Fluctuation-Induced Turbulent Transport and Sheared Flows close to Instability Threshold in the TJ-II Stellarator

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Magnetic well and instability thresholds in the TJ-II stellarator

TJ-II is a low magnetic shear stellarator of the Heliac type [1] (average major radius of 1.5 m and average minor radius of < 0.22 m) that provides plasma stability through the existence of a magnetic well in the whole plasma radius (magnetic well depth is defined as $W=100x[U(\rho)-U(0)]/U(0)$, where $U(\rho)$ is the specific volume at a given effective radius ρ; ρ=0 refers to the magnetic axis). Previous magneto hydrodynamic (MHD) studies [2, 3] have examined the stability properties of the device and shown the characteristics of the magnetic well term for ideal and resistive interchange modes, finding that the presence of magnetic well is the main stabilising mechanism in TJ-II. Experimental evidence of the influence of the magnetic well in regulating the fluctuations in the plasma edge region of the TJ-II stellarator has been recently reported [4].

Making use of the flexibility of the TJ-II magnetic configuration, the magnetic well depth may be modified over a broad range of values, from 0% to 6%. Three different magnetic configurations with very similar iota profiles and magnetic well 2.4, 0.6 and 0.2 % have been investigated. Figure 1 shows the vacuum configurations under study (configurations are labelled by means of the current flowing in three of the four sets of coils of TJ-II). Magnetic well profiles are shown in figure 2. In the magnetic configuration with magnetic well 0.2 %, a

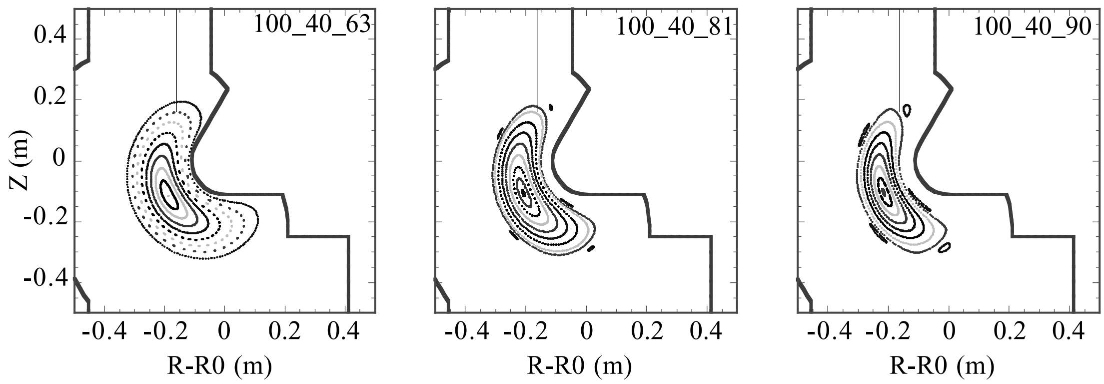

Fig. 1.- Vacuum calculations of the plasma magnetic surfaces in configurations with magnetic well 2.4, 0.6 and 0.2% respectively and similar rotational transform profile. Lines show the approximated position of the Langmuir probe.

region having magnetic well in the plasma core can coexist with a region having magnetic hill in the plasma edge.

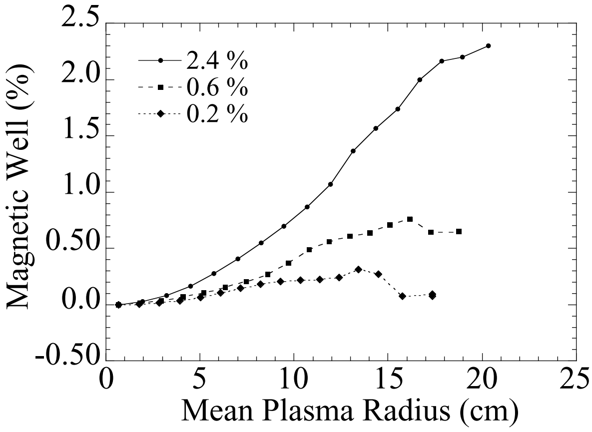

Fig. 2.- Radial profiles of the magnetic well.

Measurements carried out using Langmuir probes allow us to get ion saturation current and floating potential profiles as well as its fluctuations in the plasma edge, up to $\rho \approx 0.8$ [5]. The Langmuir probes are inserted into the plasma edge region from the top of TJ-II at a velocity of about 1 m/s. By means of this probe array, it is possible to measure edge plasma profiles in a single shot and at two radially separated positions.

Figure 3 shows the time evolution of ion saturation current and of floating potential signals for magnetic configurations with different magnetic well depth and for similar relative probe positions ($\rho \approx 0.9$). The level of edge plasma fluctuations increases when the magnetic well is reduced.

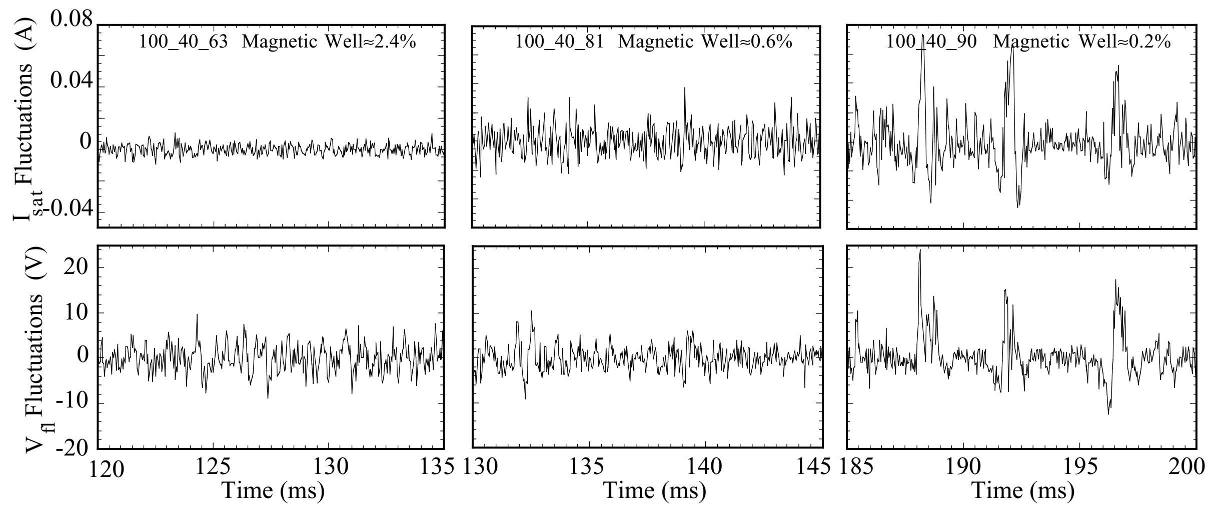

Fig. 3.- Fluctuations of the ion saturation current and of the floating potential for the studied configurations with different magnetic well in the plasma edge.

As is shown in the figure 3, large fluctuation bursts are observed in the most unstable configuration (0.2 % magnetic well). These large amplitude transport events are observed simultaneously in the H_{α}, ECE and line average density signals.

The set-up of the employed Langmuir probes allows to measure the radial velocity of those events. Figure 4 shows the time evolution of the ion saturation current as measured by two probes radially separated about 1 cm during the propagation of transport events generated in the configuration with reduced magnetic well (0.2 %). The measured time delay gives rise to a radial velocity in the range 500 – 1000 m/s.

The evolution of the electron density profile has been measured by microwave reflectometry [6]. Electron density profiles measured by reflectometry during the magnetic well scan show differences in shape depending on the magnetic configuration as is shown in figure 5. A noticeable change in the electron density profile is observed in the most unstable magnetic configuration, with a reduction in the gradient of the density profile.

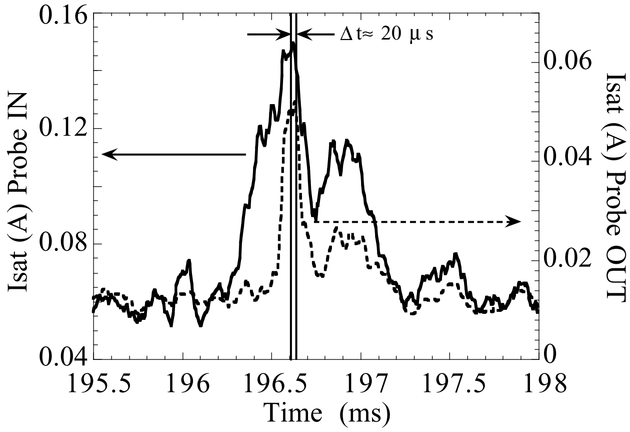

Fig. 4.- Time delay of the maximum of one of the observed events measured in two probes radially apart.

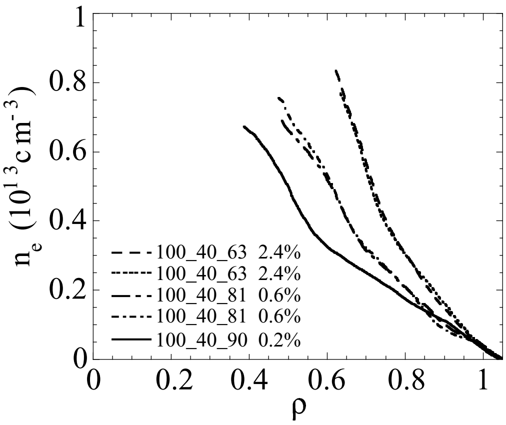

Fig. 5.- Density profiles measured in three different configurations as a function of the normalized radius.

Sheared poloidal flows close to marginal stability

From the wave number and frequency spectra *S(k,ω)*, computed from the two points correlation technique we define the poloidal phase velocity of fluctuations as,

$$v_{phase} = \sum S(k,\omega)\,(\omega / k) / \sum S(k,\omega)$$

A reversal in the phase velocity of fluctuations (shear layer) has been observed in the proximity of the last closed flux surface (LCFS). These changes in the poloidal phase velocity of fluctuations can be explained, or at least are consistent, in terms of E×B drifts.

Figure 6 shows the radial profiles of the fluctuations (rms) of the floating potential and the computed poloidal phase velocity of the fluctuations. In some plasma conditions (as is shown in the figure) a reduction in the level of fluctuations close to the velocity shear layer is obtained. This reduction is due to the decay of the low frequency components of the spectra. Furthermore the frequency resolved cross-correlation between floating potential signals radially separated 1 cm shows a significant reduction at low frequencies (f < 30 kHz).

The resulting radial gradient dv_{phase}/dr is in the range of 10^5 s^{-1}, which turns out to be comparable to the inverse of the correlation time of fluctuations τ, in the range of 10 μ s. This result suggests that there is no continuous increase of the E×B flow when approaching the critical power threshold for the transition to improved confinement regimes and that E×B sheared flows organize themselves to be close to marginal stability.

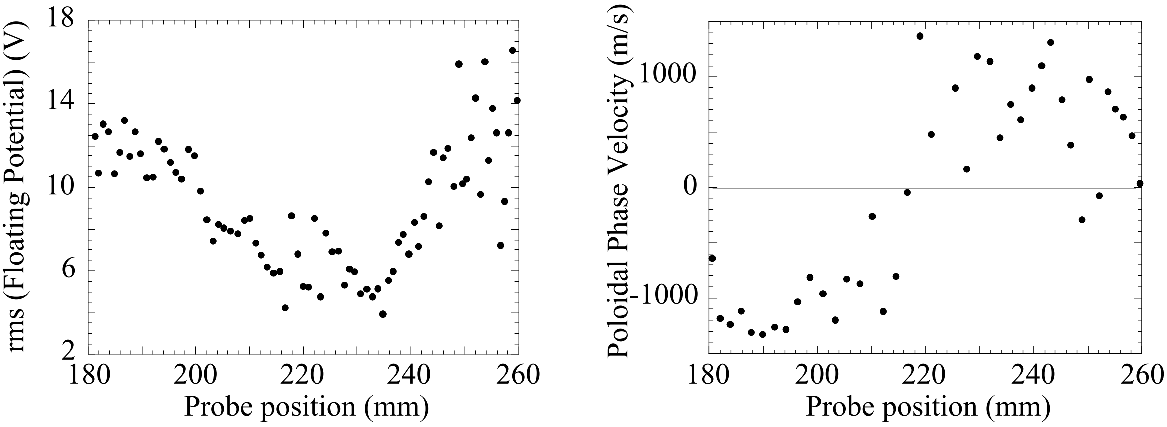

Fig. 6.- Radial profiles of the fluctuations (rms) of the floating potential and the computed poloidal phase velocity of the fluctuations

Conclusions

Comparative studies for plasma configurations with different magnetic well depth show changes in density and potential fluctuations in the plasma edge. A widening of density profiles and the increase of its gradient as the magnetic well increases has been also observed up to $\rho \approx 0.5$. The turbulent flux and the level of fluctuations increase when reducing the magnetic well from 2.4 to 0.2%. The radial velocity of large transport events in magnetic configurations with reduced magnetic well is in the range 500 – 1000 m/s, a value which is comparable to the radial propagation of ELMs in the JET plasma boundary region [7]. These results might suggest the existence of different transport mechanisms for small and large transport events (diffusive versus non-diffusive) in the plasma boundary region.

For the different plasma configurations under study, the naturally occurring velocity shear layer organizes itself to reach a condition in which the radial gradient in the poloidal phase velocity of fluctuations is comparable to the inverse of the correlation time of fluctuations ($1/\tau$). Furthermore, under some plasma conditions there is a significant reduction both in the level and in the radial correlation of fluctuations at the velocity shear layer. This property should be considered as a critical test for L-H models and as an important ingredient in the L-H power threshold physics.

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