Studies on RFX-mod discharges with spontaneous rotation

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Introduction - The Reversed Field Pinch (RFP) has a magnetic configuration characterized by a wide spectrum of m = 0, 1 tearing modes (TM), involved in the dynamo process. These modes have the natural tendency to lock in phase together (slinky-mode) and to the wall, such to create stationary bulges at the plasma surface. In RFX-mod an advance control system of 4 x 48 independently fed saddle coils feedback induces slow rotations in order to avoid a strict wall-locked condition [1]. Recent experiments demonstrated the possibility to recover the tearing modes fast rotation by lowering the plasma current under a certain threshold [2], and opened a new RFX-mod scenario characterized by the "natural" rotation of the dynamo modes. In this new scenario plasma flow rotation changes as well, being affected by the new magnetic perturbation dynamics. Passive toroidal and poloidal impurity flow measurements have been performed during these experiments, despite their low electron densities, $n_e<10^{19}$ m^{-3}. The most intense line emission of RFX-mod main impurities could be detected, in particular: O V line at 650 nm, C III line at 464.7 nm and C II line at 464.9 nm. In the following, some of the results are discussed.

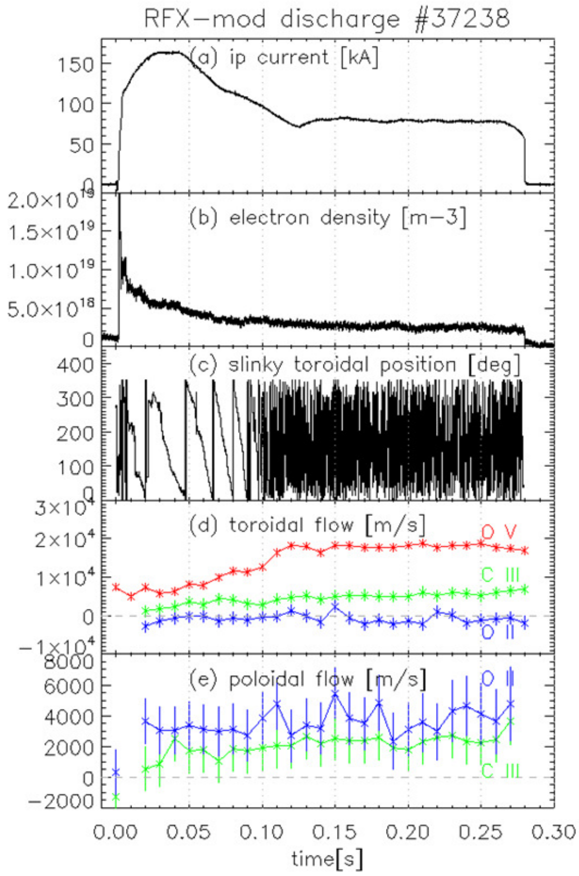

Figure 1 Time traces of RFX-mod low current experiment. From top panel to bottom one: plasma current, electron density, slinky- mode toroidal position, toroidal impurity flow and poloidal impurity flow.

Experimental results and discussion - The time traces of a typical RFX-mod low current experiment are reported in Figure 1. A descending ramp in the plasma current starts soon after the discharge has reached its maximum value at about 150 kA (1a). In this phase the slinky-mode rotation (1c), consequence of the feedback system actively controlling the TM, increases with the lowering of the plasma current, while the toroidal flow of O V grows by a factor three (1d). The TM spontaneous rotation starts at about 100 ms, when the current reaches the threshold value of about 100 kA, and it is clearly seen in the spectra of the m = 0,1 n = -1,-23 modes, Figure 2b. The frequencies of the most internal resonant TM increase of more than one order of magnitude, from few hundreds of Hz to about 15 kHz, Figure 2c. In the following of the discharge the slinky-mode signal is no more reliable because of the screening effect of RFX-mod vacuum vessel (VV) on the fast magnetic modulation.

It is interesting to note that the more external impurities species, C III and O II, are less affected by the mode rotation, both in the poloidal and in the toroidal flow (Figure 1d and 1e).

In RFX-mod the impurity toroidal flow exhibits a strong dependence on electron density [3]. To better study the synergy of mode rotation and electron density the graph reported in Figure 3 has been created. Different colors have been used to represent O V toroidal flow intensity at different plasma currents and electron densities. The dependence on electron density is clear when moving from the right side of the graph to the left, but the highest velocities are reached only by lowering the plasma current under the threshold of 100 kA, when the mode rotation occurs. The C III toroidal flow dependence on plasma current is too

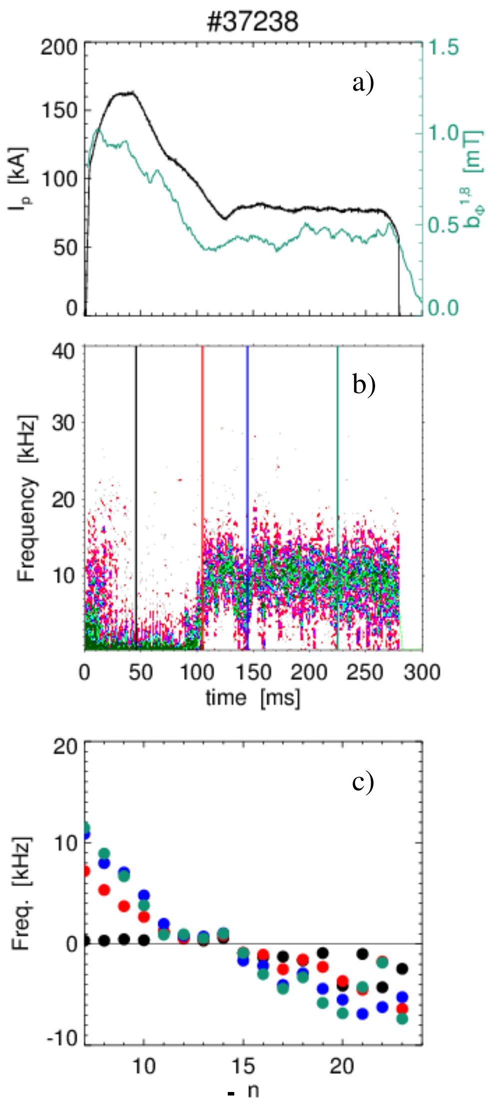

Figure 2 Magnetic modes frequencies vs discharge time (b), and vs toroidal number n (c). The different colours in (c) correspond to the coloured lines in (b).

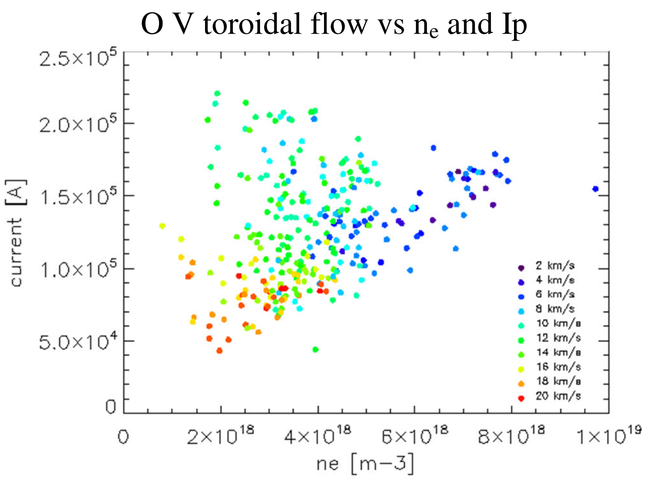

Figure 3 Dependence of O V toroidal flow on electron density and plasma current.

weak to be seen in Figure 4, where the only clear dependence is on the electron density. A similar graph plotting the poloidal velocity is not significant due to the strong influence of the slinky-mode rotation on the impurity flow. Large oscillations in the poloidal flow up to +/- 20 km/s occur when the slinky-mode passes by the diagnostic line of sight, so affecting the measurements at higher current. Also the poloidal flow measure of O V is not fully reliable due to its low emissivity near the edge, where the poloidal lines of sight are placed. However data seem to suggest an O V poloidal flow of few km/s, consistent with the C III and O II measurements.

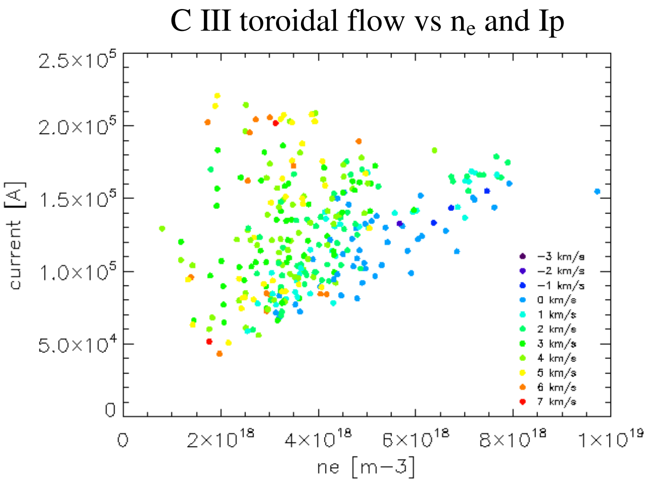

Figure 4 Dependence of C III toroidal flow on electron density and plasma current.

The averaged radial positions of each ion species have been calculated with the help of a 1-D transport code [4] in order to reconstruct a possible impurity flow profile. The unfavourable signal to noise ratio of the interferometer and of the Thompson scattering measures, not optimised for such low plasma currents, does not allow a detailed reconstruction of electron density, $n_e(r)$, and temperature profiles, $T_e(r)$. Anyhow the observation that n_e and T_e do not change significantly during the current ramp down, neither the impurities influxes from the wall, indicates that the modification of the impurity flow is mainly due to the evolution of the flow radial profile and not to the change of the ions radial positions. An averaged radial normalised position (ρ) of about 0.5 has been found for O V toroidal flow measure, while for C III and O II ρ is 0.78 and 0.81 respectively. Figure 5 shows the modification of the impurity toroidal flow radial profiles when the spontaneous rotation occurs. The measurements cover only a small portion of the radius, but they suggest an increase in the toroidal flow, that affects only marginally the outer region.

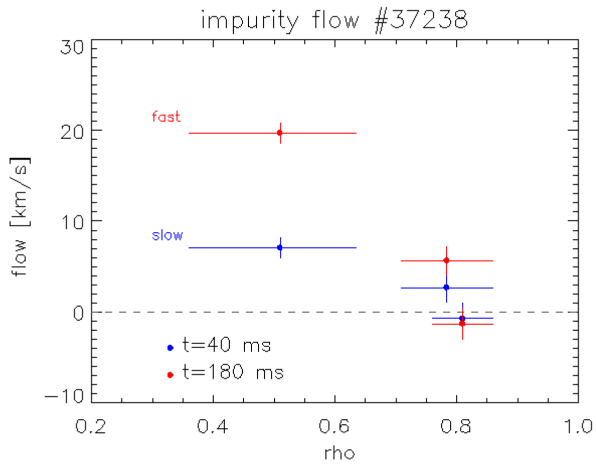

Figure 5 Radial profile of impurity toroidal flow of the discharge of **Figure 1** at 40 ms, before the transition to fast rotation, and at 180 ms.

To check the consistency of the impurity flow measurements with the magnetic results, according to [2], we considered the following formula that ties together the ion flow angular frequencies Ω (aproximated by the impurity flow measures) and the magnetic modes frequencies $d\varphi^{m,n}/dt$.:

$$\frac{d\varphi^{m,n}}{dt} = -n\Omega_\phi(r_{m,n},t) - m\Omega_\theta(r_{m,n},t) + \frac{nB_\theta}{enR_0B^2}(1+\frac{m^2}{n^2}\frac{R_0^2}{r^2})\frac{d(p_e+p_i)}{dr}\Big|_{r_{m,n}}$$

The last term represent the diamagnetic terms and as stated above can not be calculated with precision due to the uncertainties on $n_e(r)$ and $T_e(r)$ reconstructions. Assuming stationary n_e and t_e profiles, and negligible variations in the poloidal flow, by subtracting the fast rotation condition to the slower one, we obtain:

$$-n\Delta\Omega_\phi(r_{m,n}) = \Delta\left(\frac{d\varphi^{m,n}}{dt}\right) \approx \frac{d\varphi^{m,n}}{dt}\Big|_{fast}$$

Assuming the O Vemission at the position ρ = 0.5 where mode m = 1, n = -9 is resonant, from the toroidal flow increase of about 12 km/s we deduce an angular frequency variation of 0.95 kHz that multiplied by n = -9 matches fairy well with the magnetic mode fast rotation of about 8 kHz. For C III the same calculation fails first of all because of the the fast mode rotation opposite to the current. Supposing to place C III toroidal flow measure at the resonance radius of m = 1 n = -23 mode (the most external measurable mode), a toroidal rotation increase of 3 km/s corresponds to an enancement of the mode frequency of about 5 kHz, that matches the result of the magnetic mode analisys only in absolute value, Fig.2c.

Conclusion - The analysis of impurity flow measurements on RFX-mod low current discharges, featuring the unlocking of the magnetic modes and their fast rotation, has started and produced the first results. The impurity toroidal flow increase of more than 10 km/s at middle radius has been consolidated and is consistent with the fast rotation of m = 1, n = -9 TM. Some inconsistencies still persist in the outer radial region where the impurity flow modification is not able to explain the fast counter-current mode rotation. The diamagnetic term may probably have a major role in the outer region; this suggests to better optimize the diagnostics measuring n_e and t_e profiles in future experiments.

References

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