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Influence of Biasing on Coherent Structures in TJ-K

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Abstract: Poloidal shear flows play an important role in the improvement of plasma confinement in fusion devices. They limit the radial correlation length via the shear decorrelation mechanism [1] and can trigger transitions into transport barriers. The torsatron TJ-K is operated with low-temperature plasmas in hydrogen, helium and argon, which are accessible by electrostatic probes throughout the plasma column. External biasing is used to drive poloidal shear flows in order to study the decorrelation mechanism. An 8x8 Langmuir probe matrix serves to trace the quasi-coherent modes, which reflect the background flow.

Introduction: The underlying mechanism for the improvement of plasma confinement by shear flows is the decorrelation of radially extended eddies [1,2]. Poloidal flow shear can be generated by different processes. A natural one is the Reynolds stress drive of zonal flows, which are poloidally and toroidally symmetric ($k_\theta = k_\parallel = 0$), radially localised ($k_r \neq 0$) potential structures [3]. An analysis of the existance of zonal flows, their drive and their impact on turbulence was carried out on simulated data [4]. Indications to the existence of Reynolds stress driven zonal flows in TJ-K have not been observed yet.

Furthermore, poloidal shear flows can be driven externally by biasing the plasma potential [5, 6]. To balance the current through an electrode inserted into the plasma, a radial return current runs from the plasma edge to the core. This current leads to a torque and the generation of a poloidal flow. In this work the shear decorrelation mechanism and the influence of shear flows on coherent structures by means of biasing is studied. First biasing results in TJ-K are presented. It is shown, that biasing leads to a transition into a state, where fluctuation levels are reduced and the density is increased. In this state conditional averaging fails in detecting coherent structures, which are observed in the unbiased phase.

Experimental Setup: TJ-K [7] is an $l = 1$, $m = 6$ torsatron. Minor and major plasma radii are 0.1 and 0.6 m, respectively, and the magnetic field strength is $B \leq 0.3\,\mathrm{T}$ at $\iota \approx 1/3$. It is operated with a low temperature plasma at densities up to $n_e = 6 \times 10^{17}\,\mathrm{m}^{-3}$ and electron temperatures up to $T_e = 30\,\mathrm{eV}$. The ions are cold ($< 1\,\mathrm{eV}$). Working gases are hydrogen, helium and argon. Discharges presented here were produced by electron cyclotron resonant heating (ECRH). The input power reaches up to $P_{\mathrm{ECRH}} = 6\,\mathrm{kW}$. ECRH is possible in the range $72\,\mathrm{mT} \leq B \leq 96\,\mathrm{mT}$ at a typical neutral gas pressure p_0 in the rage of 10^{-5}–10^{-4} mbar. The discharge duration is up to 40 min.

The biasing probe is a closed stainless steel wire of 3 mm diameter, aligned to the calculated separatrix. Figure 1 (left) shows the good agreement between the calculated flux surfaces and the contours of the relative density measured by a 2D movable Langmuir probe. The electrode is positioned directly onto the dashed line. Preliminary experiments with smaller probes, in particular an emissive probe negatively biased, were less successful.

In order to have a measure for the flows and their effect on turbulence, the motion of quasi-coherent modes is detected by an 8x8 matrix of Langmuir probes. Each probe

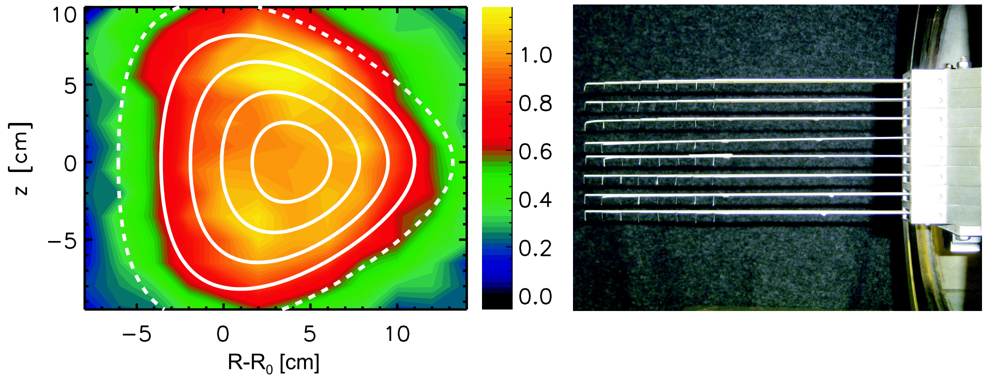

Fig. 1: Left: Ion saturation current measured by a 2D movable Langmuir probe for an argon plasma at $B = 89\,mT$, $p_0 = 5 \cdot 10^{-5}\,mbar$ and $P_{\mathrm{ECRH}} = 1.8\,kW$. The profile is overlaid with the calculated flux surfaces. The dashed line depicts the separatrix. Right: Picture of the 8x8-Langmuir probe array.

consists of a tungsten wire of $200\,\mu$m in diameter insulated against the plasma by a ceramic tube. The tip has a length of 4 mm, which is vertically aligned as can be seen on the right hand side of figure 1. These probes cover a spatial grid with a resolution of 1 cm in horizontal an vertical direction. Floating potential or ion saturation current at 64 positions are simultaneously acquired by means of a 64-channel transient recorder.

Coherent Structures as a Tracer of the Flow: Simultaneous measurements of density fluctuations at 64 positions in the vicinity of the separatrix have been carried out using the 8x8 matrix. A cross-correlation analysis technique has been applied to the data in order to extract information about the size and propagation of coherent structures. The degree of correlation as a function of the time lag Δt was calculated according to

$$C_{uv}(\Delta t) = \int \frac{u(t)}{\sigma_u} \frac{v(t + \Delta t)}{\sigma_v} \, \mathrm{d}t,$$

where u and v are the mean-free density fluctuations at different positions in space. For a single time lag the degree of correlation between a fixed position (u) and at all other positions (v) is mapped onto the matrix area. Similarly this technique has been applied to simulated data in [8]. Examining consecutive time lags the spatio-temporal evolution of the coherent structure becomes visible.

Figure 2 shows a map of the density perturbation at $\Delta t = 0$ for the gases argon, helium and hydrogen. The cross-point marks the position of the reference probe. Ellipses indicate a correlation of about 50%. The decrease of structure size at decreasing ion mass reflects the scaling with the drift scale $\rho_s = c_s/\omega_{ci}$ (where $\omega_{ci} = eB/M_i$ is the ion cyclotron frequency and c_s the sound speed) – in agreement with results in [9]. For each gas figure 2 depicts a snapshot of a structure poloidally propagating clock-wise. This observation has also been made in [9] by means of the conditional averaging technique [10].

The aim of this work is to compare the results of both two-dimensional data analysis techniques quantitatively and to study the influence of biasing on the size and propagation of the coherent structures observed in TJ-K.

First Biasing Experiments: In order to achieve sufficiently high radial currents the probe is biased positively. In figure 3 an example of an experiment in argon is shown.

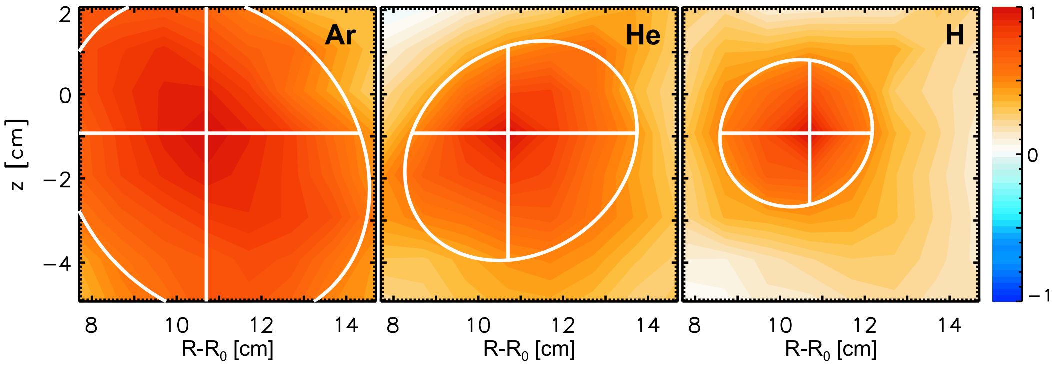

Fig. 2: *Cross-correlation at $\Delta t = 0$ mapped onto the matrix area for argon (left), helium (centre) and hydrogen (right). The parameters are $B = 89\,mT$, $p_0 = 5 \cdot 10^{-5}$ mbar and $P_{\mathrm{ECRH}} = 1.8\,kW$ respectively. The position of the reference probe is marked by the cross-point. Ellipses frame an area of a degree of correlation larger then 50%. The decrease of structure size at decreasing ion mass reflects the ρ_s-scaling.*

By increasing the bias voltage, transition at about $U = 17\,\mathrm{V}$ is observed. The electron density measured by microwave interferometry suddenly decreases (fig. 3, left), which is linked with a drop in the effective ECRH power deposed in the plasma (fig. 3, right). The density drop is different from what is observed in H-mode transitions in fusion plasmas [11]. Nevertheless the fluctuation level is decreased after the transition. Measurements of the ion saturation current at the plasma core and in the density gradient (fig. 3, centre) show a little different behaviour. A small drop is visible at both positions. After the transition the density at the gradient stays at a smaller value, whereas the density at the core slightly carries on increasing with increasing bias, pointing to a steepening of the density gradient.

The density drop after the transition might be related to the heating mechanism. The plasma density is clearly above the ECRH cutoff of $n_{\mathrm{cutoff}} = 7 \cdot 10^{16}\,\mathrm{m}^{-3}$. The working hypothesis is, that there exists a standing wave between the cutoff surface and the wall with a part of the wave tunnelling to the core by the OX-B conversion process. Changes in the density gradient lead to an immediate increase of the reflected power (figure 3, right) and therefore a possible improvement in confinement is nullified due to the reduced heating power

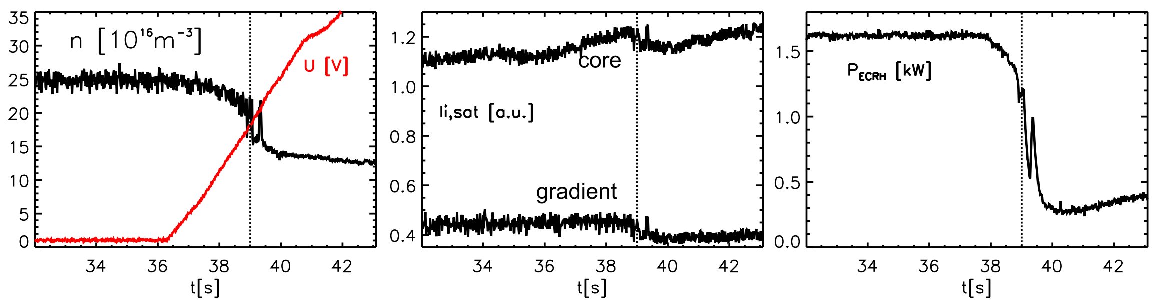

Fig. 3: *Left: Temporal evolution of electron density measured by microwave interferometry (black) while increasing the bias (red). Centre: Temporal evolution of the ion saturation current measured by Langmuir probes at the radial positions 4 cm (core) and 9.5 cm (gradient). Left: Effective power deposition. A transition occurs at $t \approx 39$ s (marked by the dotted line).*

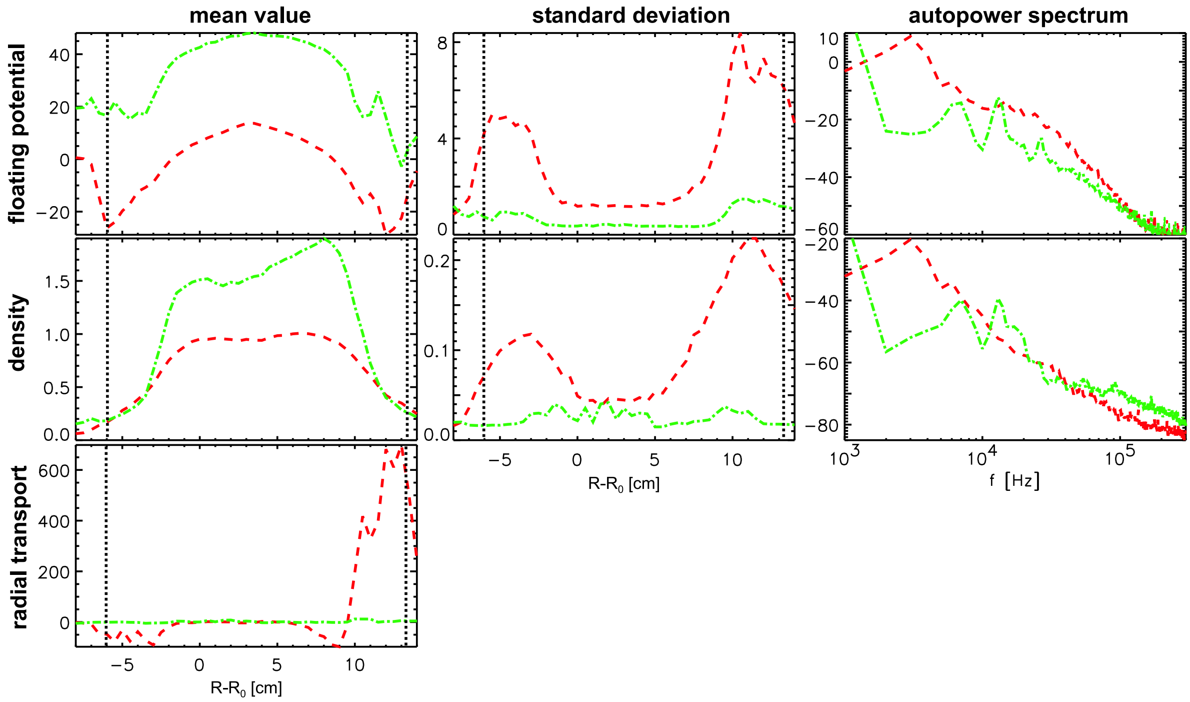

Fig. 4: Radial profiles of floating potential (top), density (centre) and radial turbulent transport (bottom) without biasing (red, dashed line) and with biasing (green, dash-dotted line). The parameters are as in figure 1. Dotted lines mark the separatrix.

But the effects accompanying that transition are typical for a transition into a higher confinement mode observed in other devices: Increasing the bias leads to an increasing current drawn by the probe until a transition occurs. Due to an increase in radial resistivity this transition is accompanied by a sudden drop in the probe current [5]. After the transition the ECRH can be re-matched in order to compensate the drop in ECRH power. After this profile measurements by means of Langmuir probes give the preliminary results shown in figure 4, which depicts the radial profiles of density, floating potential and temporally averaged radial transport before and after the transition. After the transition the floating potential is shifted to higher values. Steeper gradients are found at $-2.5\,\mathrm{cm}$ and $10\,\mathrm{cm}$, pointing to a higher E_r and $\mathbf{E} \times \mathbf{B}$ flow shear at this positions. The density is increased by at least 50%, revealing steeper gradients as well. The fluctuation level in density and floating potential as well as the turbulent transport is decreased drastically.

In the unbiased phase the auto-power spectra of density and floating potential fluctuations at the position 9.5 cm show a prominent peak at $f = 3\,\mathrm{kHz}$, which is damped in the biased phase after the transition. This peak corresponds to the poloidally propagating structure shown in figure 2, which is a quasi-coherent mode. An additional examination of higher statistical moments (skewness, kurtosis) showed, that fluctuations in density and floating potential become more Gauss like. After the transition a poloidally propagating structure couldn't be detected any more by means of conditional averaging.

In future work the results of the cross-correlation technique and the results of the conditional averaging technique will be compared qualitatively. The relation between poloidal flows and propagation velocities of the coherent structures will be studied. In order to investigate the influence of shear flows on the size and propagation of coherent structures, it is of special interest to trigger the simultaneous measurements of the 8x8-

probe array at the transition directly.

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