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Particle transport in different magnetic field topological configurations in the RFX-mod experiment

L. Carraro, D. Terranova, F. Auriemma, F. Bonomo, A. Canton, A. Fassina, P. Franz, P. Innocente, R. Lorenzini, R. Pasqualotto, M.E. Puiatti
Consorzio RFX, Associazione Euratom-ENEA sulla fusione, Padova, Italy

1. Introduction

In the last few years the reversed field pinch community confirmed experimentally the theoretical prediction that the dynamo mechanism underlying the magnetic field configuration can be based either on a large number of harmonics composing the magnetic field fluctuation (turbulent dynamo, multiple helicity) or on a configuration with a dominant mode (ideally a single mode, laminar dynamo, quasi single helicity QSH). Recent results showed that QSH configurations can actually occur into two topologically different regimes depending on the presence of the separatrix associated to the magnetic island. Experiments done in RFX-mod [1] applying the oscillating poloidal current drive (OPCD) technique [2] succeeded in systematically inducing QSH states that in several cases exceeded the threshold of the ratio between the dominant and secondary modes necessary for separatrix expulsion [3]. Experimentally this is visible in the electron temperature profile (large gradients with core temperature up to 1 keV [4] involving a large region) and is well correlated with the reconstruction of the internal magnetic topology done by means of the magnetic filed line tracing code FLiT in toroidal geometry [5]. Up to now all the evidence showed an increase in the energy content due to the presence of the internal structure, however no effect on particles was observed. This is clearly due to the lack of significant particle source in the plasma core given the very limited penetration of neutrals from the edge and the typical broad density profiles in RFX-mod [6]. To investigate the subject we considered two ways of providing a known particle source inside (or outside) the magnetic structure present in QSH states: hydrogen pellets and nickel laser blow off (LBO) injection. In order to control the formation and poloidal position of the structure it was decided to consider OPCD discharges with a small rotating perturbation (40 Hz) able to drag the structure itself so that the injection both of pellets and LBO could be programmed to hit it. In this work we present the first experimental results and their preliminary interpretation obtained in terms of correlation with the internal magnetic topology for discharges with plasma current of 1.5 MA.

2. Pellet injection experiments

The multi pellet injector of RFX-mod [7] was used to inject pellets with a nominal mass of 1.5×10^{20} particles and velocity around 600 m/s. The diagnostic system associated to the injector consists in a PSD tracker detector [8] for reconstructing the 3D trajectory inside the plasma and measuring the H_α emission due to the ablation, and a fast CCD camera. An 8–chords CO2 interferometer [9] is used to measure the time evolution of the electron density.

In figure 2 we show an example of the configuration in which a pellet launch was set to hit the island itself. The figure shows two Poincaré plots of magnetic field lines obtained with FLiT: on the left at the pellet cross section and on the right at the interferometer cross section. The pellet is entering from the right in the figure. The colour of the points is defined by the starting point of each line that corresponds to the position of the pellet moving inside the plasma towards the core going (from blue to red). In the example one can see that the pellet at the very end of the ablation did enter the island.

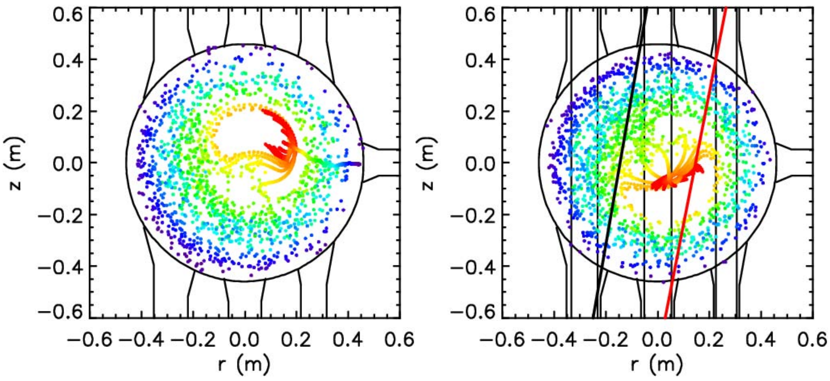

Figure 2: Poincaré plot of magnetic field lines (#24129): at pellet port (left) and at the interferometer (right) where the 8 chords are also shown.

Since the pellet injector and the interferometer are located at different toroidal positions (120° apart) it was necessary to consider a compromise between the best poloidal angle for hitting the island and that required to see an asymmetry (due to the helical topology of the QSH state) in the time evolution of “symmetric” chords (e.g. black and red thick lines in the plot on the right of figure 2). In figure 3 we show two examples of asymmetries in the time evolution for two homologous central chords (same colour code for the thick chords as in figure 2). A correlation with the internal magnetic field line structure shows that in general the differences are due to two simultaneous effects: the helical topology that produces a direct connection path between the pellet and the interferometer only for some chords, and the increased ablation rate due to the higher electron temperature of the structure. The first effect is shown in the top panel of figure 3: the flattening of the black line at 99 ms indicates that this chord is not measuring additional particles from the pellet ablation. The second effect is clearly shown by the abrupt increase in the H_α emission when the pellet hits the island and its border, where large T_e gradients are present (see figure 4 top panel). In addition to these observations (that do not allow a quantitative estimate of the particle confinement time) in some cases we have evidence that the region defined by the

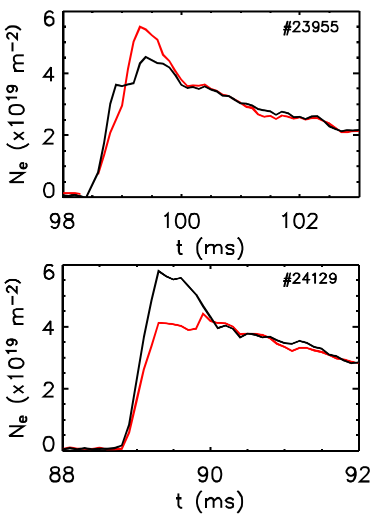

Figure 3: Asymmetries in the time evolution of density line integrals. The colors correspond to the red and black thick chords of figure 2.

thermal structure potentially can confine particles. This can be see in figure 4 (bottom), where the magnetic field structure is shown: though there are no preserved magnetic flux surfaces (as expected), there is a region of sticky lines, i.e. lines that remain around the structure (see red dots around the island). In particular in the case of the figure the time evolution of the four central interferometric chords shows a short time interval in which they are almost constant at the end of the ablation instead of starting immediately to decrease. The presence of sticky regions is an indication of a reduced stochastic transport in the approximation that the collision rate is not large compared to the time of propagation of the sound wave due to the pellet [10] as it is the case for the time scales here observed. An interesting result is that in several cases the injection of the pellet was able to sustain the dominant mode in a phase in which the QSH was disappearing. As a general remark, though the FLiT reconstruction is compatible with the observation, some cases suggest that the reconstruction underlying the code is underestimating the real size of the structure and additional improvement is required.

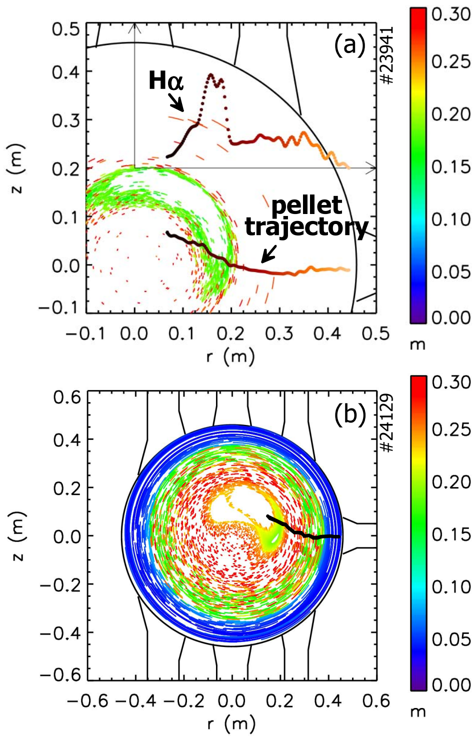

Figure 4: (a) pellet H_α emission along its path and pellet trajectory: H_α increases when the pellet hits the hot island (green region). (b) pellet trajectory (black thick line) and sticky regions around the island: colors refer to the radial displacement with respect to the starting point of each line.

3. Laser Blow Off experiments

In addition to pellet injection LBO was also attempted for the first time in RFX-mod as a way to provide a traceable particle source inside the island present in QSH states. Taking into account the ionization potential of the species to be injected with respect to the plasma maximum electron temperature (in the range 600 eV to 800 eV in high current discharges) and the typical impurities (C and O) for RFX-mod, Ni was chosen for LBO since it is able to provide sufficient SXR emission emerging from the background signal. To this end the edge Thomson scattering laser beam was deviated and focussed onto the rear of a Ni target (a 2 μm thick Ni layer onto a glass support).

The injection into the hot structure was successful since we were able to measure the emission lines Ni XVII 249 Å and Ni XVIII 292 Å, indicating that the impurity reached high temperature regions compatible with what is typically found for the helical structure [4]. In figure 5 we show an example of the SXR signals following Ni injection (by a single laser pulse) when a QSH was developing: the SXR signal (and also Ni lines, not shown) lasts for the whole QSH phase (taking as indicator the amplitude of the dominant mode, bottom panel of the figure), clearly following the time evolution of the electron temperature measured with a double filter diagnostic [11]. Although there is clear evidence of Ni penetrating the internal structure, due to the strongly varying plasma conditions (including poloidal and toroidal asymmetries in the T_e profile due to the helical geometry) it is not possible to numerically reproduce the Ni transport with the available 1D impurity transport code [12]. However, considering the whole data base of LBO discharges, a first analysis seems to indicate that the observed time evolution depends more on the electron temperature evolution (i.e. on the energy content of the island) rather than on strong differences in the Ni transport properties that one could expect in a QSH states with respect to a MH configuration.

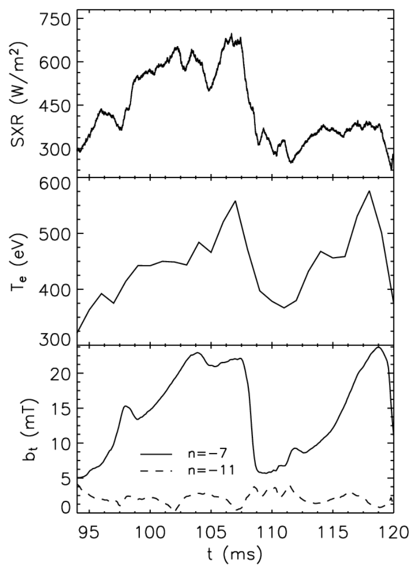

Figure 5: Top: line integrated SXR brightness. Centre: T_e. Bottom: b_t of mode m=1,n=-7 and m=1,n=-11 (representative of the secondary modes). Shot #24073 at 1.2 MA.

4. Conclusion

Pellet injection and LBO were used to experimentally study particle confinement properties in QSH states. Observing the pellet ablation process and the resulting evolution of plasma density we were able to show that the underlying helical structure is playing a significant role in particle transport. Furthermore the observed thermal structure is also potentially able to confine particles. The first experiments with LBO system in RFX-mod showed that the technique can be applied without perturbation to the plasma itself in different regimes. The interpretation of the data collected shows the limits of the axisymmetric assumption and the necessity to study transport properties of these regimes in helical geometry in order to be able to correctly interpret the results and take into account the different topology with respect to the standard RFP picture.

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