OFF-AXIS SAWTOOTH CRASH IN THE COMPACT HELICAL SYSTEM HELIOTRON/TORSATRON

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Introduction

A tokamak plasma configuration with negative magnetic shear ($q' < 0$) has attracted as an operational mode which enables to attain high beta and high confinement plasmas with large bootstrap current fraction in a future economical steady-state reactor. In recent negative magnetic shear experiments in several tokamaks, $q = 2$ off-axis sawteeth which lead to plasma collapse only in an annular region around the $q = 2$ surface are observed.[1−3] The driving mechanism of the $q = 2$ off-axis sawtooth is thought to be a double-tearing reconnection at the double rational surface of $q = 2$ in non-monotonic q-profile. In the compact helical system (CHS) heliotron/torsatron ($R = 1\,\mathrm{m}$, $\langle a \rangle \sim 0.2\,\mathrm{m}$, $B_\phi \leq 2\,\mathrm{T}$), where rotational transform profile is similar to that in the nagative magnetic shear configuration of a tokamak, $q = 2$ off-axis sawtooth oscillations are often observed in neutral beam injection (NBI) heated plasmas.[4,5] Comparison study of this type of sawtooth in CHS with that in the negative magnetic shear tokamak is important and interesting. This investigation of another type of sawtooth crash other than a familiar $q = 1$ sawtooth crash may give us much information about magnetic reconnection physics.

Experimental Results

Although magnetic configuration is basically formed by external coils in helical plasmas without large toroidal net current, tangentially injected neutral beams can drive the toroidal net current. The beam-driven current by the co-injected NBI is sufficiently small to destabilize current-driven instabilities, but can appreciably change the rotational transform profile. Magnetic shear and magnetic well region decrease by this current and pressure-driven instabilities become unstable. Thus, the effects of the net current is important for stabilization of pressure-driven magnetohydrodynamic (MHD) instabilities. In CHS, Sawtooth oscillations are observed in relatively low density ($\bar{n}_e \simeq 1 - 3 \times 10^{19}\,\mathrm{m}^{-3}$)

and low beta (plasma beta evaluated from diamagnetic measurement $\langle\beta_{dia}\rangle \leq 0.5\,\%$) plasmas with a small net current ($I_p \simeq 5-15\,\mathrm{kA}$), of which current is induced by co-injected NBI. In Fig. 1, data points of I_p and $\langle\beta_{dia}\rangle$ are plotted for the conditions with and without sawtooth crashes, at $B_\phi = 1.2$ and 1.5 T. Lower current limit for the appearance of

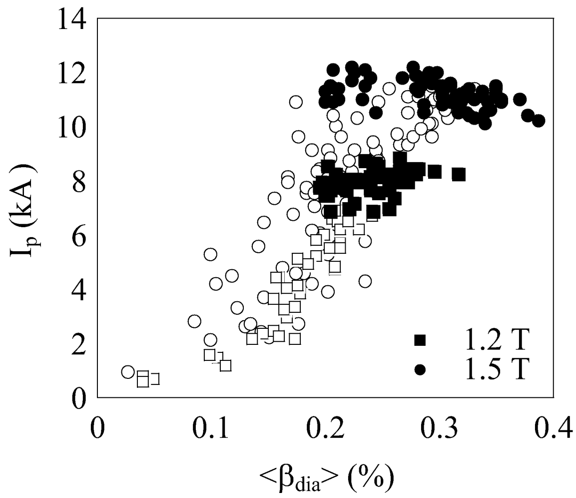

Figure 1: Plasma conditions where sawtooth crashes are observed are summaraized on I_p - $\langle\beta_{dia}\rangle$ plane. Solid symbols indicate the conditions with sawtooth crashes, and open ones for no sawtooth crash.

sawtooth crashes (for example, $I_p \sim 7\,\mathrm{kA}$ at $B_\phi = 1.2\,\mathrm{T}$) tends to decrease with the decrease in B_ϕ. In these cases, the rotational transform profile including net current effects is similar for each lower limit current. This indicates the existence of threshold value of magnetic shear that causes the sawtooth crash.

Typical time traces of sawtooth oscillations obseved with the soft X-ray (SX-) detector array and magnetic fluctuations are shown in Fig. 2(a). High frequency precursors of $10-50\,\mathrm{kHz}$ having $m/n = 2/1$ (m: poloidal, n: toroidal mode number) mode structure are preceded for the sawtooth crash. These instabilities are thought to be fishbone-like burst mode excited by energetic ions and their characteristics are investigated previously.[6,7] Large amplitude $m/n = 2/1$ postcursors of several kHz are enhanced just after the crash. Radial profile of local SX emissivities at the $q = 2$ sawtooth where line-integrated effects are eliminated is shown in Fig. 2(b). Thr profile change of SX emissivity clearly shows the annular relaxation and the inversion radius of the crash observed is $\rho \simeq 0.5$ and agrees well with the location of the $1/q = 1/2$ rational surface in the rotaitonal trasform profile including the net current effects. The double-rational reconnection may not excited because the double rational surface of $q = 2$ is not realistic in our experimental conditions. Moreover, the sawtooth crash in CHS may be excited by interchange modes with or without energetic ion effects instead of double-tearing modes in tokamaks.

For the sawtooth period τ_{saw} (repetition time of the sawtooth crash), much attention

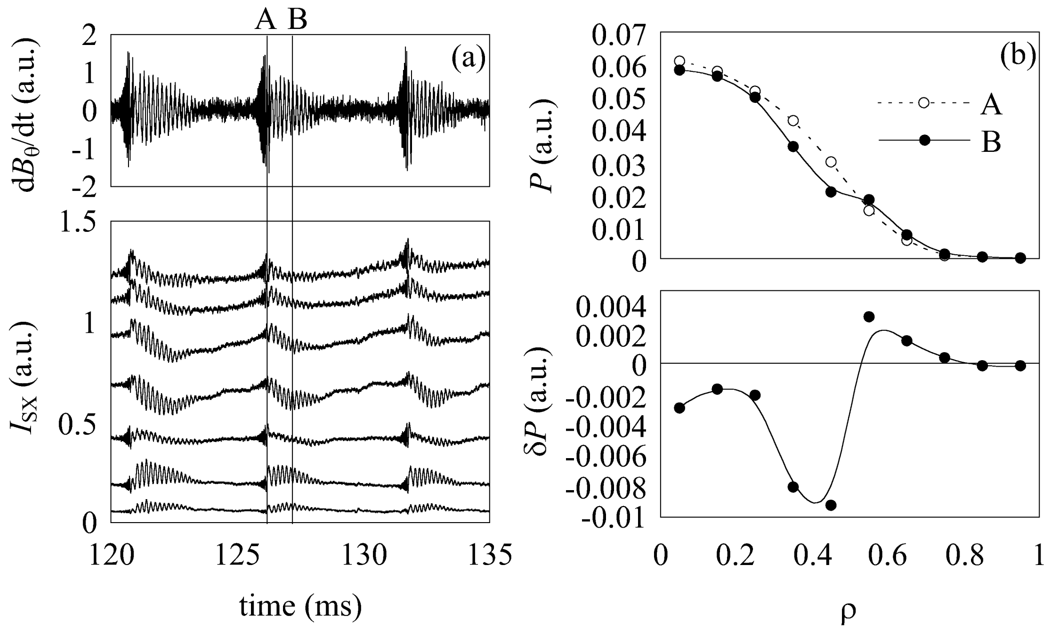

Figure 2: (a) Typical time traces of SX signals at $r/\langle a\rangle = 0.08$, 0.18, 0.29, 0.39, 0.49, 0.59 and 0.71 from upper trace, togehter with magnetic fluctuations for a two periods of sawtooth oscillation. (b) Local SX emissivity profile just before (A) and after (B) the sawtooth crash. δP is the increment of the SX emissivity just after the crash for that just before it.

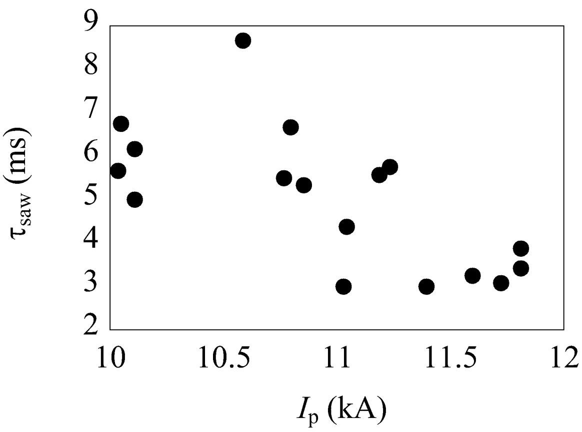

Figure 3: Sawtooth period as a function of plasma current in the case of $B_\phi = 1.5\,\mathrm{T}$

is paid from a viewpoint of the MHD stability. In CHS, the sawtooth period sensitively depends on the value of the net plasma current (i.e. magnetic shear near the $q = 2$ surface). The sawtooth periods τ_{saw} in the case of $B_\phi = 1.5\,\mathrm{T}$ are shown in Fig. 3. The period τ_{saw} tends to decrease with the increase in the plasma current.

Summary

In the CHS heliotron/torsatron, $q = 2$ sawtooth oscillations are observed in NBI heated plasmas. The sawtooth crash indicates a character of an annular crash. Lower current limit for the appearance of sawtooth crashes tends to decrease with the decrease in the toroidal magnetic field. The sawtooth period sensitively depends on the value of the plasma current.

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