ACTIVE CONTROL OF INTERNAL DISRUPTIONS VIA COLD PULSE PROPAGATION IN ADITYA-U TOKAMAK.

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Internal disruption [1] in a tokamak plasma is a quasi-periodic phenomenon where electron temperature gradually rises in the core region followed by a sudden crash. The mechanisms for the sudden temperature crash are not yet well known. The instabilities that cause internal disruptions are referred to as sawtooth instability because of the periodic nature of the disruptions, which imitate sawtooth-like oscillations. The phenomenon is detrimental to heating and particle confinement in the core of the plasma. The study of internal disruptions or the sawtooth crash is important for better understanding of the major and minor disruptions in Tokamaks. The sawtooth-crash also leads to generation of instabilities affecting the steady-state scenario [2] of fusion grade plasmas. Therefore, the disruption needs to be controlled; though, its complete suppression is not desirable, as it can lead to impurity peaking which causes substantial degradation of confinement. A controlled stabilization is thus ideally desirable to proceed towards the fusion reactor goal. The sawtooth crash is attributed to magnetic relaxation by Kadomstev's well-known resistive reconnection model [3], which considers excitation and nonlinear growth of a m/n=1/1 internal kink or tearing mode near the q = 1 surface (m and n are poloidal and toroidal mode numbers, respectively and q, the safety factor, is a measure of the helicity of the magnetic field) to be the cause behind the internal disruption. The model predicts crash times that agree well with several tokamaks but predicts much larger crash time than that observed (~ 100µS) in large tokamaks. Furthermore, the mode oscillations are not always observed before the crash. So, understanding sawtooth relaxation remains an open question, and deserves further studies to control it effectively. Several models have been proposed to explore possible mechanisms for the stabilization: some are based on controlling the fast particles generated during heating mechanisms to lower the pressure gradient, while others depend on decreasing the magnetic shear near the q=1 region. It has been conjectured that the growth rate of the m/n = 1/1 mode can be influenced by the presence of energetic ions [4] [5], or by intrinsic plasma rotation, or by shear in rotation. Dynamic modification of plasma parameters near q= 1 surface seems to be crucial to prevent the crash. Experimentally, localized heating by lower-hybrid current drive, ion-cyclotron resonance heating, electron cyclotron resonance (ECR) heating and neutral beam heating [4], have demonstrated substantial control of the sawtooth stabilization. Recent experiment in DIII-D tokamak [6] using ECR heating suggests the temperature turbulence inside the inversion radius (a radius beyond which the sawtooth character reverses) is involved in triggering the sawtooth crash. In this paper, we present employment of a successful alternate scheme that experimentally demonstrate delaying the sawtooth crash substantially in ADITYA-U tokamak, by controlling the plasma temperature profile inside the q =1 surface.

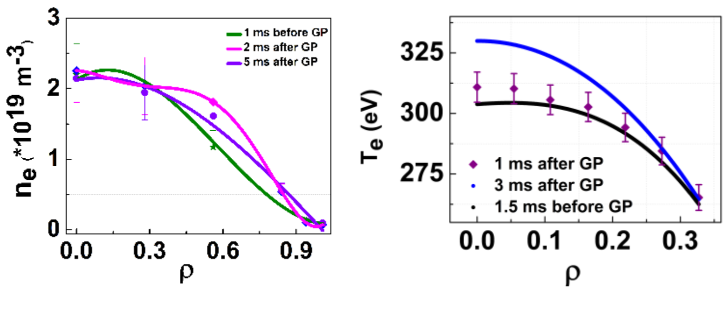

Figure 1: (a) Radial profile of density and (b) radial profile of core T_e before and after gas-puff. The curves are the spline fits to the experimental data (symbol)

The scheme involves injection of short puffs of fuel-gas (containing around ~10^{17}-10^{18} molecules/m^3) in the plasma edge. The injection results in a cold-pulse propagation [7] which modifies the radial profile of plasma density in the mid-radius region and subsequently modifies the electron temperature profile in the core region (inside q=1 surface) as depicted by the fig.1. To examine the sawtooth activity closely, the time span 150-170 ms during the plasma current flat-top is shown in figure 2.

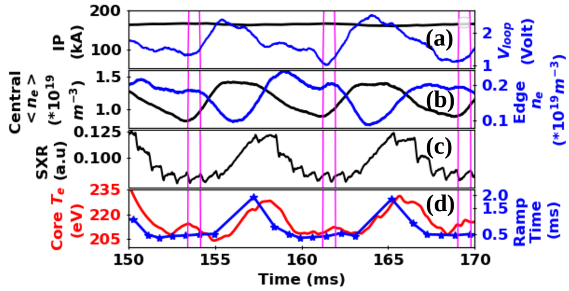

Figure 2: Temporal evolution of (a) I_p (black), V_{loop} (blue) (b) $< n_e >$ (black), edge n_e (blue) (c) central chord SXR intensity (black) (d) core T_e (red solid line), Ramp time of sawteeth cycle (blue stars) (Shot # 33689).

Impact of the gas pulse injection (done repeatedly at 8 ms intervals) is clearly visible on the sawtooth oscillations in SXR intensity (Figure 2c), as well as on I_P, V_{loop}, $\bar{n}_e$, n_e^{edge} (at r = 24 cm) and T_{e0}. The most interesting point to note here is that the ramp phase is extended substantially after each gas-puff and the crash is delayed. The ramp time of each cycle is plotted in Figure 2d. After each gas-puff the ramp time is increased to nearly 1 - 1.5 ms, which is about double the time compared to that seen without gas-puff. The increment in the ramp time gradually decreases in subsequent sawtooth pulses and attains the pre-gas-puff value after 3-4 cycles depending on the amount of gas injected.

Experiments on ADITYA-U tokamak show a marked enhancement in the sawtooth period by application of short gas-puffs of fuel that cause a modification of the radial density profile. A consequent suppression of the trapped electron modes (TEMs) then leads to an increase in the core electron temperature. This slows down the heat propagation following a sawtooth crash causing a delay in achieving the critical temperature gradient inside the q = 1 surface required for the next sawtooth crash to happen. The overall scenario has strong similarities with the behavior of sawtooth under electron cyclotron resonance heating (ECRH). Our findings suggest an alternate, simpler technique for sawtooth control that may be usefully employed in small/medium sized tokamaks that do not have an ECRH or any other auxiliary heating facility.

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