Experimental Study of Secondary Instability to 2/1 Magnetic Island in Compass Density Limit Disruptions

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Introduction

- Increase in electron density n_e ⇒ edge cooling ⇒ plasma current I_p profile shrinkage ⇒ MHD mode excitation, particularly $m/n = 2/1$ magnetic island where m and n are poloidal and toroidal mode numbers respectively.
- During non-linear growth of the $2/1$ magnetic island, a rapid fall in the electron temperature profile called thermal quench (TQ) is followed by a subsequent loss of the plasma current called current quench (CQ).
- Such an unplanned termination of the plasma discharge, which limits the maximum electron density, is known as Density Limit Disruption (DLD).
- TQ is admitted as the most critical phase but the active mechanism behind its triggering is not yet fully accepted.
- It is somehow linked to the growth of magnetic islands, the most pronounced often being the $2/1$ island.
- TQ phase is usually attributed to be triggered by stochastisation of the field lines due to overlapping of the islands of different helicity that can be locked with the vessel wall, but can also be rotating.
- In a recent study[1], focused only on the locked modes, TQ was found to be triggered when the mode amplitude has reached a distinct level.
- At JET, just at the outset of TQ, a secondary instability (SI) was identified during growth of $2/1$ magnetic island[2].
- A systematic study in COMPASS DLDs, primarily on Ohmic D-shaped plasmas at $q_{95} \sim 4$, with focus on the interrelation between the SI and the growing $2/1$ mode also complemented the observations of SI at the onset of TQ phase[3,4,5].
- In COMPASS, DLD was noticed preceding to both rotating (~ 85% cases) as well as to the quasi-locked modes (remaining least cases).
- TQ was found to develop in all the analyzed DLD discharges when SI was clearly visible, not essentially at a particular value of the mode amplitude as proposed by the study[1] based only on the quasi-locked modes.
- In this study, SI emerges as a potential active mechanism for triggering TQ phase of DLD.
- Moreover, SI observations in two distinct size plasmas (COMPASS and JET) reveal that SI is not just a machine dependent instability.
- SI is, therefore, plausibly expected at the onset of TQ phase of DLDs in other tokamaks including ITER.

COMPASS Tokamak[6]

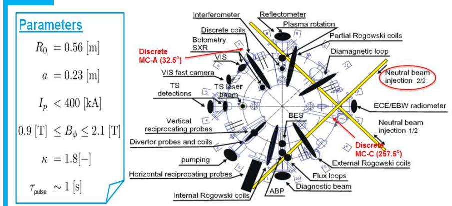

Figure 1: Basic Parameters and Diagnostics of COMPASS

Plasma parameter	Typical range
Edge safety factor q_{95} [–]	~ 4 (fixed)
Plasma current I_p [kA]	140 – 230
Line-averaged electron density n_e [$\times 10^{19}$ m^{-3}]	7.0 – 11.2
Toroidal magnetic field B_ϕ [T]	0.92 – 1.38
Poloidal magnetic field at LFS B_θ [T]	0.11 – 0.19
Poloidal magnetic field at HFS B_θ [T]	0.21 – 0.39
Normalized beta β_N [%]	1.2 – 1.5

Table 1: Basic Plasma Parameters of the Scanned L-mode Diverted D_2 – Puff Discharges

Mode Analysis and SI Observations in COMPASS

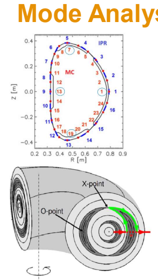

Figure 2: Mode Analysis by MC Data

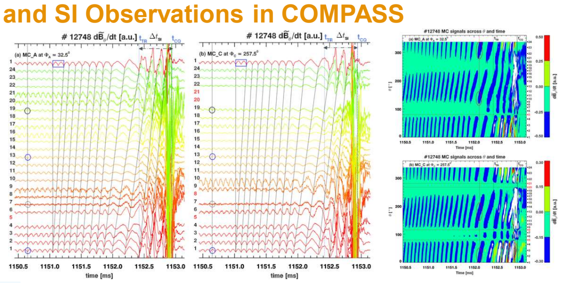

Figure 3: SI Observations to a rotating $2/1$ magnetic island at t_{TR}

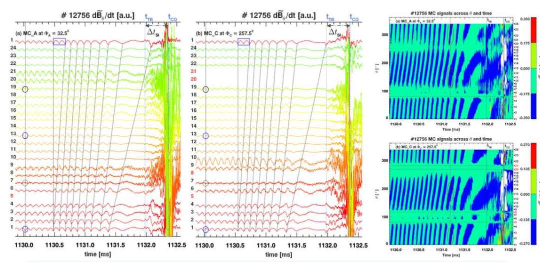

Figure 4: SI Observations to a quasi-locked $2/1$ magnetic island at t_{TR}

SI Characterisation in COMPASS

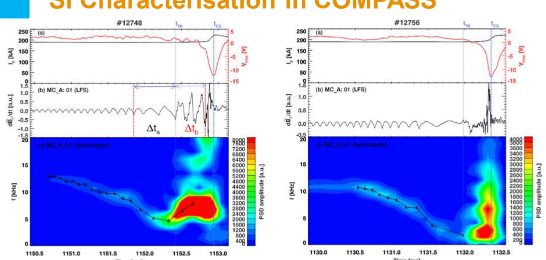

Figure 5: SI Characterisation by Mode Frequency $f_{2/1}$ at t_{TR}

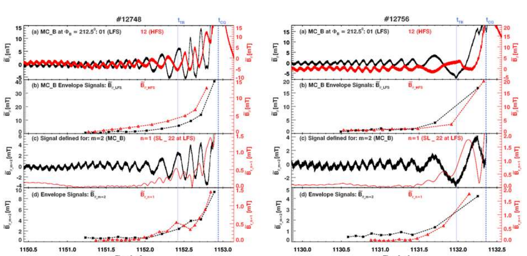

Figure 5: SI Characterisation by Mode Amplitude $\tilde{B}_r$ at t_{TR}

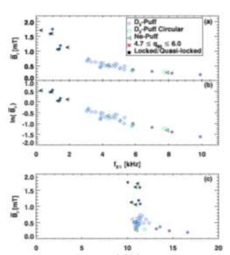

Figure 6: Interrelation of $\tilde{B}_r$ and $f_{2/1}$ at t_{TR}

Conclusions

- At some transition time t_{TR} in the precursor of DLD, the sinusoidal $d\tilde{B}_\theta/dt$ oscillations of the evolving $2/1$ magnetic island become anharmonic and exhibit higher frequency but smaller amplitude perturbations revealing an SI.
- SI appears, prior to TQ, both to the rotating as well as to the quasi-locked $2/1$ modes.
- No poloidal m or toroidal n mode number can be assigned to this SI, in consensus with SI observations in JET.
- SI undergoes fast non-linear dynamics during a time interval $\Delta t_{SI} \equiv t_{CQ} - t_{TR}$ as both its frequency and amplitude commence increasing, independent of the growth of $2/1$ mode.
- During Δt_{SI}, degradation of the energy confinement also occurs that culminates abruptly at TQ phase.
- Δt_{SI} in COMPASS is found 2 orders of magnitude less than that in JET DLDs.
- In COMPASS, SI is characterised by the $2/1$ mode amplitude $\tilde{B}_r$ and its rotation frequency $f_{2/1}$ at t_{TR}.
- At t_{TR}, $\tilde{B}_r$ displays a random variation within a range of values at odds with the recent study[1] focused only on locked modes where it was concluded that $\tilde{B}_r$ attained a distinct value before TQ.
- This study reveals that just about the outset of TQ phase, $\tilde{B}_r$ and $f_{2/1}$ have an inverse relation at t_{TR}, implying that TQ can start at different range of $\tilde{B}_r$ values, depending on what is the island rotation frequency $f_{2/1}$ at the onset of SI ⇒ TQ does not essentially occur at a critical value of the mode amplitude $\tilde{B}_r$ or island width.
- SI emerges as a more credible empirical trigger for the TQ phase of DLDs than $\tilde{B}_r$ or any other signal.
- A broader study of SI, based on the experimental data of other existing tokamaks, may play an essential role in developing disruption control and mitigation techniques more reliably for future fusion devices including ITER.

References

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