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Parallel and perpendicular flow measurements in the edge region of RFX-mod

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Sheared flows are recognized to play an important role in regulating turbulent transport since the discovery of improved confinement regimes in fusion experiments. Among the sheared flow generation mechanisms, strong attention is devoted to Reynolds stress, so that a self-regulation mechanism between turbulence and average flow scales has been proposed. A clear relationship was found between the E×B sheared flow profile and the radial gradient of the complete Reynolds stress in Reversed Field Pinches (RFP) [1]. Aim of this contribution is to provide a detailed reconstruction of edge flow profiles measured both in their parallel and perpendicular components with respect to the magnetic field in the edge region of the RFX-mod RFP experiment, a toroidal device with R/a=2m/0.459m [2].

The different components of the plasma flow at the edge and their shear are obtained by combining and comparing information provided by two insertable probe systems, placed 30° toroidally apart from each other. The first one, dubbed "U-probe", placed at =217°30'. consists in a new and original probe head including 2D arrays of both electrostatic and magnetic sensors. Simultaneous measurements of electrostatic quantities, such as radial profiles of plasma density, electron temperature, T_e, E×B flow and magnetic fluctuations are provided [3]. For the present analysis a radial array of balanced triple probes radially spaced by 6 mm is used. The second system is a Gundestrup probe head [4], placed at =247°30', equipped with 8 directional pins located on a 23 mm diameter circle perpendicular to the radial direction, which allows obtaining the evaluation of both parallel, M_{par}, and perpendicular, M_{perp}, Mach numbers at a given radial position. This probe has been used with all the pins measuring floating potential, V_f. The flow has been reconstructed according to the models for magnetized and not magnetized plasma, see refs [4]; however in this case, following the suggestion of [5], the V_f signals have been used instead of ion saturation current, I_s, according to the relationship $V_f=V_p - T_e \ln(I_{es}/I_{is})$, where V_p is the plasma potential and I_{es} and I_{is} are the electron and ion saturation current respectively. All signals are digitally sampled at a frequency of 5 MHz so that high time resolution measurements are obtained.

Radial profiles can be obtained on a shot to shot basis by inserting the probes up to about 10% of the minor radius. Due to the limited power that probes can withstand, the plasma current was kept at values below 400 kA, the normalized density n/n_G was in the range 0.2÷0.7. The RFP is a magnetic configuration with a toroidal magnetic field reversing its sign at the edge; its configuration can be described using the reversal parameter F=B (a)/<B >, the ratio between the toroidal field at the edge and the average magnetic field. The reversal surface constitutes a resonance for the m=0 modes and its radial position, r_{rev}, depends on F value. In this region the magnetic surface reconstruction shows a m=0 island chain [6] placed 1-2 cm far away from the first wall, for shallow F (F>-0.05), whereas this distance increases up to some cm for deeper F (r_{rev} ranging from 3 to 5 cm for -0.2<F<-0.15), see for instance fig 3.

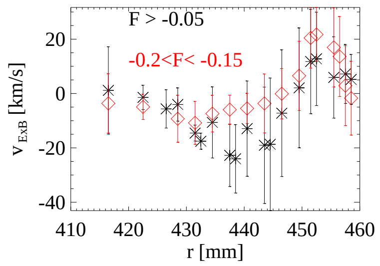

Fig 1 Average radial profiles of E×B flow, as measured by the U-probe head, for two classes of reversal parameter F.

Average radial flow profiles

Thanks to an improved magnetic boundary control with a reduced plasma wall interaction [7] and to a feedforward controlled reversal parameter [8] a set of low current reproducible discharges has been obtained operating at shallow F (F>-0.05) and deep F (-0.2<F<-0.15), so that two classes of magnetic equilibria could be compared. The average radial profiles of $v_{E\times B}$ flow (mainly toroidal in the edge region of a RFP, since B≅B) are shown in fig. 1, as measured by the U-probe, by accounting for the radial derivative of the plasma potential, $v_{E\times B} = (-dV_p(r)/dr)/B$.

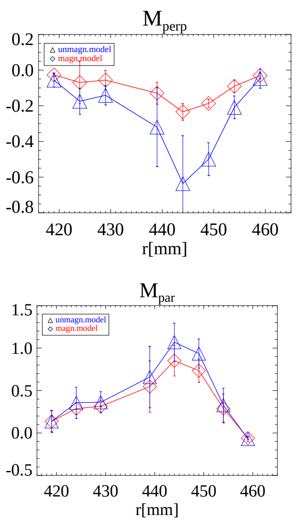

Fig 2 Average radial profiles of M_{par} and M_{perp} as measured by the Gundestrup probe for a set of discharges with shallow reversal. The blue and red curves indicate the flow reconstruction through a magnetized and not

It can be observed that in the shallow F configuration relatively higher values of E×B flow and of its shear are found within few cm from the first wall. This different behaviour can be related to the outer radial position of the reversal surface and is in agreement with a picture of a better confinement experimentally observed when operating at shallow reversal, see also [9] for sheared flow at high plasma current (I_p>1 MA). A slight increase in the edge toroidal flow has been observed also by the Gas Puffing Imaging diagnostic [10] as deduced from the toroidal propagation of the HeI emission fluctuations.

As mentioned before the Gundestrup probe provided the radial profiles of M_{par} and M_{perp}. Average radial profiles of these quantities for the shallow reversal dataset are shown in fig.2. It can be observed that $M_{par}(r)$ exhibit the highest shear within 2 cm from the first wall, which for the shallow F equilibrium corresponds to the position of the m=0 chain of magnetic islands. The M_{perp} profile is consistent with the $v_{E\times B}$ flow measured by the U-probe, supporting the reliability of the method based on Gundestrup probe collecting V_f signals.

Investigation of the local edge boundary

With the aim of gaining insight on the relationship between the local magnetic topology and the corresponding local edge flow properties a specific experiment has been conceived exploiting the versatility of the magnetic boundary control system of the RFX-mod experiment.

Specifically, a step in the reversal parameter F has been induced during the discharge aiming at comparing different magnetic equilibria: a phase with a shallow reversal (F>-0.05) and a phase with deeper reversal (F<-0.15). The transition occurs within a range of about 5 ms, an example is shown in fig. 3. In such a way the insertable probes could monitor the edge properties of the two equilibria and of the transient phase as well.

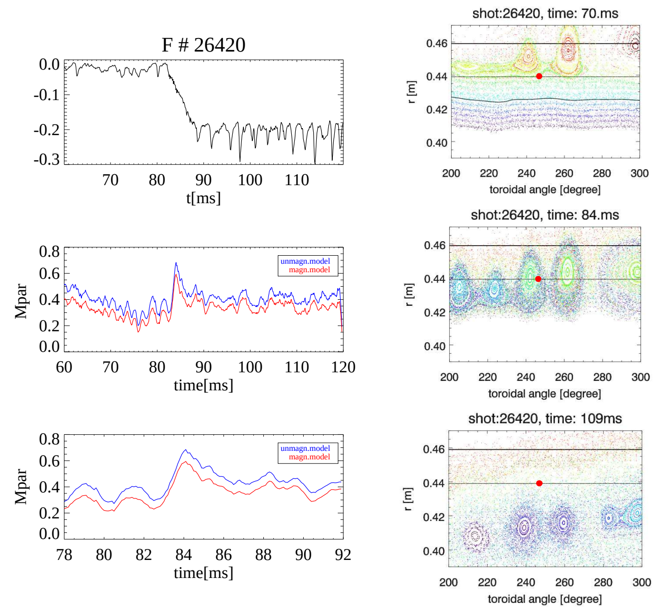

Fig. 3 Time evolution of M_{par}, at r=439mm, during a transient of F parameter (left). Poincaré plots of local magnetic topology at three different time instants (right). The red dot indicates the probe measurement point.

In the left panel of fig. 3 the time behaviour of the parallel flow (M_{par}) is shown during the transient of the reversal parameter. It is observed that a peak characterizes this phase. With the aim of better understanding this behaviour the local magnetic topology evolution has been studied through Poincaré plots on the (r-) plane, provided by the FLiT code[11], during three time instants representative of the transition (fig. 3, right panels). In the present case the radial position of the measurement is at r=439 mm. It can be observed that the measurement point is progressively dipped into an m=0 island so that the time behaviour can be considered as an indication of the M_{par} radial profile within the magnetic island, suggesting that the magnetic island m=0 is characterized by a sheared parallel flow. Within this framework the time behaviour of M_{par} suggests also that the peak observed in the average M_{par} profile shown in fig. 2 is due to the m=0 magnetic island chain positioned at about 1-2 cm inside the first wall that characterizes the shallow F configuration.

Analogously in fig 4 (left panels) is shown the transient observed in the $v_{E\times B}$ flow shear exhibiting a correlation with the induced step in the reversal parameter, shown in the same picture. Also in this case the reconstruction of the local magnetic topology helps in understanding the origin of this behaviour (see fig. 4 right panels): the probe measurement shown in the picture is obtained at r=434.5mm, highlighted by a red dot in the Poincaré plots. The flow shear variation observed in the time series seems related to the location of the probe, which becomes closer to the edge proximity of a m=0 island, characterized by well conserved surfaces and corresponding to a high sheared flow. This picture is in agreement with the hypothesis of a highly sheared region surrounding magnetic islands as proposed in [12] and suggested by experimental results [13].

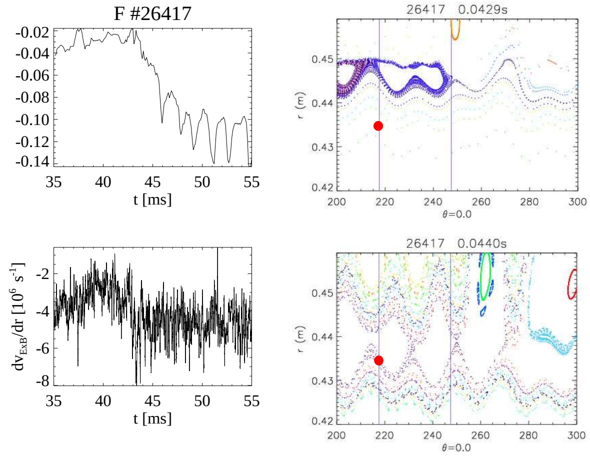

Fig. 4 Time tracing of $v_{E\times B}$ shear flow measured at r=434.5mm, during a transient induced on the reversal parameter (left). The Poincarè reconstructions corresponding to the transition are shown as well (right).

Summarizing average and local flow features in the edge region of RFX-mod are affected by the equilibrium configuration and local magnetic topology, so that a cross check between probes and magnetic reconstruction provides a useful tool for investigate this issue.

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