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Sideband Generated Magnetic Islands and Magnetic Coupling in JET Tokamak

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** See annex of F. Romanelli et al, "Overview of JET Results", (Proc. 22 nd IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).*

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1. INTRODUCTION

The aim of the paper is to study experimentally the poloidal mode number (*m*) spectrum produced by a single toroidal mode number (*n*) Neoclassical Tearing Mode, showing how the sidebands of this spectrum may interact together via magnetic coupling, and how this multiple resonant structure interacts with the plasma, this could give a new point of view to understand the stability properties of these modes. In fact we expect that these sidebands, having different *m* numbers from the main one, can resonate inside the plasma at different radial positions: for example a n=1, m=2 mode produces m=+/-1 sidebands, which may lead to the formation of other magnetic islands at $q=(m+1)/n$, $(m-1)/n$=3, 1.

In the paper this effect has been studied in advanced tokamak plasma scenarios with high triangularity on JET [1] to investigate both the possible dependencies on plasma rotation and normalized beta. In order to detect the presence of islands, a frequency domain coherence technique [2] was implemented using two different diagnostic measurements: the signal from a fast magnetic pick up coil and the set of 48 signals from the Electron Cyclotron Emission (ECE) fast radiometer which measures the radial profile of electron temperature and its temporal fluctuations, with a spatial resolution of about 4 cm and a sampling frequency of 500kHz. The technique is based on the observation that a magnetic island induces also a particular structure in the radial temperature profile fluctuations, in such a way that time fluctuations of the magnetic signals are linked to the time fluctuations of temperature signals coming from localized points inside the plasma [3], and coherence phase radial profile shows a p jump whenever an island is crossed moving along the plasma radius. Also the temperature fluctuation auto-spectrum can be calculated, and can be used in a rough approximation, together with temperature gradients, to calculate the periodic displacement of magnetic surfaces due to island rotation, which is in turn linked to island width. Starting from the magnetic spectrogram in Figure 1, in which also mode n number is highlighted, the whole analysis can be summarized in a plot as Figure 2 in which the radial position of phase jumps for each time slice and for each mode is shown. An example of the use of this method is shown for JET pulse 77590, which is characterized by a 2.1MA plasma current, a 2.7T toroidal field, β_n=2.2, and an Advanced Tokamak scenario with a high triangularity configuration and a total power of approximately 30MW subdivided in 20MW of neutral beam power, 7MW of ICRH and 2.5 MW of LH heating. From the magnetic spectrogram the presence of two NTMs during the heating phase is highlighted, in fact an early NTM appears at 4.2s and is identified by the green n=3 track, its *m* number is estimated to be 7 since its frequency is slightly lower than three times the latter 2/1 mode frequency. A larger 2/1 NTM (in red) appears at 6.5s and remains in the plasma for the rest of the heating phase. In Figure 2 the location of coherence phase inversion is shown as a function of time, and a contour plot of magnetic q profile has been over laid for reference. The q profile displayed is inferred from the EFIT reconstruction constrained by Motional Stark Effect (MSE) polarimetry, Charge Exchange Spectroscopy (CXS) and pressure data, and also ECE radii are calculated using the reconstructed equilibrium magnetic field. In the plot the main 2/1 NTM localized in both the high field side at 2.7m and the low field side at 3.4m is visible. The uncertainty on mode position is about 3.1cm, that is the average distance between the two neighbouring channels that enclose the phase jump. This localization is not in perfect agreement with reconstructed q profile, that does not show any q = 2 surface at that time, but on the other hand this surface has to be present in the plasma since the related resonant mode is present. A secondary track is also present in the LFS and partially in the HFS, this track is localized between the reconstructed q = 2 and q = 3 surfaces, a similar experimental behaviour is observed in [4].

The magnetic frequency of a NTM in the easiest approximation depends on plasma rotation frequency at the resonant surface, and since the toroidal component of flow rotation frequency (ω_ϕ) in advanced scenarios is order of magnitudes larger than the poloidal one, the resulting expression for mode frequency is $\omega = n\omega_\phi (R_{res})$. A more detailed approach is used in [5].

Therefore to really understand the physical meaning of this second track a very important piece of information comes from the profile of plasma toroidal rotation frequency. In fact accordingly to [6], the main magnetic island can indeed generate a secondary island at a different resonant surface inside the plasma, but only if the difference in toroidal rotation frequency between the two surfaces is small enough. This secondary island should be born phase locked to the main one, in other words it should have zero toroidal rotation in the frame of the moving main mode, generating a multiple resonant structure which tends to rotate at the same angular speed at different resonant radii. Such a structure is in clear conflict with the natural rotation shear of the plasma, and can interact with the plasma itself via a torque, changing the rotation profile. An example of this behaviour is shown in Figure 3, in which the temporal evolution of toroidal rotation radial profile, measured with CSX, is shown. The first part of the heating phase exhibits a monotonic rotation profile from the plasma edge to the core. At 5.55s the doubling of 7/3 NTM amplitude is followed by a modification of the rotational shear, with the creation of a low shear region between 3.4m and 3.6m in major radius. The rotation flattening in this zone, which therefore appears to be linked to the 7/3 NTM, has the effect of modifying the rotation profile to the boundary conditions required for a double resonant structure onset. In the third part of the heating phase, from 6.6s on, the discharge is seriously affected by the onset of the large 2/1 NTM, with a significant drop in confinement. A larger effect on toroidal rotation is observed as well, in fact a negative rotational shear zone is created, with an off axis rotation minimum around 3.36 meters, in agreement with the position of the 2/1 NTM. The difference between black line and red line is very near to measure uncertainty (~5%), so further investigation to confirm the negative rotational shear is needed. This is an evidence for the action of a very localized braking mechanism, since the effect of the 2/1 mode is to reduce the rotation frequency around 3.35m and 3.6m, while at 3.4m and 3.5m rotation is unchanged. The origin of this braking mechanism is still to be understood, and the presence of an interaction between the mode and an external error field is possible.

In this paper the presence of a double resonant structure in ECE phase radial profiles has been shown, also the consequences of this structure on plasma toroidal rotation has been analyzed, giving arguments for a localized torque mechanism acting at the resonant surface.

The effect of local reversal in the rotational shear on the discharge still has to be analyzed, to decouple the effects of heat transport across the magnetic island from rotation profile effects, since it is expected that the latter would affect core turbulence and transport as well.

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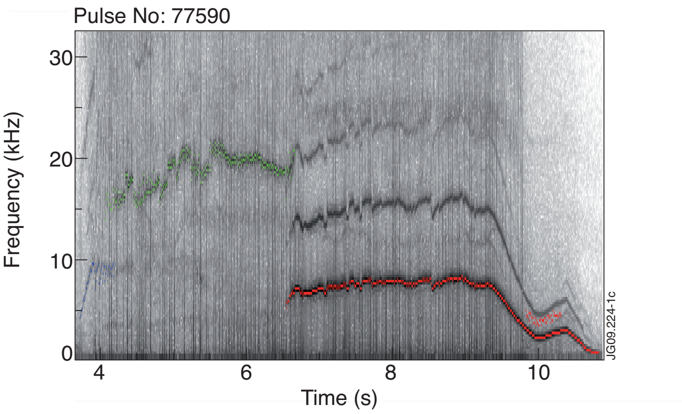

Figure 1: Magnetic spectrogram from a 1MHz bandwidth pick up coil for Pulse No: 77590. The different coloured tracks are the output of the mode tracking algorithm. Red tracks are linked to n = 1 activity, blue tracks to n = 2 activity and green tracks to n = 3 activity.

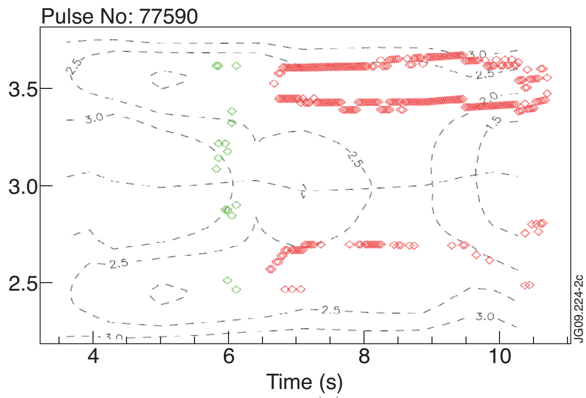

Figure 2: Mode position detected by ECE phase jumps, as a function of time and channels radii for Pulse No: 77590. Red points are due to n = 1 mode and green points to n = 3 mode. The contour plot of q-profile inferred from the EFIT reconstruction constrained by MSE, CXS and pressure data is plotted .

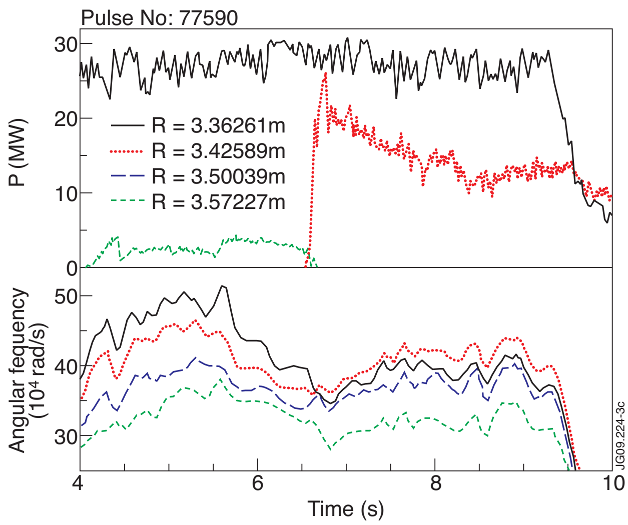

Figure 3: In the upper plot the total input power coupled to the plasma is plotted in black for Pulse No: 77590, n = 3 and n = 1 magnetic amplitudes are over plotted (a.u.). In the lower plot toroidal rotation evolution from Charge exchange spectroscopy is plotted for different radial positions in the plasma.