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On the link between flows, turbulence and electric fields in the edge of the TJ-II stellarator

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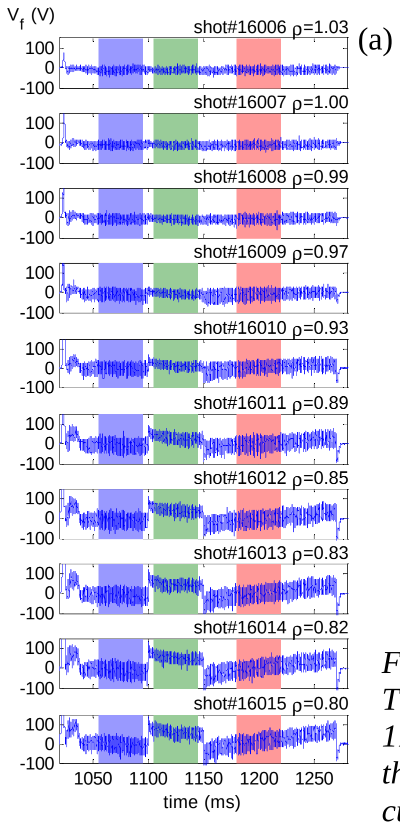
Introduction. Plasma flows play a crucial role on transport (e.g. development of transport barriers) and stability (e.g. enhacing the stabilizing effect on resistive wall modes) in magnetically confined plasmas [i]. Toroidal rotation can be driven by external forces such as momentum from neutral beam injection (NBI) but, in large scale devices like ITER, the NBI driven rotation will be limited and then it is important to identify other mechanisms which can drive plasma rotation. Recent experiments have shown the possible influence of turbulence as a component of the anomalous parallel flows observed in the plasma boundary region [ii, iii]. In the plasma core region, evidence of anomalous toroidal [iv, v] and poloidal [vi, vii] momentum transport has been reported in different tokamak devices.

Different mechanisms have been proposed to explain these results, including neoclassical effects [x], turbulence driven models [xi, xii, xiii], fast particle effects [xiv] and electric fields [xv]. Symmetrising flows, driven by a strong turbulent ballooning transport poloidal asymmetry, have also been considered as a flow driving mechanism in the Scrape-Off-Layer [iii,xvi, xvii]. Recently, the role of the sheared radial electric fields as a symmetry-breaking agent to drive parallel flows has been highlighted [xviii], showing the possible dual role of sheared electric fields as a damping of turbulence and driving of parallel flows.

Experimental setup. Experiments were carried on the TJ-II heliac stellarator with Electron Cyclotron Resonance Heated plasmas (P_{ECRH}= 200 - 400 kW, B_T = 1 T, R = 1.5 m, <a> = 0.22 m, $\iota(a)/2\pi \approx 1.7-1.8$). A graphite electrode was inserted 3-4 cm into the plasma and is biased for 50 ms during the discharges with respect to a poloidal limiter located in the proximity of the Last Colsed Flux Surface (LFCS). A combined Langmuir-Mach probe (located in a different toroidal sector of the devices separated) was used to measure the fluctuating poloidal electric field and the parallel mass flow. Profiles of the differentphysical magnitudes were obtained in a series of very similar plasma discharges on a shot to shot basis.



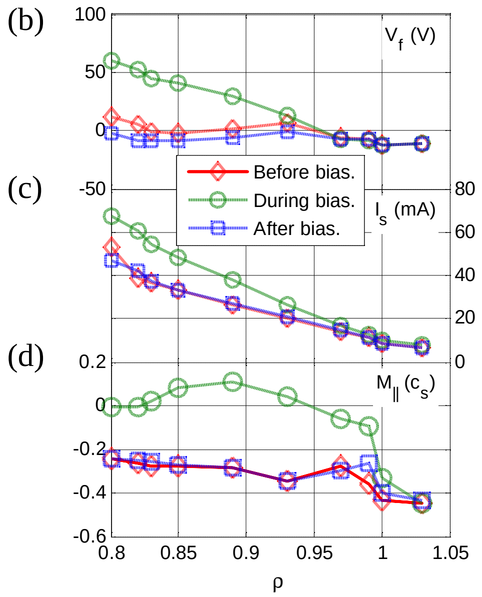


Figure 1. (a) Floating potential evolution during a TJ-II shot series with external biasing applied between 1100 and 1150 ms. (b) Floating potential profiles in the time windows marked in (a). (c) Ion saturation current and (d) parallel Mach number profiles.

Results. The effects of external biasing are clearly seen in the floating potential, saturation current profiles and parallel flows (figure 1.a-c) as well as in the turbulence level. The increased radial electric field shear reduces the turbulence intensity and the density profile becomes steeper as a result of an improved confinement [xix]. The external biasing has also a deep effect upon the parallel mass flow represented in figure 1.d as the parallel Mach number $M_{||}$. Parallel velocity profiles are rather flat when there is no external biasing with values ranging from -0.4 outside the LCFS to -0.2 some 4 cm into the plasma –the positive direction of the parallel flow is chosen as that of the local *B* field. During external biasing improved confinement regimes a stronger parallel flow shear develops in the plasma edge: the Mach number remains unaltered in the outermost position (SOL region) whereas there is a significant positive increment $\Delta M_{||} \approx 0.2 - 0.3$ at inner radial locations. A flow reversal is observed around $\rho = 0.9$.

The radial-parallel component of the Reynolds stress was computed before, during and after the biasing and is shown in figure 2. The higher gradients are seen to appear in the proximities of the LCFS where the radial-parallel correlation changes sign. The turbulence reduction during the biasing reduces the magnitude of $\langle \tilde{v}_r \tilde{v}_{||} \rangle$, however the radial gradient in this turbulence-driven velocity flux are arguably larger than those with no external biasing around $\rho = 0.9$. Normalising the Reynolds stress component with the RMS values of its constituents (which amounts to calculating the correlation coefficient) reveals that the fluctuation coherence strongly increases towards more interior positions (figure 2) and is responsible of a good part of the gradient observed in the radial-parallel coupling.

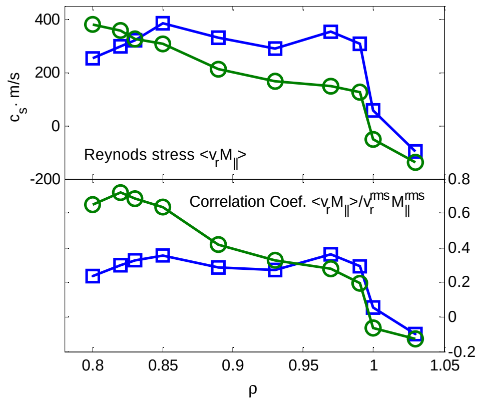


Figure 2. Profiles of radial-parallel Reynolds stress component (top) and correlation coefficient (bottom), before (blue squares) and during (green circles).

As a first estimation of the significance of the increment of $\partial_r \langle \tilde{v}_r \tilde{v}_{\|} \rangle$ in the parallel flow balance, it can be compared with the increment on the friction term $-\mu \Delta M$ where the friction coefficient (?) can be approximated by the inverse flow damping time, $\mu = 1/\tau_d$. Ithas been measured for the poloidal flows and radiel electric fields to be of the order of 10 μs [xx, xxi]. The fitting of the parallel flow relaxation times after the biasing turn-off is less concluding than those presented in [xx] but the orders of magnitude are similar. By using this estimation we obtain $-\mu\Delta M \approx -\frac{0.3 c_s}{10 \mu s} \approx -3\times 10^4 c_s / s$, to be compared with $\partial_r \langle \tilde{v}_r \tilde{v}_{\|} \rangle \approx \frac{-200 m/s \cdot c_s}{1.6\times 10^{-2} m} \approx -1\times 10^4 c_s / s$. This indicates that this mechanism can affect parallel dynamics in the plasma boundary region.

<u>Conclusions</u>. Applying a radial electric field trough external biasing was seen to have a strong impact on parallel Mach number profile in the edge of the TJ-II stellarator. Changes of $\Delta M_{\|} \approx 0.3$ were reported on interior positions whereas the parallel mass flow remained unchanged in the SOL.

The parallel-radial component of the Reynolds stress $\langle \tilde{v}_r \tilde{v}_{\|} \rangle$ has been measured in different radial locations in the SOL/edge transition region in the TJ-II stellarator. The effect of the increased radial electric field shear E_r' during external basing induced improved confinement regime on the radial profiles has been investigated. Results show a reduction in the parallel-radial Reynolds stress component as a result of the lower turbulence level. However, the ‘phase coherence’ between the fluctuations is strongly enhanced inside the plasma (around $\rho \approx 0.85$) which generates a gradient in $\langle \tilde{v}_r \tilde{v}_{\parallel} \rangle$ of a magnitude comparable to the observed change in the friction term $-\mu\Delta M$. This order of magnitude comparison of local measurements suggests that turbulence driven momentum flux (via Reynolds stress) can be an additional ingredient in the parallel momentum balance equation, in which several mechanisms can be at work [xxii]. Also, it should be noted that our experimental results are based on *local* measurements. Care should be taken in their extrapolation to other poloidal/toroidal positions [xxiii].

The results presented in this work show the dual role of sheared *E* x *B* flows as a parallel-radial symmetry breaking agent with impact on plasma parallel momentum dynamics as well as its stabilizing effect on turbulence.

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