Magnetic fluctuations during the Thermal and current quench of mitigated disruptions and comparison with 3D non-linear MHD predictions

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Plasma disruptions are considered as the main risk for the operation of ITER. In JET, the magnetic fluctuations structures taking place prior to and during the thermal and the current quench of disruption mitigated by massive gas injection (MGI) have been analysed in details and compared with the predictions of the 3D non-linear MHD code JOREK. This experimental analysis makes use of the JET full poloidal (18 coils) and toroidal (8) arrays of pick-up coils sampled at 50kHz for rotating mode up to ~10kHz, the 14 saddle loops for low frequency (<1kHz cut-off frequency) modes and uses the singular value decomposition (SVD) technique to identify the mode structure. The analysis has also made use of the JET soft X-ray arrays to confirm the internal structures of the modes in correlation with the magnetics.

Before the current quench of a discharge with massive deuterium gas injection (86887), it is found that a dominant n=1/m=2 mode and an n=2/m=3 modes are destabilized and their amplitude is growing rapidly (by typically 5 folds) in the window 5ms before the thermal quench and 6ms after the gas is launched by the mitigation valve. The analysis has been repeated for a discharge with massive deuterium + 10%Ar gas injection (89795) and consistent result have been found with in addition the presence of an n=3/m=4 structure growing in the last 2ms before the thermal quench occurs. These analyses support the picture predicted by the JOREK code [1], that the MGI gas destabilizes the n=1/m=2 tearing mode which flattens the current profile, destabilizing a n=2/m=3 mode, which in turn destabilizes higher n modes such as the n=3/m=4. This mode activity is observed to peak at the thermal quench with frequency of a few kHz and then is replaced in about 1 to 2ms by a low frequency activity (300 to 500 Hz) when the n=1/m=2 mode locks and the plasma stops rotating.

Just after the thermal quench, the chain of mode activity disappears but there is a persistent 6kHz mode identified as a core n=1 mode using the fast magnetic pick-up coils and the soft X-ray. Comparing two different massive gas injections with different pressures in the valve (90%D+10%Ar), it appears that this n=1 structure is observed in the low valve pressure case, i.e. when the disruption is imperfectly mitigated (i.e. the total radiation at the end of the current quench lower than in the high valve pressure case). In this case, this indicates that the plasma inside q=1 still exists and survives the massive gas injection for some time. In the high valve pressure case, this core n=1 mode is not observed to persist, indicating that the core has collapsed. JOREK simulations predict an n=1/m=1 kink mode in the core at the time of the thermal quench and this behaviour is also found in NIMROD simulations for other tokamaks [2]. These results suggest that the q=1 surface could prevent the gas penetration until a sawtooth occurs in the mitigation process and provide an explanation why massive gas injection has not been found efficient enough for radiating the plasma energy.

[1] : Nardon E et al 2017 Plasma Phys. Control. Fusion 59 014006
[2] : Izzo V A et al 2008 Phys. Plasmas 15 056109