ANALYSIS AND UNDERSTANDING OF ACCELERATED MODE DISRUPTIONS IN THE ADITYA-U TOKAMAK

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Disruptions in tokamaks are catastrophic events marked by a rapid loss of plasma confinement [1], accompanied by a sudden decline in thermal energy and plasma current over extremely short timescales. A detailed statistical analysis of disruptions in the Aditya-U tokamak has led to the identification of a novel disruption type, termed Accelerated Mode Disruption (AMD). Unlike conventional locked-mode disruptions [2], AMD evolves in two distinct phases: first, a gradual increase in mode frequency with a nearly constant, large amplitude over time, followed by a rapid shift involving a sharp drop in frequency and a rise in amplitude, indicating the precursor phase within a shorter time scale. This study establishes key diagnostic markers for AMD, including the edge safety factor (q_{edge}), radiated power (P_{rad}), current quench time ($\Delta\tau$), and current quench rate, which serve as critical parameters for distinguishing disruption modes and formulating targeted mitigation strategies.

In the Aditya-U tokamak [3], drift-tearing instability (DTM) with mode number (m/n = 2/1) is identified as a primary driver of disruptions [4], operating within a characteristic frequency range of 1–15 kHz. This instability controls the growth of tearing modes via coupling with drift modes, exhibiting an inverse relationship between frequency and amplitude—where an increase in frequency corresponds to a decrease in amplitude, and vice versa. The frequency evolution of DTM is governed by three fundamental physical effects: diamagnetic frequency (ω), toroidal velocity (V_{φ}) and poloidal velocity (V_{θ}) [5]. To investigate the dynamics of AMD, multiple diagnostics have been employed, including soft X-ray (SXR) measurements for thermal quench identification, bolometric analysis for radiated power estimation, SXR chords for tracking plasma column shifts, and H-alpha diagnostics for quantifying displacement. Additionally, Langmuir probes are utilized to analyze variations in floating potential, edge density, and radial electric field (E_r) dynamics preceding the precursor phase.

In several plasma discharges of the Aditya-U tokamak, the (2/1) tearing mode frequency exhibits a linear increase over time, rising from 6–8 kHz to 16–18 kHz within 10–15 ms. This frequency ramp-up is followed by the emergence of an MHD precursor in the Mirnov signal. Subsequently, the (2/1) mode frequency undergoes a sharp drop (6–8 kHz) from its peak value, coinciding with the onset of both thermal and current quench events as shown in Fig-1. Notably, during this frequency increase, no significant rise in radiative power loss is observed [6]. Soft X-ray diagnostic chords indicate an inward plasma shift, further corroborated by the H-alpha signal.

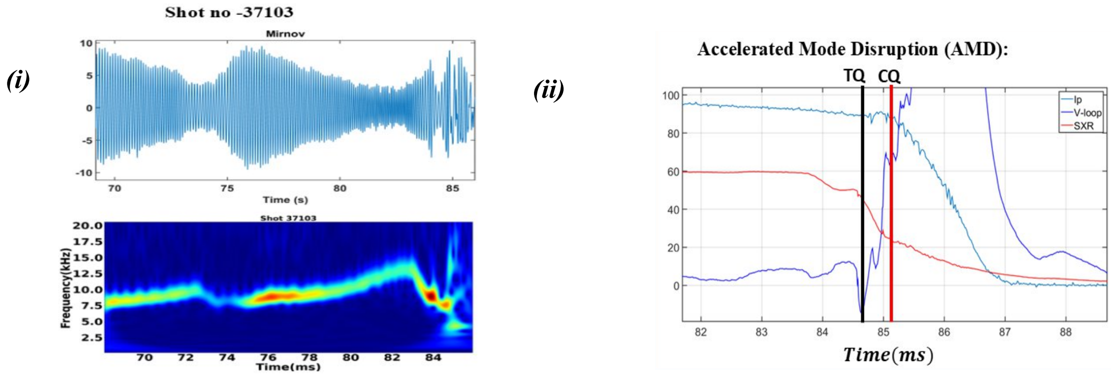

Fig. 1. (i) Time evolution of MHD mode amplitude and frequency (ii) Disruption characterized using loop voltage negetive spike (V_{loop}), thermal quench (SXR) and current quench (Ip)

Analysis of Mirnov coil data reveals an inverse relationship between mode frequency and amplitude; however, the amplitude remains substantially large throughout the disruption evolution.

A statistical comparison between Accelerated Mode Disruption (AMD) and locked-mode disruption (LMD) reveals fundamental differences in disruption dynamics as shown in Fig-2. When the edge safety factor (q_{edge}) exceeds 4, the probability of AMD occurrence increases significantly. Additionally, AMD is characterized by a shorter current quench time ($\Delta\tau < 1.5$ ms), whereas LMD typically exhibits $\Delta\tau > 1.5$ ms [7]. The current quench (CQ) rate, a critical factor influencing mechanical and electromagnetic stresses on the vessel components, is notably higher in AMD, exceeding 55 MA/s, compared to the relatively lower CQ rate observed in LMD.

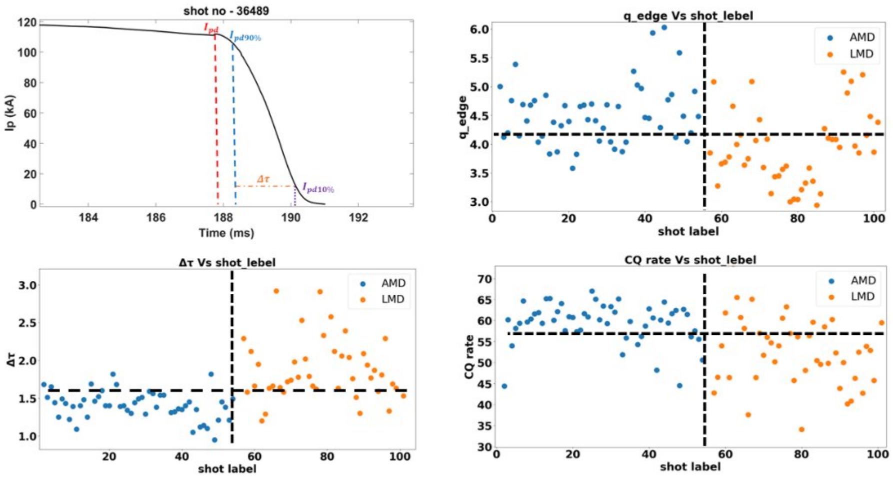

Fig. 2. (i) Current Quench characterization (ii) Statistical data of q_{edge} value for AMD and lock mode disruption (iii) Statistical data of time for current quench in AMD and lock mode disruption (iv) Statistical data of CQ rate for AMD and lock mode disruption

In conclusion, this study presents the identification and characterization of Accelerated Mode Disruption (AMD) in the Aditya-U tokamak through a comprehensive statistical analysis of multiple plasma discharges. AMD is distinguished by a linearly increasing mode frequency, sustained large fluctuation amplitude, and a higher CQ rate than conventional locked-mode disruptions. Plasma discharges with $q_{edge} > 4$ are particularly susceptible to AMD. The underlying physics suggests a nonlinear evolution of the (2/1) tearing mode, leading to confinement degradation and eventual disruption. Understanding AMD is crucial for devising effective disruption mitigation strategies in future tokamak experiments

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