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The Last Closed Flux Surface at shallow F in RFX-mod

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In a magnetically confined plasma the position and the shape of the Last Closed Flux Surface (LCFS), e.g. the outermost magnetic surface not intersecting any solid object, plays a key role determining the power and particle deposition patterns on the plasma-facing components. Two different types of LCFS exist. In the simplest configuration the LCFS touches a solid object, called limiter, on which intense particle and power fluxes impinge. In a more sophisticated approach a particular magnetic structure of open lines, called divertor, keeps the LCFS separated from the wall and brings the outcoming fluxes to dedicated regions of the wall. The Reversed Field Pinch is a magnetic configuration characterized by a toroidal field that reverses its sign at the plasma edge. The value of the reversal parameter F, given by the toroidal field at the edge $B_\varphi(a)$ normalized to the magnetic field averaged on the poloidal section $\langle B_\varphi \rangle$, determines the position of the magnetic surface where the toroidal field vanishes, called reversal radius r_s.

The reversal surface is the resonant surface of the m=0 modes which, together with the inner resonant m=1 modes, affect the edge shape of the magnetic surfaces and determine the interaction pattern.

The values of the reversal parameter used in the RFX-mod [1] experimental campaigns span from -0.2 (deep reversal or deep F) where r_s is separated from the wall by a distance of some centimeters to -0.02 (shallow reversal or shallow F) where the r_s is less than 1 cm far from the

Fig.1) Poincaré plot of a deep F shot (F~ -0.2) (a) and of a shallow F one (F~ -0.02) (b). The continuous horizontal lines mark the position of the first wall.

wall. Figure 1 shows the Poincaré plot of a deep reversal (plot a) and of a shallow reversal (plot b) cases. In the case of deep reversal the outermost magnetic surfaces touching the wall are distorted due to the funnel-like deformation of the m=0 modes [2] which superimposes to the m=1 non-axisymmetric shift [3]. The m=0 islands, that do not touch the wall in this case, enter instead in contact with the wall in the case of shallow reversal. The different magnetic topology of the edge in this two cases results also in a different location of the LCFS. The LCFS is computed on the basis of the edge topology reconstruction by means of the field line tracing code FLiT [4]. The FLiT code uses the output of an algorithm for the reconstruction of the tearing mode eigenfunctions based on the Newcomb's equation supplemented with magnetic measurements at the edge [5]. The LCFS position is determined from the FLiT output looking where, at each toroidal and poloidal position, the innermost open field line is found. In the plots 1a and 1b the thick black line shows the computed LCFS. In the deep reversal case, the LCFS is located externally to the m=0 islands and touches the wall, realizing a limiter-like configuration. In the shallow reversal an opposite behavior occurs: a divertor-like configuration is present since the LCFS is separated from the wall which is touched by the m=0 island chain.

This modification of the edge topology can explain the improved control of the plasma density obtained at shallow F in the recent experimental campaigns with plasma current higher than 1 MA. The plasma contained in the LCFS is in fact separated from the wall by a layer of 2-4 centimeter that creates a Scrape-Off Layer (SOL).

Electron temperature and density profiles are measured in this region by the Thermal Helium Beam (THB) diagnostic. The THB measures at several radial positions three HeI lines emitted by the neutral He locally puffed into the plasma edge. The intensity ratio between λ1=667.8 nm and λ2=728.1 nm depends mainly on the electron density n_e, while the electron temperature T_e is deduced from the ratio between λ2=728.1 nm and λ3=706.5 nm [6]. Figure 2 shows the time evolution of the pressure radial profile measured in the discharge #26104. In the picture the y-axis represents the distance form the plasma wall. The pressure radial profile (plot b) shows a time modulation, which is well correlated with the

Fig. 2 Time evolution of the radial magnetic field at the plasma edge (plot a) and time evolution of pressure radial profile measured with the THB. The vertical white lines in the plot b marks the two instants chosen for the results presented in the following figures.

radial component of the magnetic field at the plasma edge due to the m=1, n=-7:-20 modes (plot a) [7,8]. The radial position at which a similar value of the pressure is found changes in time, and can be radially shifted up to ~2 cm. With the aim of relating this pressure behavior to the magnetic topology, we analyzed the Poincaré plot in several time instants when the pressure gradient was either internal or external. Figure 3 shows the Poincaré plot at t=97 ms, when the pressure gradient is shifted outwards, and at t=122 ms when the gradient is shifted inwards. The magnetic topology of the two cases looks very similar: the THB is measuring along a m=0 island, while the LCFS, shown by the thick line in the plot is located at the same distance (about 4 cm) from the wall. However a Poincaré plot gives limited information since it is only 2-dimentional, while the plasma properties should be analyzed in the light of the 3-dimentional structure of the topology. In order to better understand the 3-dimensional structure of the SOL it is useful to calculate the connection lengths of field lines passing through a grid of points in the r-φ plane. Figure 4 shows the contour plots of the connection lengths at the same r-φ plane and time instants presented in Fig. 3. In case ***a*** the THB is measuring in a region where the magnetic lines either does not touch the wall or they touch it but with long connection lengths, longer than

Fig. 3) Poincaré plot for the shot #26104 at t=97 ms (a) and t=122 ms (b) at the same poloidal angle of THB. The vertical line marks the toroidal angle of THB.

Fig. 4) Contour plot of connection lengths for the shot #26104 at t=97 ms (a) and t=122 ms (b) at the same poloidal angle of THB. The vertical line marks the toroidal angle of THB.

300 m. However in the case *b* the THB is measuring in a region where the magnetic lines touch the wall with connection length shorter than 150 m.

The comparison with other reconstructions confirms that, if the LCFS position is constant, the modulation of the pressure is the result of the modification of the connection lengths. When the gradient is shifted inward the THB is measuring in a region connected to the wall with short connection lengths while, when the gradient is shifted outwards, the THB is measuring in a region which is connected to the wall with long connection lengths. This result does not depend on the presence of m=0 islands, since the same behavior is obtained when the THB is measuring outside the islands.

This picture is in agreement with the idea that longer flux tubes receive higher amounts of particles and energy by diffusion through their sides; according to this vision the plasma-wall interaction in different regions can be quantified, as a first approximation, by looking at the connection lengths.

When the plasma current is higher than 1 MA the shallow reversal favors the occurrence of Quasi Single Helicity states [9]. In these phases the dominant mode amplitude reaches sufficiently high values so that Single Helical Axis states (SHAx) occur [10]. These states are of particular interest because they are characterized by the onset of a helical transport barrier which surrounds a large fraction of the plasma core [11]. In these states even the spectrum of m=0 modes is dominated by the harmonic having the same toroidal number (n=-7) than the m=1 dominant mode, due to toroidal coupling between different m=1 harmonics. The pattern of the connection lengths in this states assumes a m=1, n=-7 toroidal periodicity, even though the effect of the secondary m=0 cannot be neglected yet. Since the amplitude of secondary modes is expected to further decrease by increasing plasma current, this pattern is expected to become more and more regular and could be in principle exploited to realize a self generated divertor.

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