Long-lasting core coherent Modes in TJ-II stellarator plasmas

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Introduction

Long lasting internal modes mainly associated with q=1 have been observed in many toroidal devices [see, for instance, 1-5]. In the TJ-II, a low-shear, low-current, low-beta stellarator with $2.2 \geq \iota(0) \geq 1.2$, highly coherent MHD modes with frequencies 4 kHz ≤ f ≤ 15 kHz, are often observed in total radiation signals in the central plasma region ($\rho < 0.5$). They can accompany sawtooth-like oscillations, resembling the precursor modes in tokamak plasmas, get destabilized during internal crashes [6], or appear independently with nearly constant frequency and amplitude. It is rather usual to detect several harmonics (up to 6) that occasionally can have higher intensity than the fundamental mode. They can be found in practically all the magnetic configurations explored to date, independently of plasma volume or shape, magnetic well value or composition. Modes appear mainly in neutral beam heated plasmas although some types can be detected in ECR heated plasmas as well, being their radial extent, intensity and frequencies weakly dependent on rotational transform and plasma pressure profiles. Namely, for a given magnetic configuration, modes are slower and apparently more extended in H-mode (dome-shaped) than L-mode type profiles (bell-shaped), and in strongly He-doped than in pure H2-plasmas.

As core coherent modes (CCM) are almost always invisible to Mirnov coils and the ECE system cannot be used in plasmas with average electron densities higher than 1×10^{19} m^{-3}, radiation signals from bolometer arrays toroidally distributed around the vacuum vessel [7], have been used to try to explore some of their characteristics. It is worthy to mention that CCMs are hardly detected with the SXR photodiodes.

Since remarkable coincidences with many reported experimental observations of distinct nature in other toroidal devices, say tokamaks, are found in plasmas of a low-shear, moderate-beta, low-current, and high rotational transform stellarator, it is worthy presenting a detailed description of these core modes in order to provide hints to clarify their origin.

Experimental

The TJ-II is a four-period flexible Heliac with low magnetic shear and major and averaged minor radii of 1.5 m and ≤ 0.22 m, respectively. Plasmas of interest are started either with ECR ($P_{in} \approx 600$ kW, 2 gyrotrons, at 53.2 GHz, 2^{nd} harmonic, X-mode polarization) or with neutral beams of $P_{in} \leq 650$ kW each, tangentially injected co- and counter- the magnetic field direction. The magnetic configurations for which CCMs develop cover almost the whole range of the TJ-II operational space (i. e., $2.2 \geq \iota(0) \geq 1.2$). The diagnostic available to follow CCMs is the bolometer system, consisting in AXUV photodiodes arranged in three 16-channel arrays with identical viewing geometry and three 20-channel arrays for tomography.

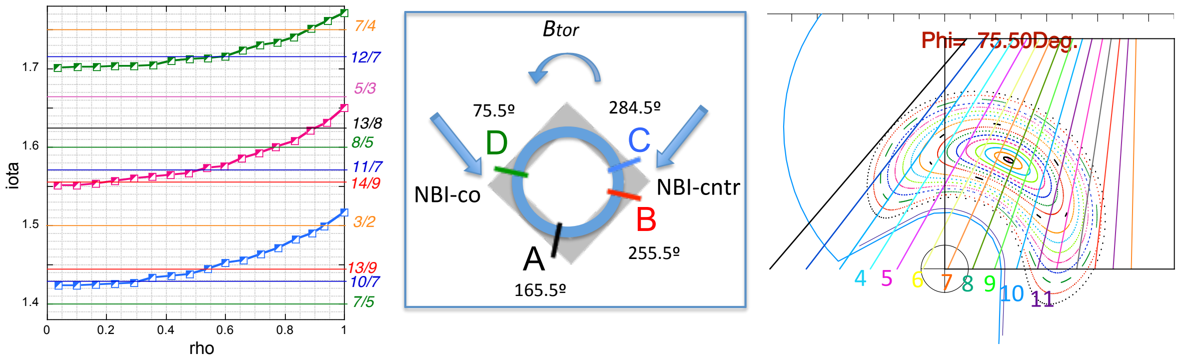

Fig.1 a) iota profiles of some of the studied magnetic configurations b) scheme of the toroidal distribution of the TJ-II bolometer system, c) cross-section and lines of sight of bolometer arrays in A, D and C.

Figure 1 shows: a) the rotational transform profiles in vacuum of the magnetic configurations used in this communication; b) the scheme of the location of the bolometer arrays around the vacuum vessel, the arrows indicate the standard toroidal magnetic field and NBI injection directions; and c) the lines of sight of the 16-channel AXUV arrays over the plasma cross-section corresponding to the centre of the observation ports of modules 7 in sectors labelled A, B and D (the cross-section in sector C-module 2 is their up-dow symmetric.

Observations

As above mentioned, CCMs appear in practically all the magnetic configurations and can exhibit different patterns. Some of them are shown in Figure 2: a) a low frequency mode accompanying off-axis sawteeth (OAS), b) a stable and intense (ΔPlin/Plin $\approx$ 6%) mode in a low temperature plasma, and c) a rather modulated frequency mode that survives to a confinement transition. In series of discharges with the same magnetic configuration of the one represented in figure 2a and with pure H_2 and strongly He-doped H_2 as working gases it could be stated that mode frequency increases as the radiation (and electron density) profiles evolve to more peaked and that for equivalent profiles, modes are faster in plasmas of pure hydrogen. It is worthy to mention that in the shots started directly with NBI, a relatively intense current (-4 to -6 kA) is generated and a non-negligible population of suprathermal electrons remains during the whole discharges duration. Different modes, not modulated but pulsed in intensity, are observed in radiation signals. At present the possible

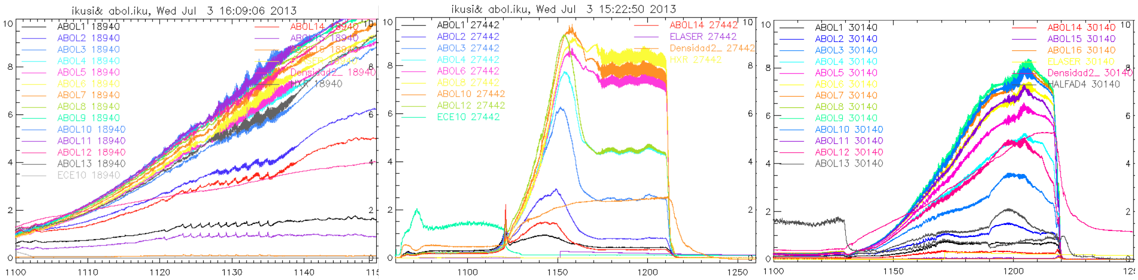

Figure 2. Raw signals of the bolometer array in sector A showing core modes from shots with different plasma conditions (see text) and magnetic configurations: a) $\iota(0) \approx 1.55$, b) $\iota(0) \approx 1.70$ and c) $\iota(0) \approx 1.42$.

role of fast electrons is under investigation [8]. In this communication we will focus on the modes shown in figure 2a.

CCMs associated to OASs resemble the precursor modes in the core of tokamak plasmas, nevertheless their intensity and frequency can be rather insensitive to profile relaxations, as is shown in figure 3a, where three cycles are shown. There it can be seen how the increment in edge radiation due to the outwards radial particle pulses produced by the OASs is detected at the same time in all toroidal locations (compatible with an n=0 mode), whilst the core signal oscillations detected in the different toroidal sectors are shifted. In fact, this is one universal finding for CCMs: for equivalent chords, a toroidal phase-shift $\Delta\phi = \phi/2\pi$ (being ϕ the toroidal angle) in the emissivity oscillations appears that is opposite to the momentum input direction (see figure 3b). This would point to a toroidal mode number n = ± 1, with (+) and (-) standing for counter- and co- NB injection respectively (note that this stands for reverse field also), with independence of the iota value. Although not shown, similar modes observed in ECRH plasmas do not exhibit toroidal phase shift. In the laboratory frame, and taking into account that mode frequencies range from 4 kHz to 15 kHz, the deduced phase toroidal velocity is $v_{\mathrm{tor\ ph}} = 2\pi Lf \approx$ 43-160 km/s. With these sets of bolometers, plus one AXUV array with an UV filter located at $\phi = 104.5^{\circ}$, we have tried to estimate the fluid toroidal velocity in a shot with a long lasting emissivity perturbation caused by a local impurity source. As is shown in figure 3c, the obtained value is around v_{tor} = + 10 km/s, with the sign (+) indicating parallel to the momentum input, i.e., opposite to the apparent CCM propagation. This value is in full agreement with the core toroidal velocity, v_{tor} = 5-10 km/s, determined by CXRS in NB heated plasmas [9].

With respect to the poloidal mode number, it cannot be determined with the three-array tomography system [7] due to the strong shaping of TJ-II plasmas, but according to the inversions in signal oscillations observed in consecutive chords, it seems to depend on the actual magnetic configuration. For a co-injected shot of the same series that the one shown in figure 3a, it was determined that the oscillations propagate in the electron diamagnetic direction at a speed of ≈ 3km/s. In the region $\rho \leq 0.5$ of NBI plasmas, a poloidal rotation velocity of 2 km/s ≤ v_{pol} ≤ 6 km/s was determined from passive spectroscopy [10].

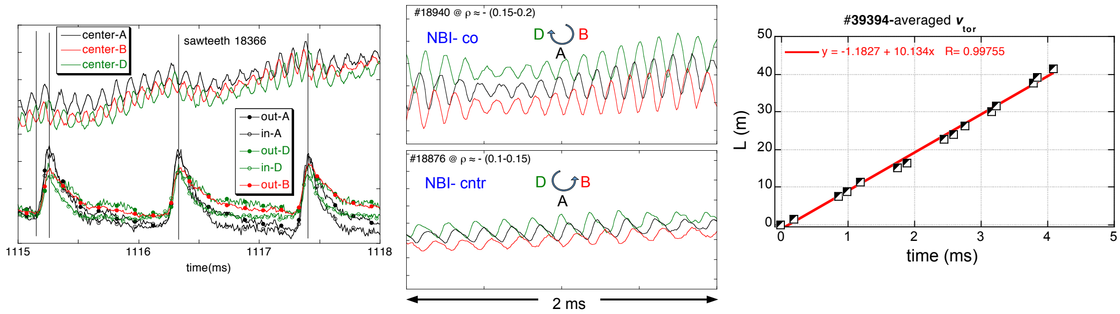

Figure 3. a) Core (upper signals) and edge radiation signals from a OAS discharge, b) toroidal shift of radiation signals from equivalent lines of sight under co- and counter- NB injection for CW toroidal field; the curved arrow indicates the phase propagation direction, and c) fluid velocity deduced from three toroidal transits of impurity-induced radiation increase.

Summary

Low frequency modes are observed in the core region ($\rho \leq 0.5$) of plasmas with all magnetic configurations and heating systems. Whilst in ECRH heated plasmas no toroidal phase shift is observed, in NBI heated plasmas a toroidal shift $\Delta\phi = \phi/2\pi$ appears that is not related with the rotational transform. The phase velocity of the oscillations is of the order of the sound velocity and about one order of magnitude higher than the toroidal flow velocity and in reverse direction, i.e., opposite to the NB injection direction. The toroidal mode number is n = ±1. Their poloidal rotation $v_{pol} \approx 3$ km/s velocity estimated at $\rho \approx 0.3$ is in full agreement with the poloidal rotation velocity measured by spectroscopy in TJ-II for $E_r \approx 3$ kV/m. The poloidal mode number is uncertain.

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