

## Impurity flow studies in RFX-mod operation with reduced MHD mode activity

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**Introduction** - The magnetic configuration of a Reversed Field Pinch (RFP) is characterized by a wide spectrum of internally resonant tearing modes, with poloidal number  $m = 0, 1$  and toroidal number  $n < -7$ . These dynamo modes have the natural tendency to lock in phase and create a localized bulge at the plasma surface. While both  $m = 0$  and  $m = 1$  modes are responsible of the local enhancement of the plasma wall interaction,  $m = 0$  modes cause the creation of magnetic islands that change the magnetic topology near the magnetic surface where the toroidal field reverses. In the RFP device RFX-mod, the introduction of the so-called virtual shell operation allowed the active control of the radial field at the edge by the independent feeding of 4 x 48 saddle coils. This led to a significant reduction of the amplitude of the MHD modes [1,2].

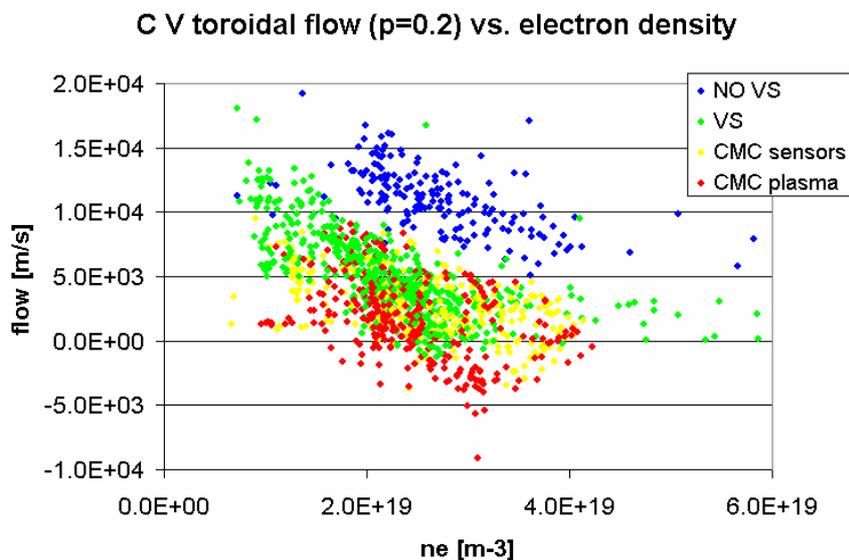
This paper reports about passive spectroscopic measurements of the plasma flow as obtained in several RFX-mod experimental scenarios. In particular, the dependency of plasma toroidal rotation velocity  $v_\phi$  on the electron density and the flow profiles in various plasma conditions will be discussed.

**Experimental results and discussion** – The toroidal rotation of the plasma is obtained spectroscopically by Doppler shift measurements of line radiation from impurities. A Czerny-Turner spectrometer with 68 cm focal length equipped by a Fast Optical Multichannel Analyser allows the simultaneous acquisition of 9 spectra collected along different toroidal *lines of sight (los)*, with a time resolution of 2 ms. The impact parameter of the *los* ranges from 0.2 to 0.8 (normalized radius  $\rho$ ). A radial *los* has been used as the reference for the Doppler shift measurements. We have collected mainly C V emission @ 2271 Å, and C II emissions @ 2837 and 2838 Å. The 5<sup>th</sup> and the 4<sup>th</sup> dispersion orders of these lines conveniently fall in the same spectral window covered by the detector.

The experimental campaigns selected for the analysis mainly consist in density and  $F (= B_\phi(a)/\langle B_\phi \rangle)$  scans of Virtual Shell (VS) and Clean Mode Control (CMC) discharges. In the CMC scenario the contribution of the sidebands, due to the finite number of active coils, is removed from measured harmonics. For both VS and CMC mode operations, the

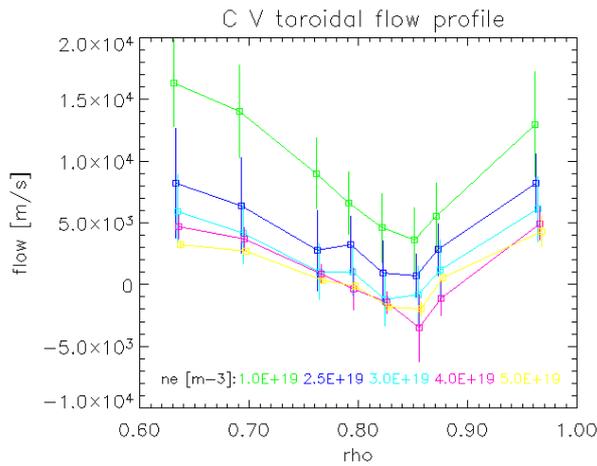
edge magnetic error field,  $b_r$ , can be computed at a prescribed radius, for a more effective correction [3].

In a previous work we have already shown the decreasing dependence of impurity flow on electron density [4] and also its reduction in RFX-mod VS pulses with respect to the non VS pulses [5]. With the recent campaigns we extended VS flow measurements to electron densities under  $1 \cdot 10^{19} \text{ m}^{-3}$  and added flow measurements in CMC pulses with the  $b_r$  control made at plasma surface and at sensor surface. The CMC discharges confirm the same dependence of VS discharges on electron density with a slight tendency to a further reduction in the toroidal rotation, more evident at low density with the modes controlled at the plasma surface. Figure 1 shows the toroidal flow measured in the inner *los*: cases of reverse rotation, previously only seldom observed in this *los*, become more frequent during CMC operations.

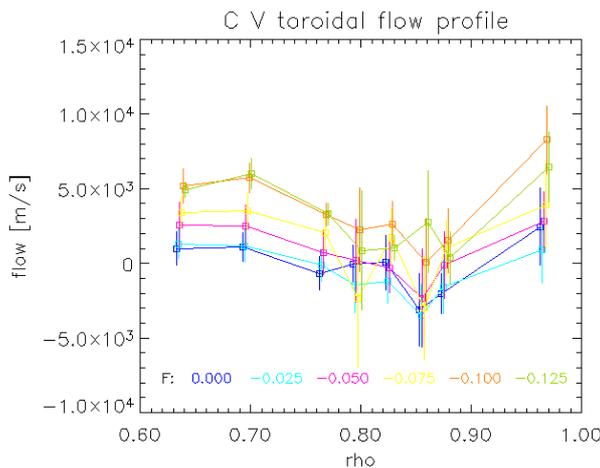


**Figure 1** – Electron density dependence of C V toroidal flow along one of the inner lines of sight (impact parameter around 0.2 normalized radius). In different colours measures from different machine operation modes. F parameter around -0.1

By the application of a 1-D impurity transport code the carbon radial emission profiles have been calculated, allowing the reconstruction of the radial toroidal flow profile in some typical discharges. A radial position has been associated to each view line, calculated as the average along the *los* weighted by the line emission profile. This method has been tested by the agreement between the experimental spectra and their reconstructions (as seen along the same *los*) based on the viewing geometry, the carbon emission profile, and the inferred radial toroidal flow profiles.



**Figure 2** – Toroidal flow profile of  $CV$  measured at different electron densities. The figure reports averaged values, of VS discharges,  $F \approx -0.06$ .



**Figure 3** – Toroidal flow profile of  $CV$  as measured at different reversal parameter  $F$ . The figure reports averaged values of CMC discharges, electron density around  $2\div 3E19\text{ m}^{-3}$ .

Since these radial positions are not strongly affected by the change of the discharge parameters, we calculated the averaged radial toroidal flow profiles in discharges with similar electron density (see figure 2). Independently of the electron density,  $v_\phi$  has a minimum value around  $\rho \approx 0.8\div 0.9$ . Figure 2 shows clearly the decrease of the entire flow profile with increasing electron density. At higher density an inversion of the rotation direction is also observed for  $\rho \approx 0.7\div 0.8$ . The increase of  $v_\phi$  at the very edge of the plasma is consistent with the change of sign of radial electric field  $E_r$ , already found in the previous device RFX [4]: indeed in that case the  $E_r$  inversion was observed at a more external value of  $\rho$ . Taking into account the poor radial resolution of the previous flow measurements, the two results can still be considered as compatible.

The  $v_\phi$  profiles as measured at different values of the reversal parameters  $F$  are reported in figure 3. The better control of plasma wall interaction and the improved feedback control on  $F$ , result in the novel capability of RFX-mod to reach very shallow  $F$ .  $F$  near 0 has been routinely achieved during last campaigns, corresponding to the best core confinement performance. The  $CV$  toroidal flow slows down while the magnetic reversal surface moves outwards. Since the electron density and temperature profiles do not change significantly in these discharges it is not possible to ascribe the flow modifications to different carbon emission profiles. The main actor to this effect could be looked for in the role of the magnetic island associated to the  $m=0$  perturbation [6]. This structure acts as a separator between the stochastic region of the plasma core and the edge region

characterized by conserved magnetic surfaces, high shear and good confinement properties. Variations of F parameter lead to a different magnetic topology of the edge region that could be associated to a different profile of the radial electric field  $E_r$ , and therefore to a different flow shear. In particular, shallow F corresponds to a lower flow shear. It is anyhow interesting to note that this slowing down propagates to inner plasma, and it is not confined to the outer region.

It has to be mentioned that in progressing towards a better plasma wall interaction (VS and CMC operations) the correlation of some of the edge impurities properties with plasma parameters has become less evident. In non VS discharge, C II toroidal flow had showed a clear correlation with the position where the  $m=1$  and  $m=0$  modes lock, changing its direction with the approaching and the presence of the magnetic perturbation in the toroidal section of the measurements [4,5]. In VS and even more in CMC discharges this correlation completely disappears. We ascribe this effect to the action of the feedback control system on the edge magnetic field. Since each *los* crosses regions whose local magnetic field is under the effect of differently fed coils, this could result in the lack of a collective motion of carbon ions all along the *los*, and then the possibility to characterize these particles with a single mean velocity.

## Conclusion

The line integrated toroidal flow measurements performed at the RFP device RFX-mod have shown that the operation with the active control of the radial field corresponds to a slowing down of the rotation velocity and to a loss of the correlation between  $v_\phi$  and the mode locking position. With increasing electron density the toroidal plasma flow decreases both in the core and at the edge. Finally, the operation of RFX-mod at very low values of the reversal parameter leads to a decrease of the flow shear.

## References

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