

TRANSIENT BEHAVIOUR IN THE PLASMA CORE OF TJ-II AND ITS
RELATION WITH RATIONAL SURFACES

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Abstract: A transient behaviour is observed in the plasma core of TJ-II stellarator with fast drops in the electron temperature. Changes in the line-averaged density occur synchronised with temperature drops. This phenomenon appears in plasmas created and heated using 300 kW of electron cyclotron heating (ECH) with high power density. The transient behaviour resembles both, the electric pulsation discovered in CHS and the “electron root” feature reported by the W7-AS team. In TJ-II fast spontaneous transitions appear related to the magnetic topology in conditions of fixed plasma density and ECH power. The flexibility and low magnetic shear of TJ-II have permitted the identification of the plasma current as the control parameter for the appearance of this phenomenon. The results obtained during the magnetic configuration scans carried out in TJ-II points to the hypothesis that the transient behaviour is connected with the presence of a rational surface close to the plasma centre, where the ECH power is deposited. Equilibrium calculations performed with the VMEC code reinforce this hypothesis.

I - Introduction

Over the last years experimental observations of “dynamic” steady state in plasmas heated by ECH have been found in some stellarator devices, CHS [1,2] and W7-AS [3,4]. Fast spontaneous transitions in the radial electric field are measured in CHS, consistent with the transitions observed in the ECE temperature traces of W7-AS. The rapid changes in the central plasma magnitudes are attributed to a bifurcation property of the radial electric field in helical devices [5]. In those devices, the fast transitions occur when the ECH power is close to a threshold value [4], which depends on the plasma density [3,6]. Above the threshold value the plasma stays in the mode of improved confinement. In TJ-II, fast spontaneous transitions appear related to the magnetic topology in conditions of fixed electron density and ECH power. The magnetic configuration flexibility together with the low magnetic shear of TJ-II has permitted the characterisation of the transient behaviour observed in the plasma core and its relation with the magnetic topology.

II – Transient behaviour characteristics

The experimental results have been obtained in plasmas using 300 kW of ECH (at a frequency of $f = 53.2$ GHz, 2nd harmonic, X-mode of polarisation), coupled to the plasma by a quasi-optical transmission line with a high power density of about 15 W/cm^3 . In these plasmas the line-averaged density is about $0.7 - 0.8 \cdot 10^{13} \text{ cm}^{-3}$, the electron temperature at the centre of

the plasma is high (close to 1 keV) as compared with the ion temperature (about 0.1 keV). The diamagnetic energy is close to 1 kJ and the net plasma current (in absolute value) is lower than 1 kA.

Under some specific conditions a transient behaviour [7] is observed with fast drops in the electron temperature as measured by the ECE radiometer [8]. At the plasma centre the electron temperature falls and recovers in a fast time scale of about 100 and 300-500 μ s respectively, being the temperature variation as large as 20-25%. Temperature profile at normalised effective radius of $\rho > 0.3$ remains almost constant. Changes in the line-averaged density measured by the microwave interferometer of up to 5% are observed synchronised with the temperature drops- there is a change from hollow to flat density profile. The delay time between the temperature drops and the changes in the line density is of about $\Delta t < 100 \mu$ s. The radiation profile measured by bolometry changes from rather hollow to more flat in concordance with the density variations. No changes in the radiation are measured for $\rho > 0.4$. Mirnov coils detect coherent magnetic fluctuations at high frequency (20-40 kHz).

In our experiments, it has been observed that the control parameter for the appearance of this pulsated behaviour is the value of the plasma current and that this value depends on the magnetic configuration [7].

III – Rotational transform scan

To study the dependence of the transient behaviour on the magnetic configuration, a scan has been performed changing the rotational transform on a shot to shot basis, from $\nu/2\pi(0) = 1.59$ to 1.67 (vacuum values). In these discharges the line-averaged density is $\langle n_e \rangle = 0.8 \cdot 10^{13} \text{ cm}^{-3}$ and the central electron temperature is $T_e = 1 \text{ keV}$. The plasma current increases (in absolute value) up to 0.9 kA all along the discharge. During the magnetic configuration scan the main plasma parameters (pressure profile, net toroidal current, etc.) do not change significantly but the transient behaviour does. Fig. 1 shows the time evolution of the electron temperature close to the plasma centre in six different magnetic configurations with increasing values of the rotational transform in vacuum, from 1.59 to 1.67 at $\rho = 0$. The time traces are vertically shifted for a clearer representation. The bottom trace shows the time evolution of the plasma current (similar in all the discharges). In these magnetic configurations a coherent mode appears in the central temperature traces, at a frequency of about 20 kHz, during the transient phase of the discharge. Fig. 2 displays the evolution of four electron temperature channels during a short time interval, at which the transient behaviour stops, for the configuration with central

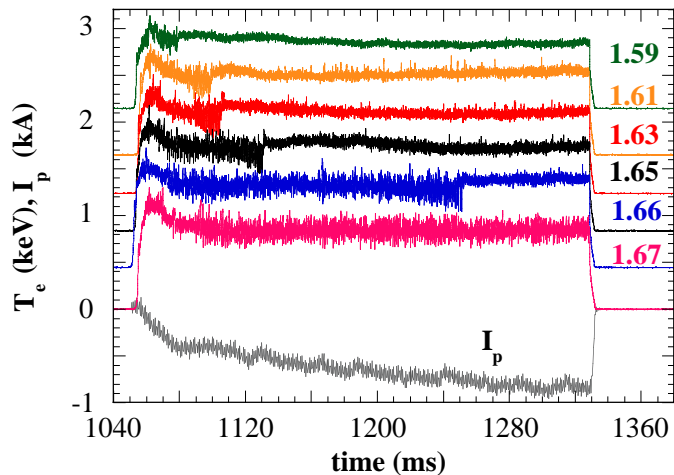


Fig. 1: Central electron temperature in a magnetic configuration scan. Central iota in vacuum varies from 1.59 to 1.67. The evolution of the plasma current is also displayed.

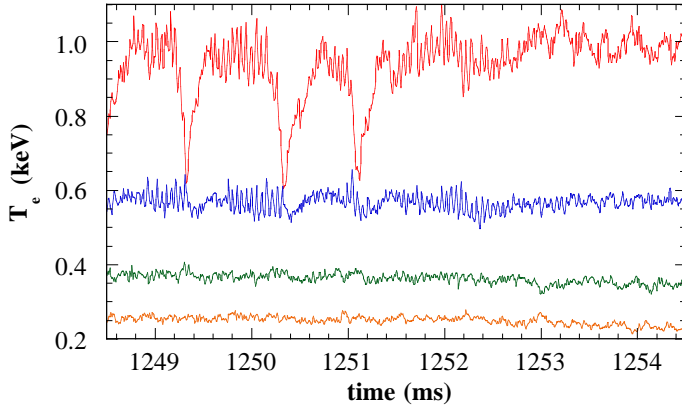


Fig. 2: Detail of the time evolution of four electron temperature channels in the configuration $\nu/2\pi(0) = 1.66$

displays T_e profiles measured by Thomson scattering, during (in blue) and after (in red) the transient phase in plasmas with central iota in vacuum of 1.66. A pronounced temperature gradient close to the plasma centre is measured after the transient phase.

In the rotational transform scan, the transient behaviour is observed in all configurations (see fig. 1) but it stops at different instants, i.e. at different values of the plasma current. The value of the plasma current at which the transient behaviour starts also increases when the vacuum rotational transform increases. Thus, the plasma current range at which the pulsated behaviour

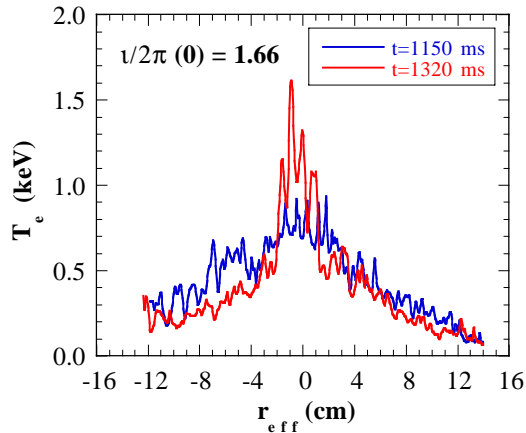


Fig. 3: Electron temperature profiles during and after the transient phase.

takes place depends on the rotational transform, in plasmas with very similar pressure profiles. To interpret this result we have to take into account that though the flexibility and low magnetic shear of TJ-II allows a very precise control of the rational values present in the rotational transform profile, a toroidal plasma current does affect slightly this profile. The measured plasma current is negative, it flows in opposite direction to the currents in the circular and helical coils resulting in a decrease of the rotational transform with respect to the vacuum case. Therefore, the higher current values needed for the appearance of this phenomenon at high vacuum rotation transforms implies a larger reduction in the actual rotational transform.

All these experimental observations suggest that the transient behaviour is connected with the presence of a rational surface in the core of ECH plasmas.

IV – Equilibrium calculations

In order to estimate the modification of the rotational transform profile due to the toroidal current we have performed equilibrium calculations using the VMEC code. The current density profile is considered to be proportional to the gradient in the plasma pressure as measured by the Thomson scattering system and the total current is set as the value measured

iota in vacuum of 1.66. The coherent oscillation only appears during the transient phase of the discharge and in the most central electron temperature channels ($\rho < 0.3$). This observation resembles the electron temperature fluctuations observed, as sawtooth crash precursor, in ECH plasmas in tokamaks [9]. When the transient behaviour stops, the electron temperature profile changes. Fig. 3

displays T_e profiles measured by Thomson scattering, during (in blue) and after (in red) the transient phase in plasmas with central iota in vacuum of 1.66. A pronounced temperature gradient close to the plasma centre is measured after the transient phase.

by the Rogowski coils. Given the launching parameters of the ECH system (set for no ECCD current drive), most of the current must be bootstrap driven. Fig. 4 shows the iota profiles

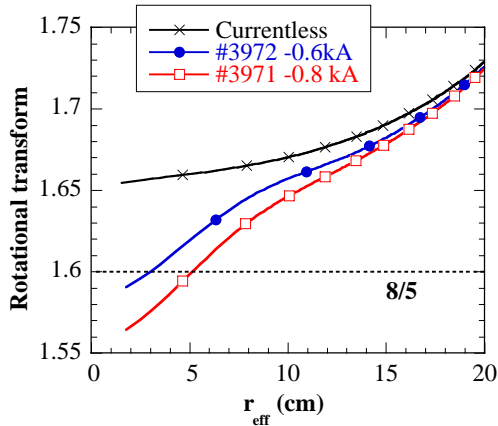


Fig. 4: Iota profiles for $I_p = 0, 0.6$ and 0.8 kA.

Increasing the plasma current (case with $I_p = -0.8$ kA in fig. 4) causes the rational surface to move radially outwards. The dependence of the rotational transform profile on the plasma current reinforces the hypothesis that the transient behaviour is connected with the presence of a rational surface in the plasma core. Experimentally, the transient behaviour and the coherent mode activity disappear (see figs. 1 and 2) at a certain value of the plasma current, and there is not a radial propagation of these effects but a change in the temperature gradient (see fig. 3). Therefore the interplay between the ECH and the presence of a rational surface within the power deposition zone seems to be the key point in the appearance of this phenomenon.

V – Conclusions

Plasmas heated using ECH, with low density and high electron temperature shows a transient behaviour in the plasma core. The flexibility and low magnetic shear of TJ-II have permitted the identification of the plasma current as the control parameter for the appearance of this phenomenon. Besides, the dependence with the rotational transform points to the hypothesis that the pulsed behaviour is connected with the presence of a rational surface close to the plasma centre where the ECH power is deposited. This hypothesis is supported by the equilibrium calculations performed with the VMEC code, in which the modification in the rotational transform profile due to the plasma current ($|I_p| < 1$ kA) is computed.

Our results indicate that rational surfaces can play an important role in the modification of the transport properties in the core of ECH plasmas.

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