Observation of Secondary Instability of 2/1 Magnetic Island in COMPASS High Density Limit Plasmas

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Introduction

Density limit disruptions (DLDs) have been observed in tokamak plasmas when high density regimes are explored. The DLDs are harmless in small size tokamaks like COMPASS, larger tokamaks like JET try to avoid them and they are extremely undesirable in ITER size tokamaks due to the severe structural damages they can cause. It is very important to understand the dynamics of the DLDs so that better strategies to ameliorate or avoid them can be developed. In this work, following detection in JET [1] of a secondary instability (SI) to the well-known $m/n = 2/1$ MHD mode (where m and n are the poloidal and toroidal mode numbers, respectively) in the precursor of DLD, we analyse the evolution of the $2/1$ magnetic island in COMPASS DLD to look for the presence of this SI just close to the onset of energy quench phase of the disruption. The presence of this SI to the magnetic island was associated with the occurrence of minor disruptions preceding the major disruption and with the major disruption itself in [1]. The coherence observed between the perturbations caused by the SI in the magnetic poloidal flux and in the electron temperature was very high (above 0.9), allowing to determine that the SI perturbations came from the same position as the magnetic island. In the work presented here, only the perturbations in the magnetic poloidal flux are analysed since at the time of the experiments in COMPASS, no diagnostics was operational for measuring the time evolution of the electron temperature with high time rate.

Nonlinear MHD numerical simulations have also shown that island deformation during its rapid growth can lead to the secondary magnetic island formation [2]. A recent review [3] of the theory of current sheet formation that leads to magnetic reconnection discusses the role of plasmoids during magnetic island evolution. Since the validity ranges of the mentioned theoretical works are not directly comparable to the experimental conditions, one cannot claim with certainty that the SI observed in JET [1] and in COMPASS disruptions (reported here) are the same as observed in those numerical works [2, 3]. However, there are some qualitative similarities between them.

The main COMPASS [4] diagnostics used for the analysis in the present work, are the three toroidally separated arrays (A at 32.5°, B at 212.5° and C at 257.5° from the vessel axis) of Mirnov coils (MCs), each with 24 MCs located poloidally. The MC arrays A and C, toroidally separated by 135°, measure the change in poloidal magnetic flux, dB_p/dt. The MC array B, toroidally separated by 180° to the array A, measures the poloidal magnetic field, B_p. These magnetic sensors have good responsivity to high frequency (up to 1 MHz).

Experimental Results

The events discussed here were observed in several (9 out of 12 shots of the DLD experimental session) COMPASS diverted deuterium plasmas with the following typical range of parameters; 190 kA $\leq I_p \leq$ 220 kA, $\bar{n}_e \approx 9 \times 10^{19}$ m^{-3} (40% of Greenwald limit), $B_\phi = 1.15$ T, $a = 0.23$ m, $R_0 = 0.56$ m, and $q_{95} \approx 4$ (see figure 1).

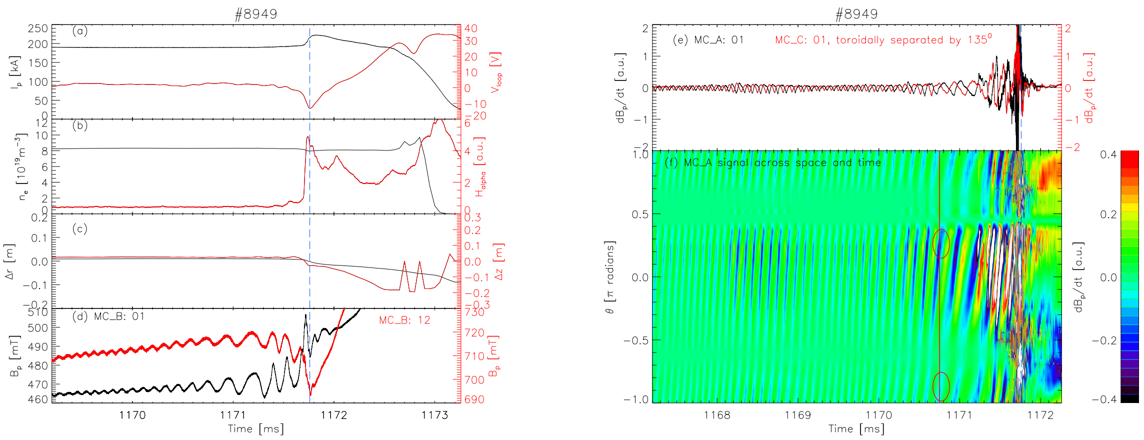

Figure 1: (a) plasma current I_p and loop voltage V_{loop}, (b) central electron density n_e and H_{alpha}, (c) radial Δr (relative to R_0) and vertical Δz (relative to the midplane) displacements of the magnetic axis, (d) B_p measured by MC 01 (on LFS of the midplane) and MC 12 (above HFS of the midplane) of array B, (e) dB_p/dt measured by MC 01 of both arrays A and C, (f) dB_p/dt measured by all MCs of array A, across poloidal angle and time

The density limit was reached by continuous increase of plasma density performed by the gas puff feedback system during the experiment. During the plasma current flat top, the precursor of the disruption revealed a typical magnetic island with $m = 2$ and $n = 1$ (see figure 2). The dB_p/dt spectrogram shows that this MHD mode is destabilized at the beginning of the plasma current flat top, with a rotating frequency of 15 kHz. The amplitude of this magnetic mode increases very slowly for more than 100 ms while the electron density n_e approaches its limit value. The mode growth rate increases and the rotation frequency drops to about 5 kHz in a time

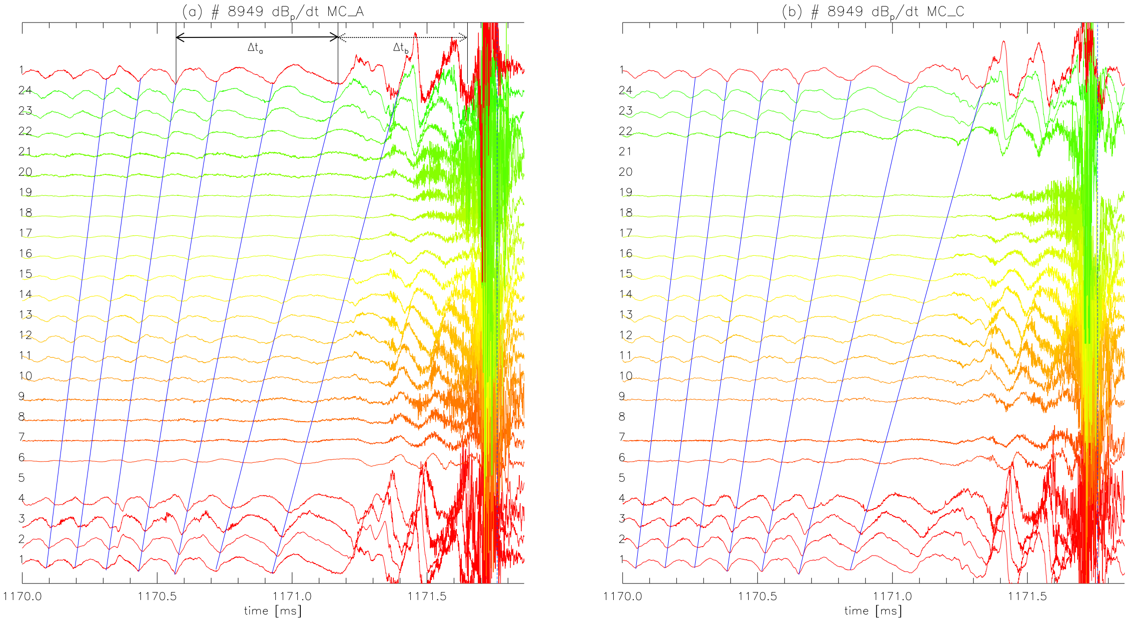

Figure 2: Change in poloidal magnetic flux, dB_p/dt with time, measured by (a) MC array A and (b) MC array C, toroidally separated by 135° to the array A

2 to 3 *ms* before the disruption (see figure 2). This behaviour was the most frequently observed (80% of the cases). In the remaining cases, it was observed that the rotation frequency decreased to just a few Hz, and the mode was quasi locked to the wall.

We are interested in particular in this phase where the rotation frequency decreases, due to the increase in the mode amplitude. SIs are observed to occur, just before major disruptions, either when the mode is rotating at ≈ 5 kHz or when it is quasi-locked to the wall. It is observed in this phase, in particular when δB_p at the low field side (MC 01) of the equatorial plane reaches ≈ 5 mT, that the sinusoidal oscillations of dB_p/dt become distorted and exhibit higher frequency perturbations revealing an SI to the magnetic island (see figure 2 after 1170.5 ms). However, it is more difficult to observe SIs during quasi locked modes with MCs alone. A standard mode analysis of the sinusoidal oscillations of the magnetic island reveals a clear $m = 2$ mode component, as shown in figure 1(f) and figure 2. Applying the same analysis in the period where the SI is observed, no other poloidal mode number is discernible, besides the $m = 2$ component of the underlying magnetic island. However, the SI is clearly visible in the last three oscillations of dBp/dt before the energy quench of the major disruption, at 1170.7 ms. Consequently, no poloidal or toroidal mode number can be assigned to this SI. These main aspects of the SI, observed in COMPASS, are in consensus with the observations in JET [1] DLD.

Figure 3 compares the power spectral density (PSD) of dB_p/dt, measured by MC array A,

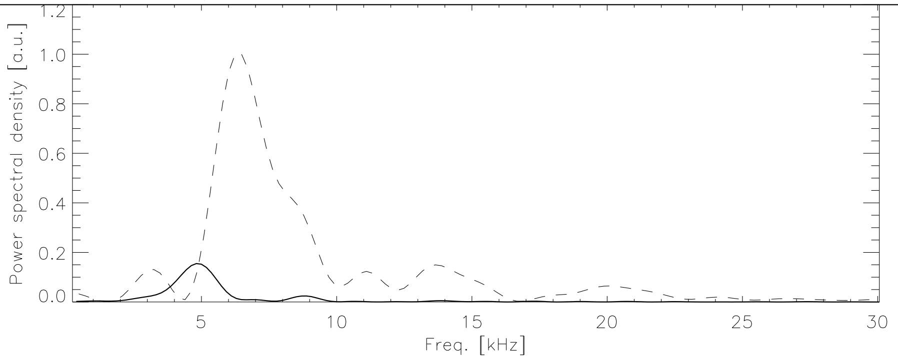

Figure 3: dB_p/dt PSD between two consecutive intervals of time, Δt_a (solid line) and Δt_b (dashed line).

between two consecutive intervals of time shown in figure 2 (a); Δt_a i.e., from 1170.57 ms to 1171.17 ms (solid line) and Δt_b i.e., from 1171.17 ms to 1171.65 ms (dashed line). In each of these intervals, the magnetic island rotates 3 times. The peak in the solid curve at 5 kHz corresponds to the island rotation frequency in interval Δt_a. In interval Δt_b, when the SI is clearly detectable, the maximum power spectral density occurs at a slightly higher frequency of 6 kHz. The higher value of the PSD is due to the poloidal flux increase as the disruption approaches, but higher frequency components are now also visible when the SI is present.

Conclusions

A secondary instability to the rotating 2/1 magnetic island is observed at the onset of COMPASS density limit disruptions. Typically, the magnetic island lasts for about 0.5 ms after the SI is visible. This timescale is about 2 orders of magnitude more in JET [1]. Density limit disruptions are observed to occur either with the 2/1 magnetic island rotating at about 5 kHz or quasi-locked to the wall. No *m* or *n* mode numbers could be attributed to this SI like the one observed in JET. This SI is expected to be observed at the onset of DLD in other tokamaks as well. Better understanding of this SI may play an important role in developing disruption control and mitigation techniques and contribute to a better understanding of the disruption physics.

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