Oscillations of Electron Temperature and Their Interplay with MHD in the Presence of Internal Transport Barriers on TCV

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1. Introduction

Regular oscillations of the electron temperature have been observed on the Tokamak à Configuration Variable (TCV; R/a = 0.88 m/ 0.24 m, h = 1.5 m, $B_T < 1.54$ T) by means of ECE, SXR and Mirnov coils in ECCD driven fully non-inductive discharges and in discharges with a combination of Ohmic/ECCD driven current. Both scenarios feature electron internal transport barriers (eITBs). The fully non-inductive discharges are sustained by strong off-axis ECCD at low density. A small constant loop voltage can be added to these scenarios and is found to control the evolution and disappearance of temperature oscillations. In predominantly Ohmic discharges, temperature oscillations appear if on-axis counter-ECCD is added, generating an eITB.

These oscillations are reminiscent of the oscillations of the central electron temperature (O-regime) seen on Tore Supra[1] in low loop voltage and fully non-inductive LHCD plasmas with reversed central magnetic shear. Although these oscillations do not have a helical structure and, therefore, are not themselves of an MHD nature, they are seen on TCV to co-exist with MHD modes. The interaction with MHD can play a strong role in the coupled dynamics of heat and current transport, as the modes can significantly perturb the current density and thus also the q-profile. During the decrease of temperature, a transition from a 16 kHz to a 7 kHz MHD mode is seen. In some discharges, the m/n = 2/1 or 3/1 mode has been observed by means of ECE and Mirnov coils, depending on a specific shot conditions. The presence of MHD modes can aid more generally in the correct identification of rational q-surfaces[2].

The following diagnostics have been used to study the phenomenology of Te-oscillations and MHD on TCV:

a) HFS and LFS heterodyne ECE radiometers (24-channel each) both viewing the plasma through antennas at Z = 0 cm and Z = +21 cm lines-of-sight, with a sampling rate up to 200 kHz[3-5];
b) 200 chord SXR tomographic system, 64 chord DMPX and the toroidal array of magnetic pick-up coils to obtain information on the locations and character of MHD modes[6];
c) 14-channel far infrared (FIR) diagnostic for the reconstruction of electron density profiles[7].

In this paper, a possible link between evolutions of the electron temperature, the MHD modes and the current density profile on TCV is discussed.

2. Oscillations of electron temperature on TCV

Recently, oscillations of the electron temperature have been observed on TCV in low-density on-axis counter-ECCD and off-axis co-ECCD discharges. These oscillations have low frequency (8 – 12 Hz), do not have a helical structure (i.e. m = 0, n = 0) and, therefore, cannot be ascribed to MHD by themselves. However, MHD modes coexist with these oscillations. Two scenarios in which oscillations may occur are discussed here, and the nature of MHD modes is analyzed.

2.1 Fully non-inductive scenario

In this scenario, the plasma is shifted to Z = +21 cm above the machine midplane. An eITB is established at r/a = 0.4 – 0.45 by co-ECCD off-axis applied at the same location (2x500 kW); so the plasma current is driven fully non-inductively ($V_{loop} \sim 0$) and the q-profile is reversed in the plasma center. Oscillations of the total plasma current are found to have a phase delay of ~ 0.01-0.015 s (angle ~ 45 degrees) with respect to the phase of temperature oscillations, and the radial excursion of the plasma column due to the oscillations is found to be 2 – 3 cm (Fig. 1(a,b)). The bootstrap current fraction changes by 40 – 60% (depending on the particular shot conditions) during the oscillation cycle, as calculated using the plasma profiles and following the method described in Ref[8]. An MHD mode is present during the whole ECCD phase of the discharge having larger amplitude during the decay of the Te-oscillation (Fig. 1(c)) and a maximum amplitude at the bottom of the oscillations. It appears that the growing MHD mode degrades the confinement and leads to a temperature decrease. After the mode amplitude is shrunk, the confinement is recovered, as evidenced by an increase in the H-factor (Fig. 1(b)). Evidently, a presence of MHD and its interplay with the electron temperature and the current density is a key requirement for the O-regime to occur on TCV. The MHD mode poloidal/toroidal numbers are estimated to be m/n = 3/1 from Mirnov coils[6]. Unfortunately, due to the large ECE sample volume at Z = + 21 cm line-of-sight, no useful information on MHD mode amplitude can be retrieved[5]. Therefore, the topology of the mode (classical tearing, double-tearing etc) cannot be deduced from ECE in this scenario.

Current profile tailoring experiments have been performed to stabilize Te-oscillations by adding an Ohmic perturbation with a positive j_{OH} (to fill in the current hole in the plasma center) or a negative j_{OH} (to make the current hole deeper) at the end of a discharge (t =1.9 – 1.25 s). In the first case, the MHD mode grows close to the ideal limit, and the O-regime is terminated by a minor disruption (t ~ 2.1 s, see Fig. 1). The confinement is recovered at 2.2 s, and oscillations do not reappear; but small MHD activity recovers. In the second case, the O-regime is softly suppressed.

2.2 Combined Ohmic/ECCD scenario

In order to create a hollow total current density profile, counter-ECCD is added on-axis ($V_{loop} \neq 0$). The plasma column oscillations are smaller (< 1 cm), and the ECCD deposition radius is well inside the barrier. As in the fully non-inductive scenario, MHD activity is present throughout the phase with oscillations. The frequency of the mode follows the evolution of dI_p/dt and falls from 16 kHz at the top of the oscillation down to 6 kHz at the bottom (Fig. 2(a-c)). Interestingly, the transition from the slow to the fast mode occurs in less than 0.4 ms on top of the oscillation, compared

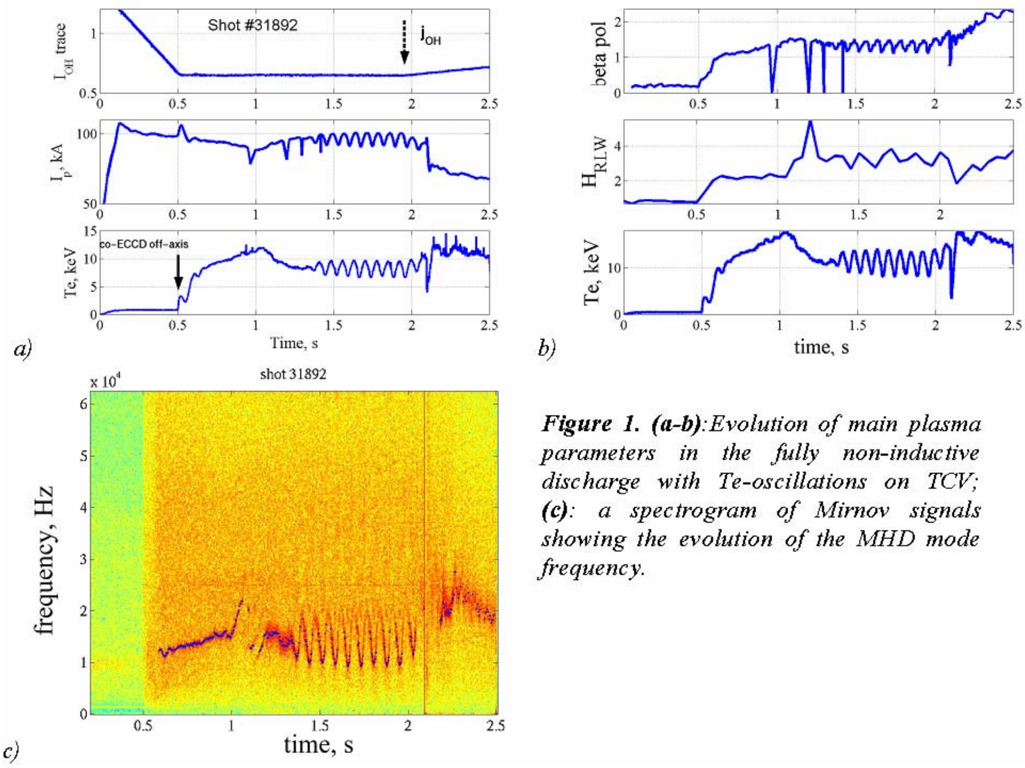

Figure 1. (a-b):*Evolution of main plasma parameters in the fully non-inductive discharge with Te-oscillations on TCV;* ***(c)***: *a spectrogram of Mirnov signals showing the evolution of the MHD mode frequency.*

to a slower transition in the fully non-inductive scenario (Fig. 1(c)). Despite the influence of non-thermal electrons on ECE spectra, a precise location of the mode at r/a = 0.4 has been determined from high-pass filtering of ECE signals at 4 kHz (Fig. 2(d)). This discharge is located at Z = 0 cm, and a detailed analysis of the electron temperature evolution with a well focused antenna is possible by ECE[5]. The localization of the mode is in a good agreement with measurements performed for this shot by means of the FIR diagnostic. During the oscillation cycle, the mode shifts radially by 2 - 3 cm, probably following the location of the rational q-surface at which it is localized. The innermost radius corresponds to the lowest T_e and maximum of the mode amplitude and width.

From the comparison between HFS and LFS ECE traces, it has been found that the mode has an even poloidal number. From Mirnov coils, the mode has been identified[6] as m/n = 2/1. Figure 3 shows the evolution of the island width for several oscillation cycles. The island width has been determined from the ratio of temperature differences between O and X-points of the island and the temperature gradients at the X-points. The maximum island width of 2 – 2.5 cm corresponds to the saturated mode at the bottom of the oscillation. When the mode shrinks, the temperature rises. The time evolution of the island width is reminiscent of NTM; however, more analysis is still needed. In general, ECE results are in qualitative agreement with the development of the island width evaluated from the fast magnetic diagnostics[6].

3. Conclusions

Oscillations of electron temperature and the plasma current on TCV in both fully non-inductive ECCD and combined Ohmic/ECCD scenarios appear from a complex interplay between the current density, electron temperature and MHD.

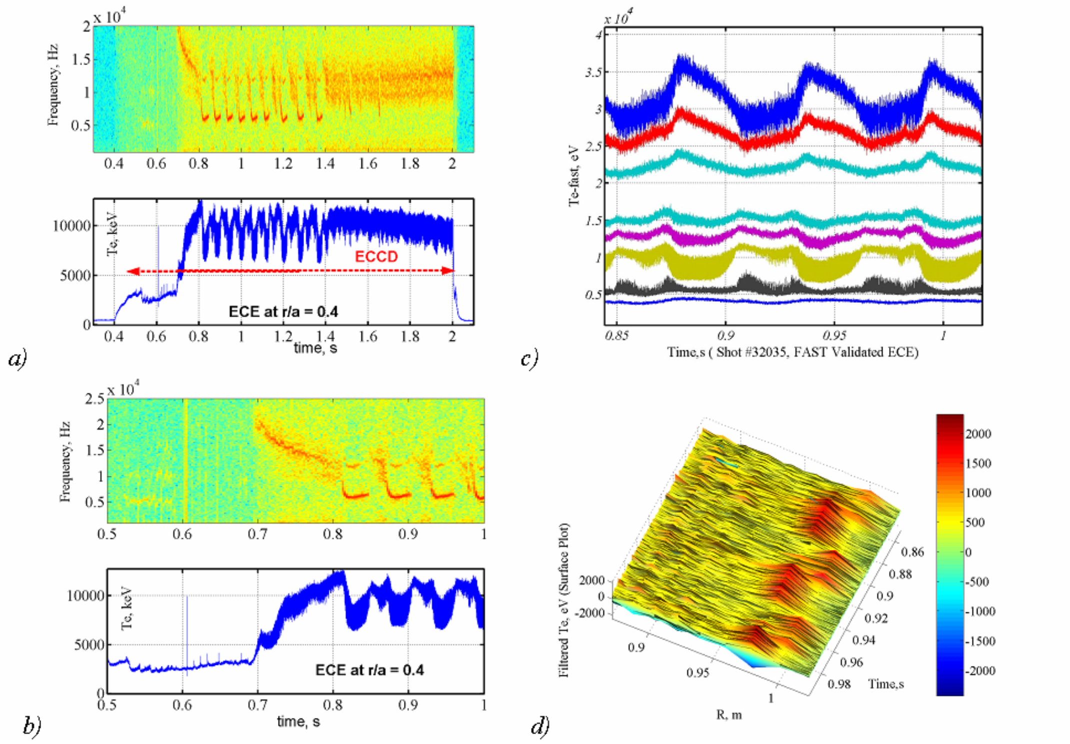

__Figure 2. (a-c):__ development of the MHD mode and its frequency seen by ECE in the discharge with temperature oscillations (scenario with counter-ECCD on axis); __(d):__ the location of the mode at r/a = 0.4 is retrieved from high-pass filtered ECE signals (surface plot).

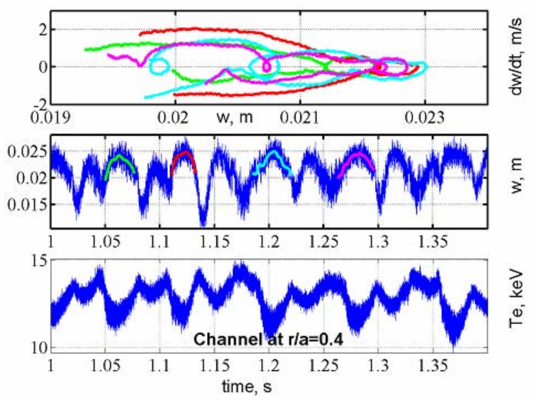

***Figure 3.** Evolution of the island width as a function of time for several oscillation cycles measured by LFS ECE diagnostic. The island width varies between 1.0±0.5 and 2.5±0.5 cm in this shot.*

The O-regime can be treated as a transition between good/poor confinement states, in agreement with results obtained in earlier on Tore Supra in fully non-inductive LHCD driven discharges[1,9]. It is proposed that MHD activity is a primary cause for confinement degradation and O-regime to occur on TCV. MHD modes in these plasmas have an NTM character; however, on this point, a more thorough analysis is needed.

References

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