

EXPERIMENTAL EVIDENCES OF THE ROLE OF MAGNETIC TOPOLOGY ON CORE TRANSPORT IN TJ-II STELLARATOR

E. de la Luna, T. Estrada, F. Medina, J. A. Jiménez, A. Cappa, M. Ochando, E. Ascasíbar, F. Castejón, A. Fernández, C. Hidalgo, K. Likin, B. Ph. van Milligen and M. A. Pedrosa.

*Laboratorio Nacional de Fusión por Confinamiento Magnético
Asociación Euratom - CIEMAT, 28040 Madrid, Spain*

Introduction

The influence of the magnetic topology, and rational surfaces in particular, on core transport has been an area of increasing interest in the recent years. In tokamak plasmas, a correlation between the appearance of rational surfaces (as the q profiles evolves) and the formation of the ITBs has been observed on several devices [1]. TJ-II is a device particularly well adapted to study the influence of the magnetic topology on transport because of its flexibility and its small shear. In the present paper we report on local transport enhancement together with different types of central relaxation of the central electron temperature that have been observed in TJ-II. The linkage between the appearance of these phenomena and the magnetic structure will be discussed.

Experimental results

A variety of core transport phenomena have been observed in low-density plasmas in TJ-II stellarator ($B_0 < 1$ T, $R = 1.5$ m and $a \leq 0.22$ m) with EC heating (300 kW at 53.2 GHz, 2nd harmonic, X mode). Repetitive spontaneous crashes of the central temperature are

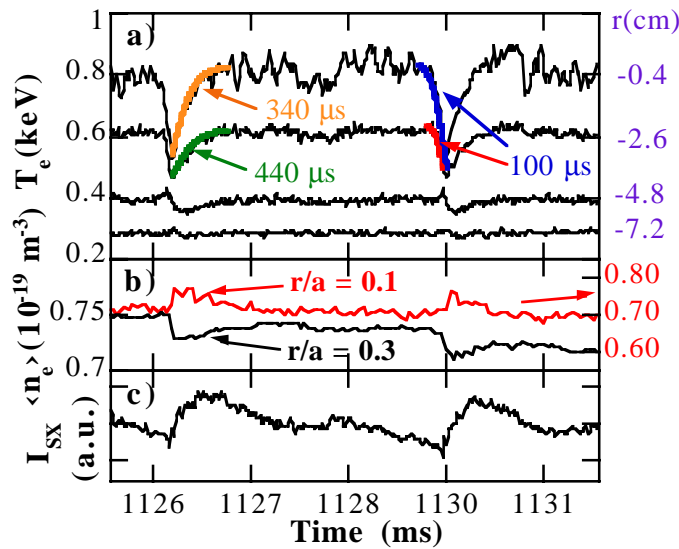


Fig 1. Time traces of the electron temperature (a) (the radial location of the ECE channel is shown on the right, $r < 0$ refers to the high field side), the line-averaged density for two plasma chords (b) and central soft X-ray intensity (c) during the occurrence of central temperature crashes. An example of the time scales calculated by using the fitting function $\tanh[(t-t_0)/\tau]$ is shown in the upper figure.

observed for certain magnetic configurations [2]. Figure 1 shows the time traces of electron temperature at different radii (as measured by ECE), the line-averaged density on two plasma chords ($r/a \approx 0.1$ and $r/a \approx 0.3$) and the SXR signal for a central chord during this transient behaviour. The time evolution of these instabilities, with amplitude of about 200 eV, is closely reminiscent of a central sawtooth, exhibiting a sharp collapse of the central part of the temperature profile ($r < 5$ cm) followed by a longer period of reheating. The time scales of these transitions are estimated by using a fitting function of $\tanh[(t-t_0)/\tau]$. The analysis shows that the time constants are $\tau \approx 0.1$ ms and $\tau \approx 0.3 - 0.5$ ms for the drop and rise respectively, which are much faster

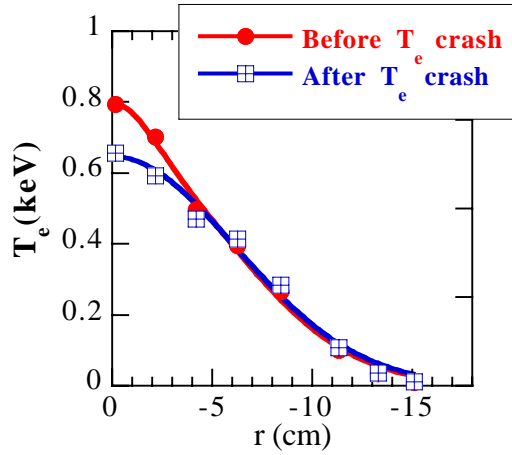


Fig 2. The electron temperature profiles measured before and after one of the central temperature crash shown in Fig. 1.

than the energy confinement time of a few milliseconds. The rise time increases as the position of the ECE channel moves away from the plasma center.

Figure 2 shows the evolution of the temperature profile during one of these temperature crashes. Note that only a narrow region at the plasma center, within the average radius $r = 5$ cm, is affected, while the outer part of the T_e profile remains unperturbed.

These sharp transitions are also clearly seen in the SXR and interferometer signals (see Fig. 1b and 1c). A delay of about $\Delta t \leq 100 \mu s$ is observed in the line density response to the temperature crashes. The measurements show that just after the sharp decrease of the central temperature the

density close to the plasma center increases while the averaged density at $r/a \approx 0.3$ decreases, which indicates a reduction in the density profile hollowness. The increase of the central density leads to an increase of the SXR intensity. This behaviour reflects the strong coupling of the heat and particle transport in the plasma core. As the reheating of the plasma takes place, the central density decreases again with the increase of the temperature gradient and the density profile recovers the shape it has before the transition occurs.

Role of the resonant surfaces on the observed phenomena

Several experimental observations [2] support the hypothesis that the dynamic behaviour observed in the core of the TJ-II plasmas is linked to the existence of a low order rational surface in the central region of the plasma. An additional confirmation of this hypothesis was obtained in a series of ECCD experiments, where the toroidal injected angle of the EC waves was varied shot by shot while keeping the deposition close to the magnetic axis. Figure 3 shows the temporal evolution of the plasma current measured by the Rogowski coil, and $T_e(0)$ (the time traces are arbitrary shifted for clarity) for three discharges: the green colour corresponds to a discharge with perpendicular injection ($N_{||} = 0$) and the red and blue ones correspond to co- and counter-current drive cases respectively. Pressure profiles are very similar in the three cases: peaked temperature profile with a central temperature of 0.9 keV and a flat electron density profile with line-averaged density of $0.75 \times 10^{19} \text{ cm}^{-3}$. A negative

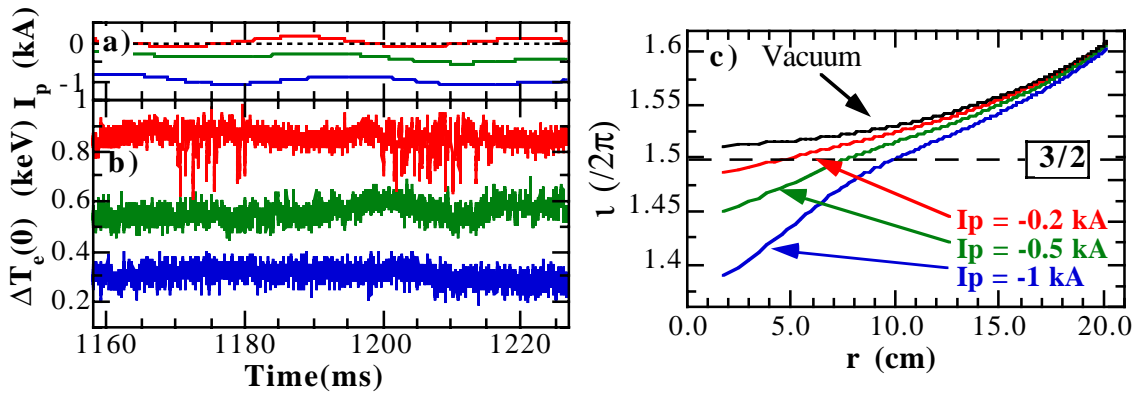


Fig 3. (a) Time evolution of the measured plasma current and (b) the central electron temperature for three discharges with pure electron heating (green colour), co-ECCD (red colour) and counter-ECCD (blue colour), respectively. The individual T_e traces in (b) are shifted by arbitrary values. (c) The rotational transform profile in the vacuum case and the ones calculated when the measured plasma current is taken into account.

plasma current ($I_p = I_{bs} + I_{ECCD}$, being I_{bs} and I_{ECCD} the bootstrap and the EC-driven components, respectively) of about -0.5 kA is measured in the $N_{||} = 0$ case ($I_{ECCD} = 0$). A negative current means, in the TJ-II case, that flows in the direction of decreasing the vacuum rotational transform. The measured plasma current increases and decreases with respect to the perpendicular injection case accordingly to the EC current drive direction. In this experiment, the plasma current is also modulated at a frequency of 40 Hz with an amplitude of about ± 200 A. This modulation was produced by a small ripple (0.2%) in the external circular coil current that induces a small amount of ohmic current. Figure 3b clearly shows that the transient behaviour in $T_e(0)$ is only observed in the co-ECCD case ($I_p = \pm 0.2$ kA) and, in that case, its appearance is correlated with the minimum of the modulated plasma current. The onset of the temperature crashes is accompanied by bursts of magnetic activity with a frequency about 40 kHz.

Figure 3c shows the calculated rotational transform profiles with the 3-D equilibrium code VMEC for a currentless case and for the cases with $I_p = -0.2$ kA, $I_p = -0.5$ kA and $I_p = -1$ kA. In these discharges, the rotational transform profile ($\iota/2\pi$) in vacuum goes from 1.51 at the center to 1.61 at the edge. The introduction of a negative toroidal current in the equilibrium reconstruction results in a reduction of the central iota profile compared to the vacuum value. In the case with $I_p = -0.2$ kA (co-ECCD case), the $n/m = 3/2$ surface appears in the central region, being $(\iota/2\pi) \leq 1.5$ for $r \leq 5$ cm. As the absolute value of the current increases, the 3/2 rational surface moves towards bigger radii. These calculations suggest that the appearance of the low order rational surface in the plasma core plays an important role on the occurrence of the central temperature crashes. It has to be mentioned that ELM-like events [3] develop in the outer part of the plasma column for the discharges with $|I_p| > 0.5$ kA. It has been found that the appearance of the ELM-like events in TJ-II is correlated with the occurrence of a resonant surface close to the maximum of the density gradient, which in those discharges is located around $r \approx 10$ cm, in agreement with the modification of the iota profile shown in Fig. 3c. This observation gives confidence that the calculated rotational transform profiles properly reproduce the experimental iota behaviour.

Forward and backward transitions

Different transition phenomenon is observed for magnetic configurations with $\iota/2\pi(0) = 1.69$ (in vacuum). An example is shown in Fig. 4, where the time evolution of the central electron temperature for two discharges with the same magnetic configuration and heating

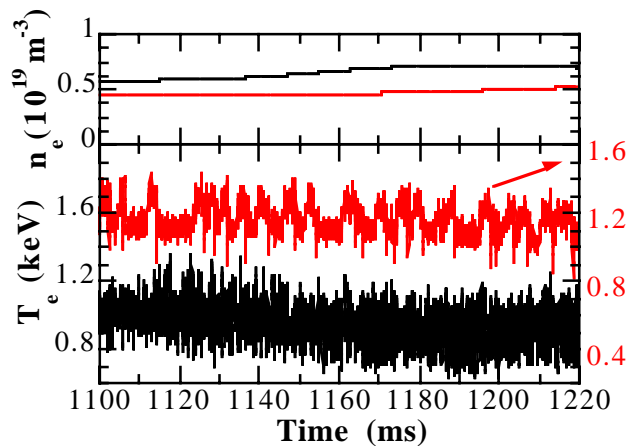


Fig 4. (a) Time evolution of the line-averaged density and (b) central electron temperature for two discharges with the same magnetic configuration ($\iota/2\pi(0) = 1.69$ in vacuum) but different line-averaged density.

power ($P_{ECCRH} = 300$ kW), but different line-averaged density is plotted. In the low-density case, $\langle n_e \rangle \approx 0.45 \times 10^{19} \text{ m}^{-3}$, the plasma alternately takes two distinct temperature values approximately every 5 ms, a behaviour that suggests the proximity to a threshold condition for the transition. The modification of the electron temperature is concentrated in the plasma core with $r < 5$ cm. During the transition, no significant change is seen in the density. In the high-temperature phase of the transition the temperature gradient increases by a factor of 1.5. Similar behaviour has been observed in W7-AS [4].

This transition pattern changes as the line-averaged density increases. In the higher density case, $\langle n_e \rangle \approx 0.65 \times 10^{19} \text{ m}^{-3}$, the frequency of the transitions increases, temperature drops occur quasi-periodically with a frequency of about 4 kHz. In both cases, a coherent mode of frequency about 20 kHz superimposed over the high-temperature phase is clearly visible on the central T_e traces and resides just inside the region with $r < 5 \text{ cm}$. Again, this observation suggests that a rational surface may extend over the core region. A negative current of about 0.6 kA is measured for both discharges that, according to equilibrium calculations, could significantly reduce the iota profile in the central plasma region just below the rational value $n/m = 5/3$ ($1/(2\pi) = 1.66$).

Discussion and future prospects for experiments.

The TJ-II observations are fully consistent with the fast transitions in the electrostatic potential profile measured with a HIBP diagnostic in CHS [5]. However, in the TJ-II case the observed phenomena can not be simply ascribed to the bifurcation properties of the radial electric field. For the TJ-II plasma conditions considered in this paper, i.e. low density ECRH discharges, with peaked T_e profiles ($T_e(0) \sim 1 \text{ keV}$) and $T_e \gg T_i$, neoclassical calculations give a unique solution for E_r , having a large positive value in the plasma core and a small negative value in the outer part of the plasma, and no additional roots exist [6]. On the other hand, the possibility of varying significantly the magnetic configuration in TJ-II shows us that the appearance of these phenomena in TJ-II is restricted to certain magnetic configurations, indicating the key role played by magnetic structure. Although a link with the low order rational surfaces has been identified, the physical mechanism causing the transport change remains unknown. It appears plausible to consider that the rational surfaces could affect the radial electric field. Evidence of ExB sheared flows at the boundaries of the low order rational surfaces has been obtained in the plasma edge region of TJ-II [7] and more recently in LHD [8]. If the ExB shearing rate exceeds a critical value, a spontaneous transport barrier may appear in the proximity of the rational surface. The electric field may also be influenced by changes of convective flux of suprathreshold ripple trapped electrons generated by the ECRH [9]. The new HIBP diagnostic, which will be fully operational for the next experimental campaign in TJ-II, will provide essential information to understand the linkage of the dynamics of the radial electric field with the core transport.

Finally, it should be pointed out that, up to now, the appearance of the described phenomena in TJ-II is restricted to on axis heating experiments and the modification of the electron temperature profile is concentrated in the ECH deposition zone ($r/a \leq 0.3$). The influence of kinetic effects (i.e. distortion of the electron distribution function [10] in the energy interval where the power deposition occurs, $v \approx 1 - 2 v_{th}$) on these phenomena appears probable, as they are restricted to high power density experiments (low n_e , high P_{ECRH}), specially so if the interaction of the very localized power deposition profile associated with ECH and the magnetic island is taken into account. Further investigations will be necessary in order to clarify the influence of these effects on the ECE measurements in TJ-II.

References

- [1] Y. Kamada, Plasma Phys. and Contr. Fusion 42 (2000) A65 (and references therein)
- [2] T. Estrada, E. de la Luna, E. Ascasíbar, et al. Submitted to Plasma Phys. Control. Fusion
- [3] I. García-Cortés, E. de la Luna, P. Castejón, et al. Nuclear Fusion, 40 (11) (2000) 1867
- [4] U. Stroth, K. Itoh, S.I. Itoh, et al. Phys. Rev. Lett. 86 (2001) 5910
- [5] A. Fujisawa, H. Iguchi, H. Idei, et al. Phys. Rev. Lett. 81 (1998) 2256-2259
- [6] V. Tribaldos, Physics of Plasmas 8 (2001) 1229
- [7] C. Hidalgo, M.A. Pedrosa, et al., Plasma Phys. and Contr. Fusion 42 (2000) A153
- [8] K. Ida, N. Ohyabu, T. Morisaki, S. Inagaki, et al. Phys. Rev. Letters (2002) 015002
- [9] M. Ochando, F. Medina, et al. (at this conference)
- [10] V. Krivenski. Proc. 11th Joint Workshop on ECE and ECRH, Oh-arai (Japan) 1999