHS: (a) SX raw and low frequency signals just inside the sawtooth inversion radius ($r/a = 0.4$); (b) just outside the radius ($r/a = 0.6$); (c) Magnetic fluctuations of $m \sim 2/n = 1$ FB ($f = 10\text{--}30$ kHz); (d) $m \sim 2/n = 1$ LF mode ($f = 2\text{--}8$ kHz); (e) root-mean-squared amplitudes of FB and LF modes in magnetic fluctuations. The crash occurs at $t = 127.8$ ms, and is indicated by a vertical dotted line.

dotted line in the figure. The SX intensity at $r/a = 0.4$ drops first, at the time of the crash, then the inverted signal is observed at $r/a = 0.6$. The root-mean-squared (RMS) amplitudes of the FB and LF modes in magnetic fluctuations are shown in Fig. 1(e). These time behaviors are very similar to those of SX fluctuations. Both modes start to grow abruptly about 0.5ms before the crash. In association with the growth of the LF mode, the SX signal at $r/a = 0.4$ begins to decrease. On the other hand, FB amplitude is already decaying when the crash occurs. This indicates that the LF interchange mode is the main trigger mode of the sawtooth crash in CHS.

The internal structure of these $m \sim 2/n = 1$ modes is essential to identification of the rational surface position. Radial profiles of the amplitudes of FB and LF modes detected on SX signals are shown in Fig. 2(a). FB has a strong peak around the plasma center. LF mode has a peak around $r/a = 0.5$, and does not have a peak in the plasma center. The radial profiles of the phases for the respective modes are shown in Fig. 2(b). The position of the phase inversion of the LF mode locates around $r/a = 0.5$, which is close to the $q = 2$ rational surface in this experimental condition, and that of FB locates appreciably inside the $q = 2$ surface.

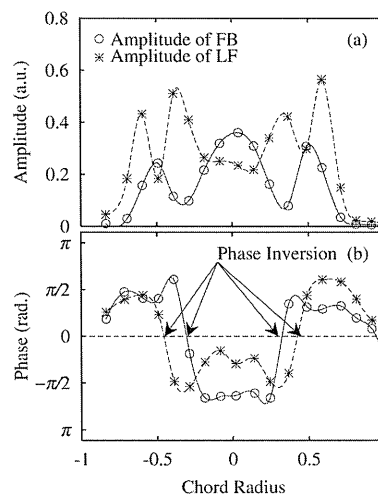


Fig. 2 Radial profiles of the amplitude (a) and phase (b) of $m \sim 2/n = 1$ FB (127–128 ms) and LF modes (128–130 ms), which were obtained from SX signals.

In NS tokamaks, the development of the double-tearing instability between two off-axis $q = 2$ surfaces is thought to be the driving mechanism of the $q = 2$ off-axis sawtooth. If the double-rational surfaces of $q = 2$ can occur under our experimental conditions, instabilities related to them may also occur in CHS. The current density profile estimated from a numerical code based on the drift kinetic equation and Monte Carlo simulation is almost a parabolic profile of power index 2, and such a profile cannot generate the double-rational surface of $q = 2$ [9]. Thus, the possibility of an instability related to the double-rational surfaces will be ruled out in the sawtooth oscillations of CHS.

In conclusion, the LF interchange mode that grows around the $q = 2$ rational surface induces the annular crash in NBI-heated inward-shifted plasmas of CHS.

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