Plasma current dependence of coherent modes frequency in low-density NBI heated discharges in the TJ-II stellarator

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INTRODUCTION. Coherent magneto hydrodynamic (MHD) modes excited by high-energy ions are often observed in TJ-II plasmas heated by neutral beam injection (NBI). Modes with frequencies in the range of 150 to 300 kHz were experimental and theoretically analyzed and their properties were found compatible with alfvènic activity [1]. Those studies were performed in a wide range of magnetic configurations and it was found that mode number and spatial location were always linked to the rational surfaces contained in (or close to) the rotational transform profiles. The available diagnostics to characterize MHD activity at that time were Mirnov coil arrays, a single point heavy ion beam probe, a broadband fast frequency hopping system with heterodyne detection and reciprocating Langmuir probes.

Very recently, the sampling frequency of one of the bolometer arrays was increased to 400 kHz, enabling so the detection of modes with intermediate frequencies (<200 kHz) with moderate spatial resolution in the whole plasma column. Now, the mode activity in a wide range of magnetic configurations has been explored as well in plasmas with different electron densities heated by NBI. Low-order rational surfaces are also found involved in mode appearance, although no evident alfvènic behavior has been detected. Instead, a tight relation between modes frequencies and net plasma current is clearly observed.

In this communication, we present a description of low-density ($<2.5\times10^{19}m^{-3}$) co-neutral beam heated TJ-II discharges showing MHD activity with pronounced frequency modulations in different plasma regions.

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 [2]. For this experiment, plasmas of different magnetic configurations were started with electron cyclotron resonance heating (ECRH) ($P_{in} \approx 600$ kW, 2 gyrotrons, at 53.2 GHz, 2nd harmonic, X-mode polarization) and maintained with a tangentially injected neutral beam of $P_{in} \approx 450$ kW in co-direction. Fig. 1a shows the rotational transform profiles of the studied discharges and Fig. 1b, the scheme of one 16-channel bolometer array whose viewing chords signals were digitized at 400kHz.

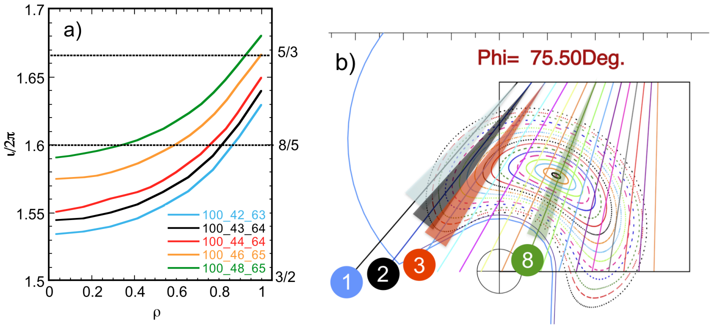


Fig.1 a) Radial profiles of the rotational transform for the studied magnetic configurations; ascending curves correspond to descending labels. b) Lines of sight of the used bolometer array [3]. Chords of interest for this communication are highlighted and numbered.

OBSERVATIONS. In low-density (<2.5×10^{19}m^{-3}) TJ-II plasmas heated with a tangential NB injector in co-direction, coherent modes in the Fourier spectra of Mirnov coils, Langmuir probes and bolometer signals are frequently detected, but their intensities are higher and their frequencies better defined for configurations in which the rational surface m=8/n=5 is placed between 0.7 and 0.9 r_{eff}. The frequency of the modes appreciably varies with the magnetic configuration, as can be seen in Fig. 2. There, the frequencies of the modes detected in signal chord #2, are plotted together with the line averaged electron density, <n_e>, for two shots with equivalent plasma parameters and quite similar magnetic configurations (see Fig. 1a).

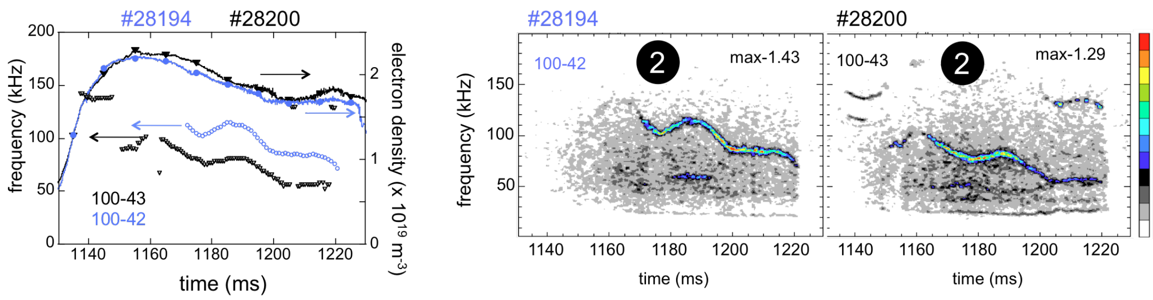


Fig. 2. left) Time evolution of <n_e> and coherent mode frequency from signal chord #2 for two shots with magnetic configurations 100_42_63 and 100_43_64. Centre and right) Fourier spectra of signal chords #2.

On the contrary, modes frequency does not seem to vary with electron density. In fact, in electron density scans for a given magnetic configuration, no differences in the mode frequency were found, even though <n_e> was changed almost in a factor of about 2 (see Fig. 3). As a general rule and even in shots with rather stable global parameters, modes present smooth but strong variations in frequency all along the discharges. In Fig. 4, two examples of modulated frequency modes from representative shots with two different magnetic

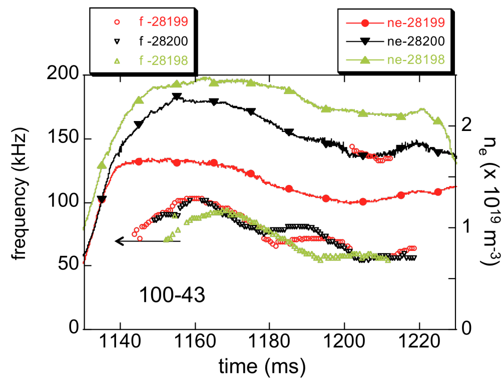


Fig. 3. Time evolution of <n_e> and coherent mode frequency found in signal chord #2 from three shots of one density scan series and configuration 100_43_64.

configurations are shown. There it can be seen that the frequency time evolution of the modes detected at the plasma periphery (#2) is right the opposite of that of the net plasma current. Frequencies of more internal modes (see bottom panels) show a looser and positive relation with I_p evolution. We have also plotted in the top panels the intensities of the magnetic coils feeding currents, I_{CC} and I_{HX}, of the central coils system, showing the tiny ripple ($\Delta I_{CC}/I_{CC}$ < 0.2%, $\Delta I_{HX}/I_{HX}$ < 0.4%, @ 20-30 Hz) produced by the current rectifying process. Although this little coil-current modulation might be expected to affect the shape of the magnetic configurations, the experimental magnetic surface mapping, performed under three-times worse accuracy in the coils currents, did not show substantial deviations with respect to theoretical calculations [4]. In the case of I_p, whose oscillations can be of the order of 20%, a dynamic change in the magnetic configuration could be expected.

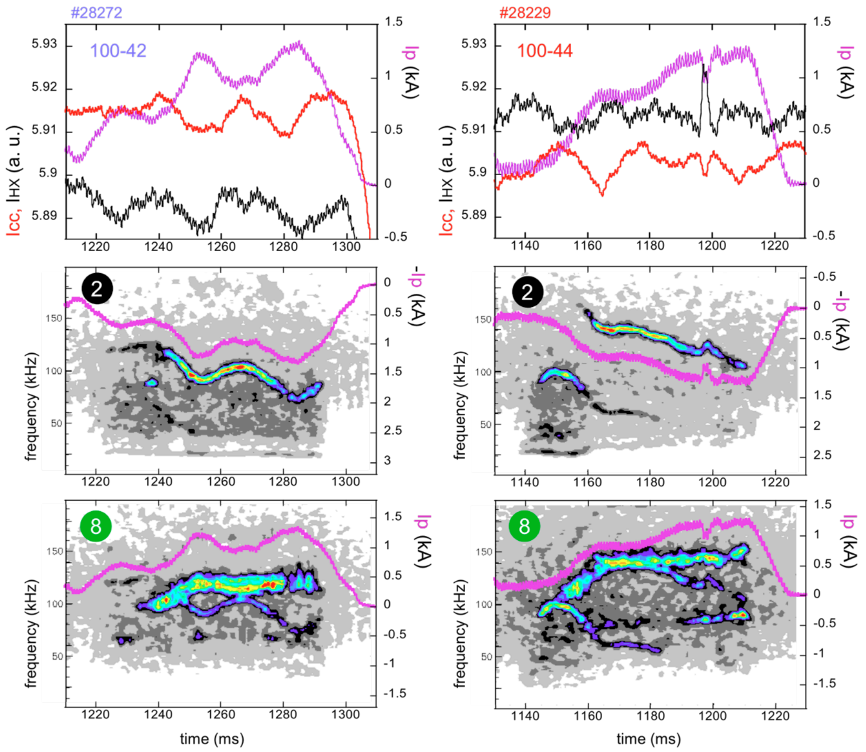
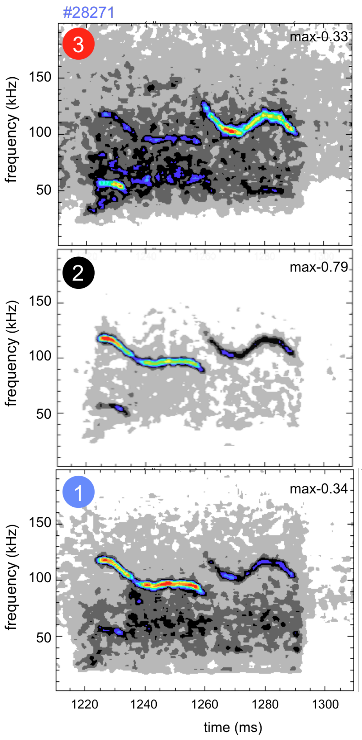


Fig. 4. Top panels) Time history of magnetic field curents I_{CC} and I_{HX}, and plasma net current, I_p, from two shots with magnetic configurations 100_42_63 and 100_44_64. Centre and bottom panels) Fourier spectra of bolometry viewing chords #2 (peripheral) and #8 (crossing the whole plasma column). $+I_p$ and $-I_p$ have also been plotted to show the respective correlations with I_p.

In some shots, together with the modulation, sudden jumps appear in the modes frequency. The example shown in Fig. 5, contains the time evolution of: (left) the Fourier spectra of three bolometer signals, (right-up) $<n_e>$, the intensity of one H_α radiation monitor, the raw signal of bolometer #8, I_p, and the main mode frequency, and (right-down) the mode amplitudes of bolometers #1, #2 and #3. It can be seen that the frequency of the mode exhibits the mentioned opposite evolution to I_p, except at 1260 ms (corresponding to a fast radial transport event), where it shows a 35 kHz upwards shift for an almost unchanged I_p. According to the mode amplitudes of the radiation chords spectra, at the frequency jump instant, the resonant region seems to move towards the plasma core, consistent with a modification of the iota profile. After the jump, the ratios of the three mode amplitudes do not change although the mode frequency variation is of the order of the jump itself. This suggests that mode position stays constant.

SUMMARY AND DISCUSSION. The coherent MHD modes described above appear in almost all TJ-II plasma discharges, provided the NB's are injected in co-direction and $n_e < 3x10^{19}m^{-3}$. Modes frequency depends on magnetic configuration but not on $<n_e>$. Instead, a tight correlation with I_p is observed. Local effects related to the radial electric field or, more probably, fast changes in the pressure profile could be responsible of the frequency jumps. These are accompanied by mode radial displacements but are not associated to any change in I_p.



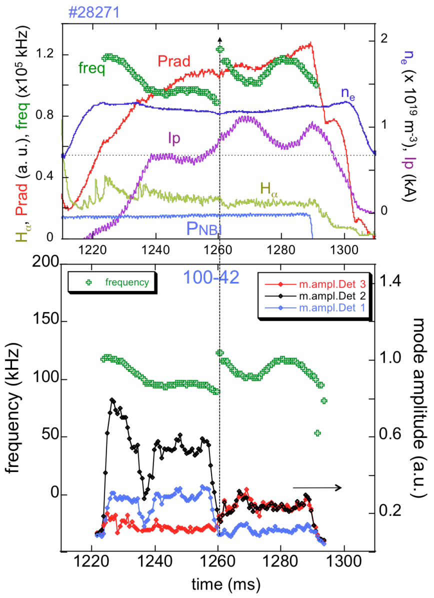


Fig. 5. Time evolution of representative parameters of shot #28271 (see text).

Although the known effect of rational surfaces on impurity ionization state and dynamics [5] cannot be ruled out, a plausible explanation we propose for the observed mode frequency variations is that the variable toroidal electric field, generated by the ripple in the magnetic field coils currents, induces oscillations in the intensity of the filamentary currents (and hence in the net plasma current, I_p) of non-collisional electrons confined at rational surfaces [6].

References

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