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Particle transport in discharges with active mode control in the Reversed Field Pinch experiment RFX-mod

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Introduction

The Reversed Field Pinch experiment RFX-mod [1] is equipped with a set of 4x48 saddle coils that allows the active control of the radial magnetic field at the edge. The operation with Virtual Shell (VS), where the coils cancel B_r as a perfectly conductive shell, results in a significant reduction of the amplitude of the MHD modes with respect to the discharges with passive control. This reduction of the mode amplitude is expected to mitigate the magnetic field stochasticisation that is responsible of the core transport in RFP configuration. This paper presents a characterisation of density profiles and of the particle transport in discharges with active mode control.

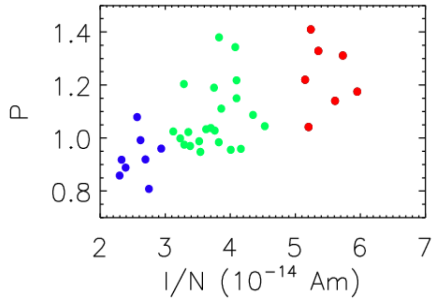

Figure 1: peaking factor versus I/N. The colors define three classes where P can be considered independent of I/N

Density profile behaviour

The analyses have been carried out on a set of about 50 VS discharges at I = 600 kA. The VS discharges are characterised by the Dynamo Relaxation Events (DRE) that affect the plasma density [2]. In order to analyse the density profile in stationary conditions we selected, in the flat top of each discharge, a time interval of 10 ms DRE-free. The shape of density profile is represented by the Peaking Factor (P), defined as the ratio ne_c/ne_e, where ne_c and ne_e are respectively the average densities measured by the two central chords of the interferometer (normalized impact parameters +0.11 and -0.11 where minus stands for inner side) and the edge chords (impact parameter -0.74). As shown in figure (1), the trend observed in RFX [3] for the profile shape with I/N

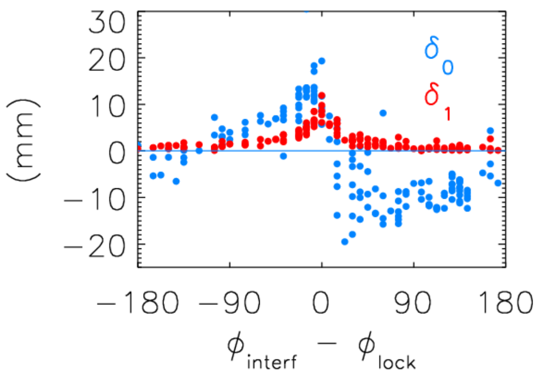

Figure 2: δ_1 and δ_0 component of the plasma column deformation

(I being plasma current and N being line density) is found to be valid also for RFX-mod: the profile changes from hollow to peaked when I/N increases.

This dependence of P on I/N is characterised by a large spread, observed also in RFX where it has been related to the status of the first wall. A factor that may play an important role in the analysis of the interferometer data is the geometrical deformation of the plasma column due to the locking in phase of tearing m=0 and m=1 modes [4]. The m=1 component of the deformation is a radial displacement δ_1 of the plasma column, while the m=0 component is a variation of the plasma radius δ_0 that affects a large part of the plasma column. Figure (2) show δ_1 and δ_0, calculated for a set of about 100 VS discharges at 600 kA, versus the distance between the toroidal position of the interferometer ϕ_{interf} =22.5° and the angle ϕ_{lock} corresponding to the maximum of δ_1.

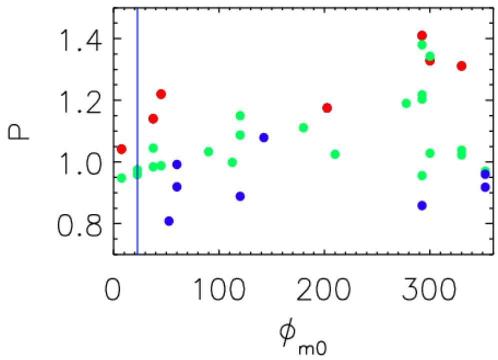

Figure 3: P versus the toroidal angle of δ_0 maximum. The colors have the same meaning than in fig. 1. The blue line indicates ϕ_{interf}.

When plotted versus the toroidal position ϕ_{m0} of the maximum of δ_0 the parameter P shows a dependence on the locked mode position (figure 3), which is evident in particular for the largest group of green points corresponding to I/N 3-5 $\times 10^{-14}$ Am. The highest P values are found at ϕ_{m0} ~ 300°, giving an indication that this dependence is related to the plasma deformation at ϕ_{interf}. The plot of P versus the deformation δ_0 at the interferometer toroidal angle (plot 4) shows that the highest peaking factors generally correspond to strong plasma shrinking at the diagnostic section; in the plot the red line separates the orange points, corresponding to the shrinking (δ_0 < -3 mm), from the blue points corresponding to small shrinking or to plasma bulging. When the plasma is shrank at ϕ_{interf} the edge chord is more external and measures a lower ne_e, while the measure of ne_c is unaffected by the plasma geometry, so that the values of the ratio P are higher. It is

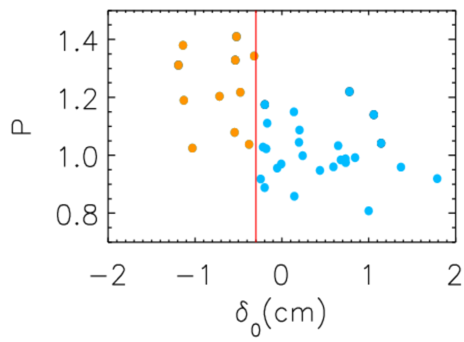

Figure 4: P versus the plasma radius deformation at the interferometer position

interesting to note that this effect accounts for an important part of the spread of the P trend with I/N (figure 5).

The inversion code has been modified in order to use the real plasma geometry in the calculation of density profiles. These inversions showed that the density profiles in the shrunk zone are hollow as in the rest of the column (blue profile in figure 6), while the edge gradient is steeper in the region where the plasma is bulging, at $-70 < (\phi_{interf} - \phi_{lock}) < 0$ (pink profile in figure 6). Furthermore these analyses show that the density profiles in RFX-mod are similar to the RFX ones (figure 7), and maintain the characteristic hollow shape with the maximum located at the plasma edge.

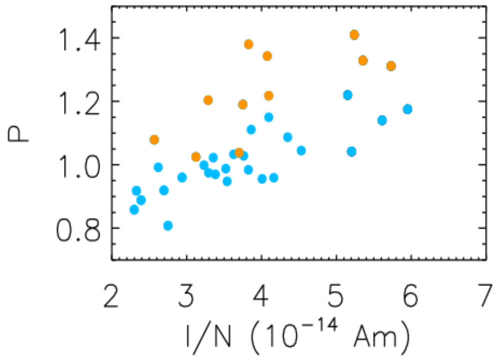

Figure 5: P versus I/N: the colors have the same meaning than in figure 4.

Particle transport

In the RFP configuration the stochasticisation of the magnetic field due to the action of the tearing modes is responsible for the transport in the plasma core, while the electrostatic fluctuations drive the transport at the edge. According to the theory of the transport in a stochastic magnetic field the particle diffusion coefficient D_{ST} is proportional to the square of the normalised magnetic fluctuation [5]. The ambipolar electric field gives origin to a pinch velocity V_{ST} [6] outward directed, which is believed to be at the origin of the hollow shape of density profiles, proportional to D_{ST} and to the normalised temperature gradient. The particle transport coefficient D has been calculated by means of the 1D transport code TED [7]. As a density profile we used the blue profile of figure 6. Since the RFX-mod profiles are similar to the RFX ones we expect to obtain similar D profiles.

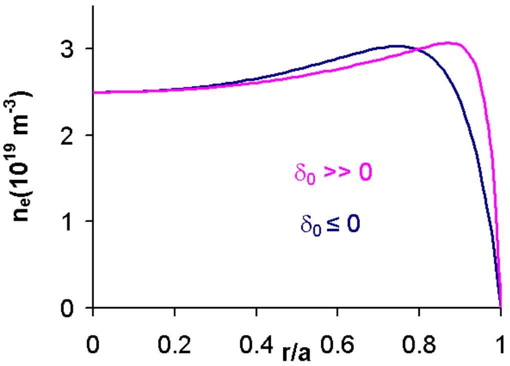

Figure 6: average density profiles

Anyway, due to the better energy confinement obtained with the VS, the temperature profile of RFX-mod is more peaked than the RFX one [8], where it was usually parametrised as $T=T_0(1-(r/a)^{\alpha_T})+T_a$ with $\alpha_T=4$. In order to understand the effect of temperature gradient the simulations have been carried out both using $\alpha_T=4$ and $\alpha_T=3$. The red line in figure (8a) indicates the D profile giving a good agreement with the experimental data when $\alpha_T=4$, the blue line when $\alpha_T=3$. The two lines are clearly separated at 0.4 < r/a < 0.8 because, if $\alpha_T=3$, D values lower by a factor 2 can be used.

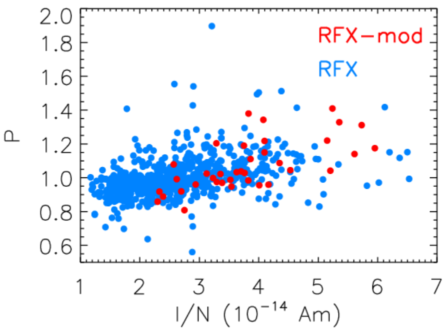

Figure 7: comparison of P in RFX and in RFX-mod

Therefore it is possible to suppose a decrease of the particle diffusion coefficient at 0.4 < r/a < 0.8 by a factor 2 for the RFX-mod VS discharges with respect to the RFX values. This value is too low to be considered in agreement with the stochastic transport model. Considering that the mode amplitude is reduced by a factor 10 at the edge and by a factor 2 in the core, we expect a reduction of the D by a factor 4-100. A possible explanation is that the collisionality mitigates the effect of the field stochasticity on the transport in RFX, or that, despite the reduction of the mode amplitude, the overlapping of the magnetic islands responsible of the anomalous transport still occurs in RFX-mod.

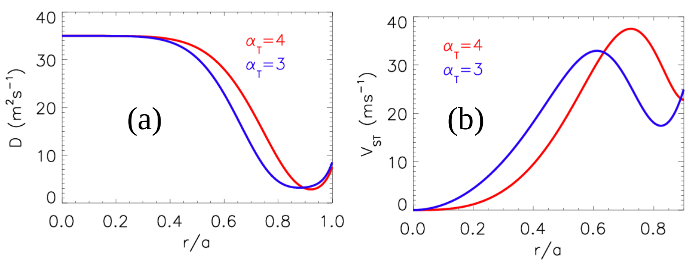

Figure 8: D and V profiles obtained with the transport analyses

Acknowledgement

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