MHD activity in TJ-II

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Abstract: Magnetic fluctuations have been studied in the TJ-II stellarator. MHD events have been analysed for ECRH heated pressure driven modes and NBI Alfvén Eigenmodes.

Keywords: MHD, Alfvén, GAE, chirping, confinement.

1. Introduction

TJ-II is a four period heliac-type stellarator with magnetic field, B = 1 T, major radius, R=1.5 m, and averaged minor radius, <a> ≤ 0.22 m. TJ-II has low magnetic shear, and its rotational transform can be varied in a wide range ($0.9 \leq \iota/2\pi(0) \leq 2.2$). These characteristics allow controlling the presence of low order rationals in the rotational transform profile and, consequently, facilitate the identification and characterization of magneto hydrodynamic (MHD) instabilities. The plasma current is tipically ~1 kA, except for ECCD and Ohmic current induced discharges, where it can reach ~10kA.

Electron Cyclotron Heating (ECH) plasmas are produced with two gyrotrons with ~200 kW each, with frequency f = 53.2 GHz. The ECH power deposition profile can be focused at different plasma radius by moving the last mirror in the two quasi-optical transmission lines. The ECH cut-off condition imposes a maximum density of $n_e = 1.75 \times 10^{19}$ m^{-3}. Electron and ion temperatures are in the range 1-1.5 keV and 100-150 eV, respectively. The frequency range of the MHD activity observed in ECH plasmas is, typically, 10-80 kHz.

The experimental setup and data processing to study MHD instabilities in TJ-II has been recently improved. Fig. 1 shows the arrangement of the Mirnov coil array (25 coils) for measuring the poloidal component of the magnetic field. It has been extended to cover poloidally all the space available and now it spans $3\pi/2$ rad. The spatial structure (m-number) of the coherent modes detected are analyzed using different methods: SVD techniques [1], Lomb periodogram [2] and cross-checking against simulations.

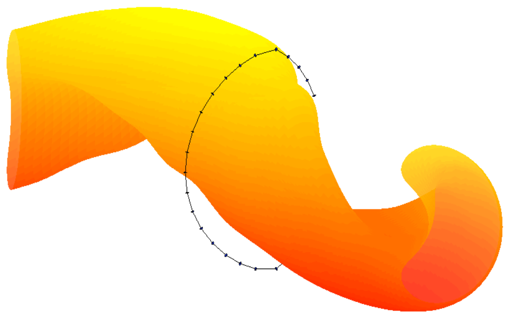

Fig.1: Schematic view of one period of the TJ-II plasma, showing the arrangement of the poloidal Mirnov array located in the period centre, $\phi = 45°$

Comparison of the magnetic fluctuation measurements with the results from other diagnostics with spatial resolution (reflectometer, bolometers) allow in some cases the radial localization of MHD events

2. Low frequency ECRH modes

The characteristics of low frequency MHD instabilities observed in TJ-II, mainly in ECRH discharges, have been found to depend on the magnetic configuration (low order rationals present in the iota profile), heating power, plasma density and plasma current [3].

In this section we are going to describe three magnetic configuration-related MHD events producing coherent mode activity.

Fig. 2 shows the rotational transform profiles of several

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TJ-II configurations. The main low order resonances (3/2, 8/5 and 5/3) present in the confinement region are drawn.

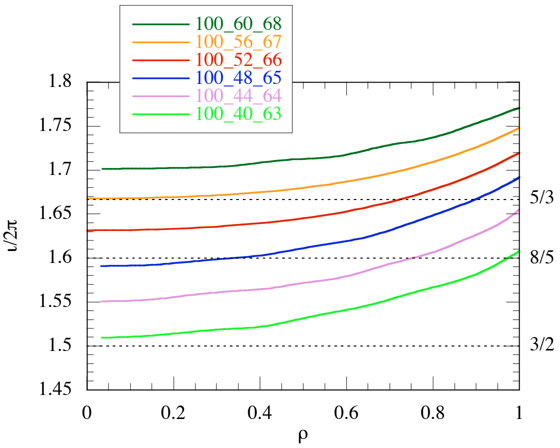

Fig. 2. Vacuum rotational transform profiles for several TJ-II magnetic configurations.

Fig.3 shows spectrograms of a Mirnov coil and a bolometer chord in the discharge #15817, with configuration 100_44_64 (see Fig. 2). A clear coherent mode with poloidal m number=5 at 20 kHz can be seen.

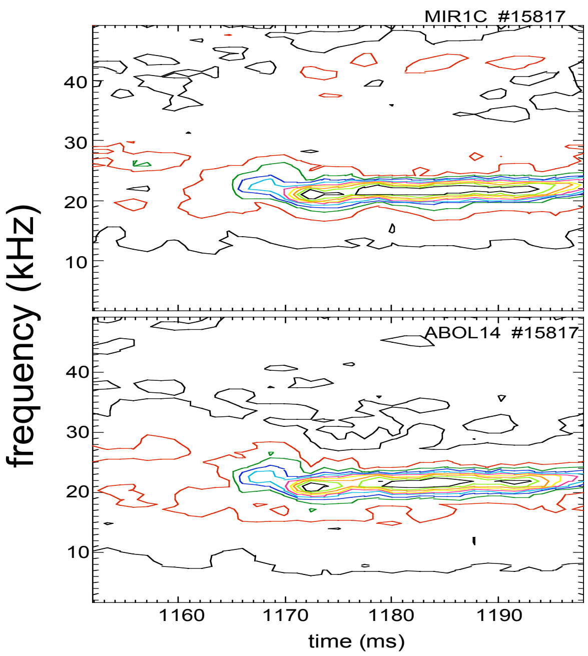

Fig. 3: Spectrograms a Mirnov coil (up) and a bolometer chord (down).

The m-number of the coherent mode deduced from the Mirnov coil array is 5. Fig. 4 shows the difference between two bolometer tomographic reconstructions corresponding to the maximum and the minimum of the oscillation. The measured plasma current in this discharge is negative, Ip ≈ -1 kA so it is expected to pull down from the iota profile in the central region. Thus, the MHD event could be interpreted as a periodical lose of emission in the inner region $0 < \rho < 0.3$ produced when the 3/2 resonance enters in the plasma central region. An outward flux is produced until it reaches $\rho \approx 0.7$ (which, as seen in Fig. 2, is the estimated position of rational surface 8/5), where it is retained.

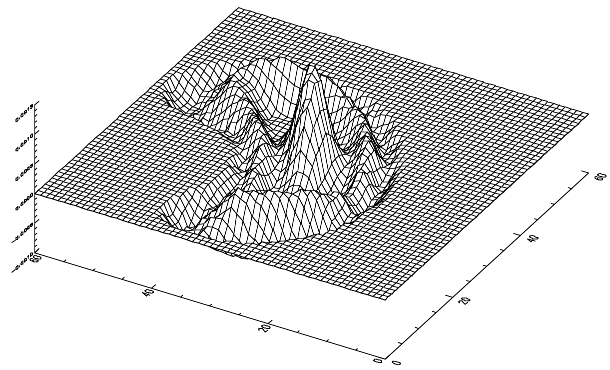

Fig 4: 3D plot showing the difference between radiation tomographic reconstructions corresponding to consecutives maximum and minimum of the coherent mode observed in #15817

Reflectometer signals also detect the mode rotation in this case and provide independently its radial localisation. The mode amplitude peaks at $\rho \approx 0.7$-0.8.

Figure 5 displays a Mirnov coil spectrogram and the time evolution of the plasma emissivity for the shot #15807 (configuration 100_40_63 with electrode biasing). It shows a transient phenomenon, which affects nearly all the plasma column.

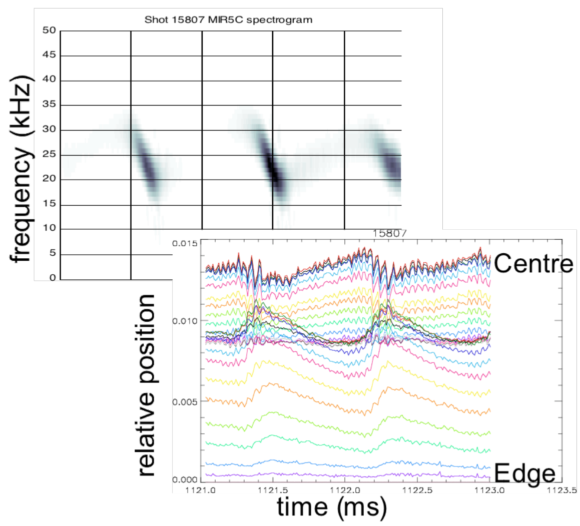

Fig. 5: Coil spectrogram (up) and time evolution of plasma emissivity (down) for shot #15807. Periodic bursts of MHD activity correlate with peaks of radiation from the centre (top) to the edge (bottom)

As the mode frequency chirps down, the plasma radiation shows an abrupt perturbation. In this occasion, the poloidal mode number of the fast magnetic periodic burst has been found to be m=5, probably related to the presence of 8/5 in the edge region. The reflectometer also detects the mode but no precise information on localization can be extracted. This transient phenomenon could be interpreted in terms of interaction between low order resonant surfaces, playing also a role the radiation of impurities (electrode).

The third example is a remarkable phenomenon, illustrated by the magnetic coil spectrogram (#11376) in Fig.6, which is found in NBI plasmas, for the standard configuration 100_44_64.

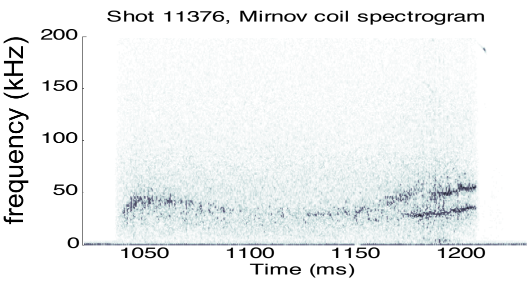

Fig. 6: Magnetic coil spectrogram showing a coherent mode that splits into two branches

As density increases during the NB injection, the typical low frequency MHD mode splits in two branches. Mode number reconstruction gives the same poloidal structure m=5 for both modes, moving in electron diamagnetic drift direction with poloidal angular velocities of about ~$0.6 \cdot 10^5$ rad/s. Both branches continue until the shot termination.

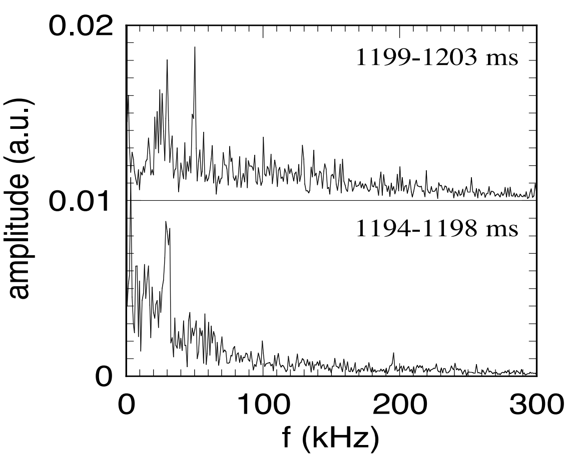

Fig. 7: Reflectometer spectra measured at two consecutive time windows in the shot #11364. Mode splitting is detected in the second one (upper box)

Fig. 7 shows that the reflectometer is able to detect the mode splitting in a similar discharge (# 11364): only one rotating mode is detected in the time window 1194-1198 ms; later, two modes are measured in 1199-1203 ms. The radial position of the mode is fixed at $\rho \approx 0.7$ and do not change in the time interval of mode splitting. There is yet no clear explanation of the phenomenon but it seems that two ingredients are needed: the presence of a low order resonance close to the edge (8/5 in this case) and NBI heating.

3. Global Alfvén modes

In NBI heated plasmas (with beam energy $v_{beam} \approx 30$ kV), high frequency coherent modes (150 - 300 kHz) are found in several magnetic configuration with a clear dependence of the frequency on plasma density and fuelling gas ($f \sim 1/n^{1/2}$, $f \sim 1/m_i^{1/2}$) which qualifies them as Global Alfven Eigenmodes (GAEs)[3]. The typical Alfven velocities found in TJ-II are $v_A \approx 5 \times 10^3$ Km/s. Fig. 8 (up) shows in a (β-v_A/v_{beam}) diagram all the configurations where GAEs have been observed. Fig. 8 (down) shows a typical example of GAE measured in TJ-II.

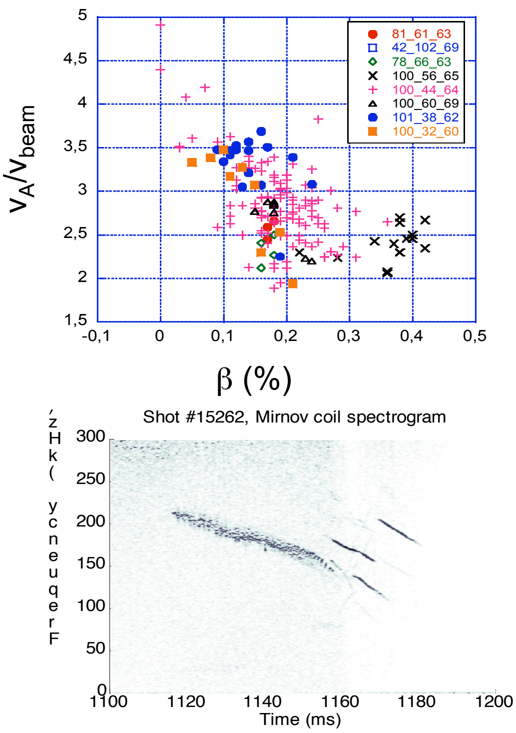

Fig 8.: Up: v_A/v_{beam} ratio versus β value. Down, typical Alfven activity in shot #15262, standard configuration, where three branches of m=4,2,6 appear.

Chirping Alfvén Modes

The Alfvén activity measured in TJ-II depends strongly on the way in which the plasma target is heated with ECRH. NBI shots whose target plasma is off-axis ECR heated show an interesting phenomenon not observed in on-axis ECRH plasmas. Chirping Alfvén -type modes are detected in the Mirnov signals as long as electron temperature at the $\rho \approx 0.6$ region remains above certain threshold that is $T_e \approx 0.2$ keV. Fig. 9 and 10 illustrate this finding. The reason of this threshold is related to the fact that off-axis ECRH in these discharges is deposited at $\rho \approx 0.4$. The electron temperature profile gets broader until it reaches the cut-off value in that region and then it drops. The frequency chirping observed can be upwards, downwards or both (see Fig. 11), with $\Delta f \sim 10\%$.

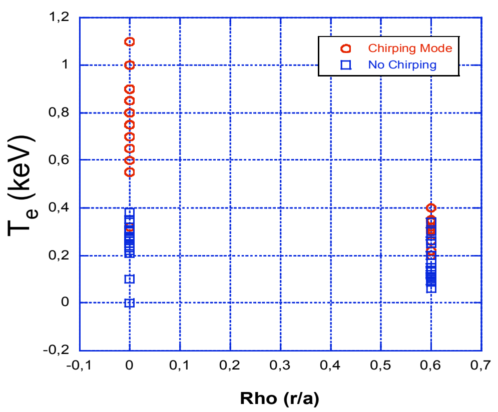

Fig.9: As density peaks and the electron temperature at $\rho \approx 0.6$ drops below ~0.2 keV, chirping modes disappear.

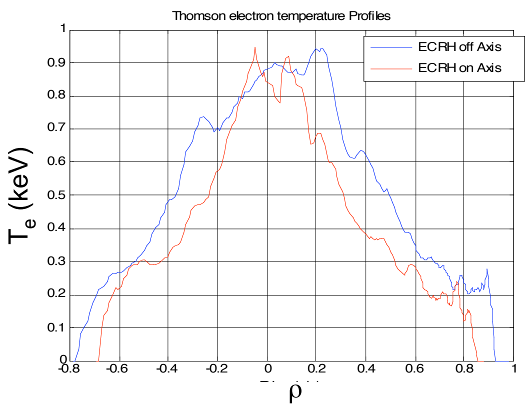

Fig. 10: Electron temperature profiles for discharges heated with on-axis (red) and off (blue) ECRH

These MHD burst do not correlate with Hα, bolometers or fast ion detector; no ion losses are detected. Chirping GAE phenomena have been studied before in stellarators and tokamaks [4, 5]. In particular, the 'Angelfish' frequency structure shown in fig. 10 [5], has been explained by Berk, et al [6] as a non-linear 'hole and clump' creation in the phase space.

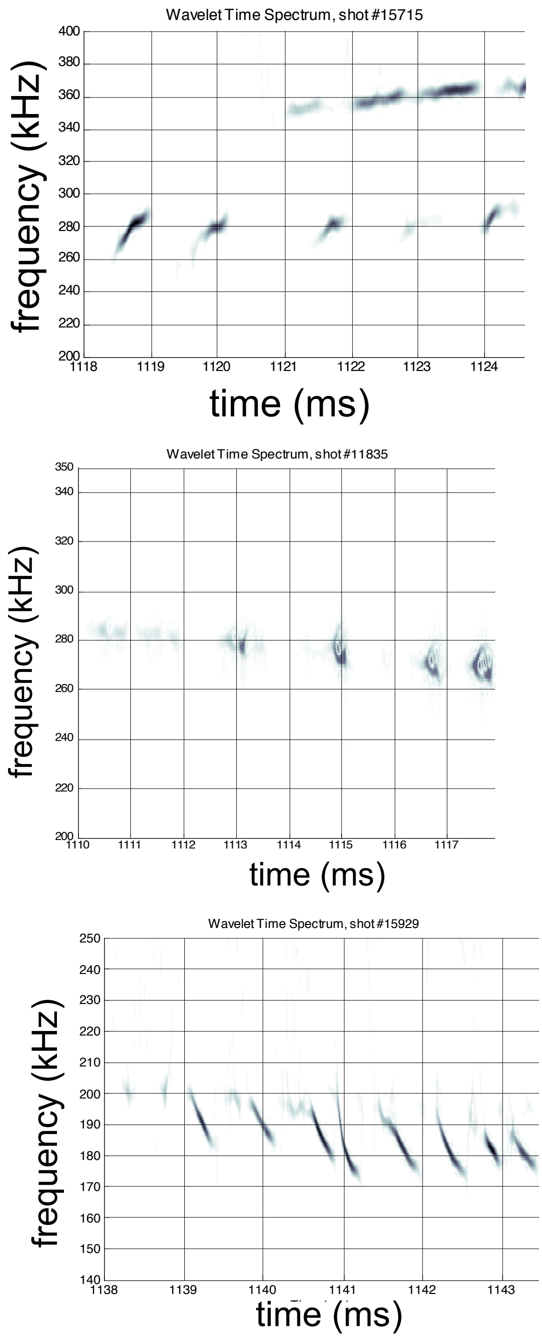

Fig. 11: Upwards, downwards and Angelfish bursting modes in TJ-II NBI discharges.

References

[1] M. Anton et al., Proc. 24th EPS Conf. **21A** 1645 (1997)

[2] S. Zegenhagen et al., Plasma Phys. Control. Fus. **48** 1333 (2006)

[3] R. Jiménez-Gómez et al., Fusion Sci. Technol., **51**, 20 (2007)

[4] A. Weller et al., 30th EPS Conf. 2003

[5] Fredrikson et al. Physics of Plasmas **13**, 056109 (2006)

[6] H. L. Berk et al, Phys. Lett. A **A234**,213 (1997)