Magnetic topology and role of the m=0 islands in the plasma-wall interaction in RFX-mod

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Single Helical Axis (SHAx) states [1] are the self-organized helical RFP states developing at high plasma current in RFX-mod discharges, where the helical deformation arises from the dominance of the tearing m=1/n=7 mode in the MHD spectrum (calling m the poloidal mode number and n the toroidal one). This configuration leads to enhanced confinement properties, due to the development of an internal transport barrier, with a milder PWI than the chaotic multi-mode state. During SHAx states also the m=0 tearing mode spectrum is strongly peaked on the n=7 mode, which is a direct consequence of the toroidal coupling between modes having the same n number [2]. The m=0 modes play a crucial role in determining the Scrape Off Layer (SOL) and therefore the PWI properties, due to the presence of the toroidal field reversal q=0 surface (and therefore of the m=0 island chain) near the first wall (at a=0.459m). In particular the PWI seems to be toroidally localized in correspondence with the maxima of the helical (m=1) deformation, whereas on the poloidal plane the PWI seems to be larger on the internal equatorial plane, where the dominant m=1/n=7 and m=0/n=7 modes are in phase. A detailed examination of the edge magnetic topology has been done e.g. in [3] with the conclusion that intrinsic properties of the edge magnetic configuration could be exploited to develop a divertor concept for RFPs, similar to the island divertor of Stellarators.

Further theoretical studies need to be done, and a practical implementation has to be demonstrated, anyway a divertor concept for RFP is conditioned to a good control of the radial magnetic field at the edge, which in RFX-mod is obtained through a complete system of 192 feedback-controlled saddle coils. In this contribution we present an active approach to the edge topology modification or control through the feedback control system [4], by applying non-zero boundary conditions (BCs) to both the dominant m=1/n=7 and m=0/n=7 harmonics. Previous experiments have been done with the application of non-zero BCs only on the dominant m=1 mode, in order to sustain the helical deformation of the plasma, with good results [5]. New experiments have been now performed varying the non-zero m=0 reference amplitude and its phase relationship with the dominant m=1 mode, in order to affect the m=0 island amplitude and to study the PWI distribution on the poloidal plane. In the following the mode eigenfunctions are computed solving a Newcomb-like equation in toroidal geometry.

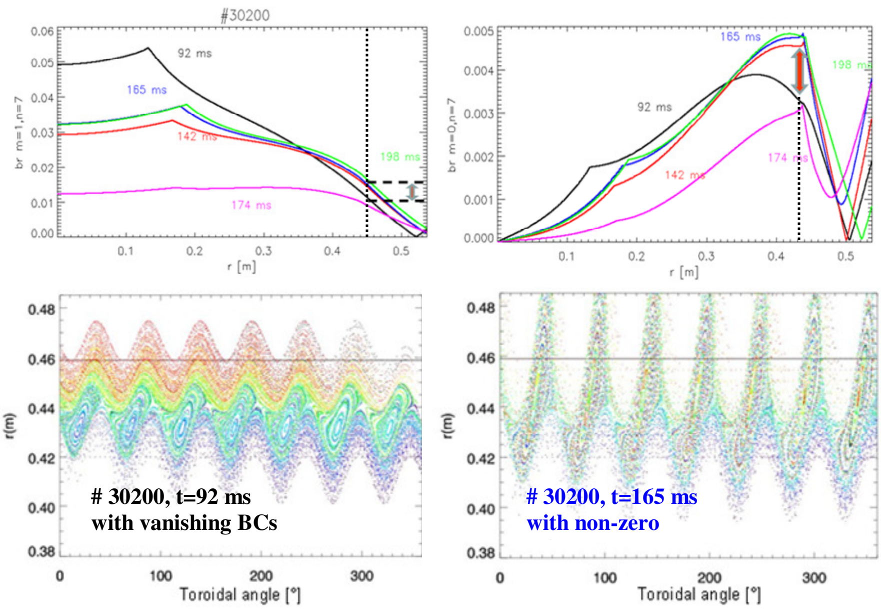

Figure 1. **#30200. Top:** eigenfunction profiles of the m=1/n=7 (left) and m=0/n=7 (right) modes. Colors used for time instants during the application of non-zero BCs, black used for a time instant with vanishing BCs for comparison. Vertical lines mark the reversal surface. **Bottom:** Poincaré plots with vanishing BCs (left) and non-zero BCs (right). Horizontal lines mark the position of the first wall.

Effect on the harmonics amplitude: In order to increase the amplitude of the m=0 islands (and therefore of the SOL) one needs to act on the amplitude of the m=0 mode radial magnetic field on the resonant surface (i.e. the q=0 reversal surface). In fig.1 the eigenfunction profiles of the m=1 (top-left) and m=0 (top-right) dominant modes are shown for different time instants during the application of non-zero BCs with different colours - the black curves being related to a time with vanishing boundary conditions for comparison. The application of the non-zero BCs on both the dominant modes are expected to have two main effects on the m=0/n=7 mode amplitude at the reversal surface [6]: 1) a direct contribution by the externally imposed amplitude reference on the m=0/n=7 mode; 2) a further contribution coming from the toroidal coupling with the m=1/n=7 harmonic, which has an increased amplitude at the reversal surface during the application of non-zero BCs (as indicated in fig.1-top-left). Peculiar of the application of non-zero BCs to the m=0/n=7 mode is the shape of its eigenfunction (as it is easy to see comparing the coloured lines with the black one in fig.1 top-right). From the magnetic topology point of view, the superposition of these effects produces a larger radial extension of the m=0 island chain and an increased volume of the SOL with respect to the case with vanishing boundary condition: the effect on the magnetic topology can be seen in the Poincaré plots in fig.1-bottom that are shown on the same y scale on the equatorial plane. One can see both the increased island amplitudes and their change in shape due to the increased amplitude of the modes on the reversal surface.

Effects on the phases: The magnetic boundary is characterized by the m=0/n=7 island chain and the PWI is strongly affected by its phase relation with the dominant m=1/n=7 mode (responsible for the helical SHAx state deformation of the whole plasma column). The toroidal coupling between the two modes is one of the main mechanism acting in the plasma. Here we analyze the effect on the phases of the m=0 and m=1 modes and on their phase difference, when non-zero BCs are applied on both the dominant modes. In shot #30184 the feedback-controlled system imposes the two modes rotating in opposite directions with respect to the toroidal angle, so that the phase difference between the two modes is continuously changing. Even if the dynamics of the applied phase difference is clear, its effects on the magnetic topology at the edge are not obvious. The Poincaré plots in fig.2 are performed at three different time instants, with different phases between the two modes. But, on the contrary, it can be seen that the m=0 islands are always in the same position with respect to the m=1 helical deformation (the 'wave' which modulates the islands).

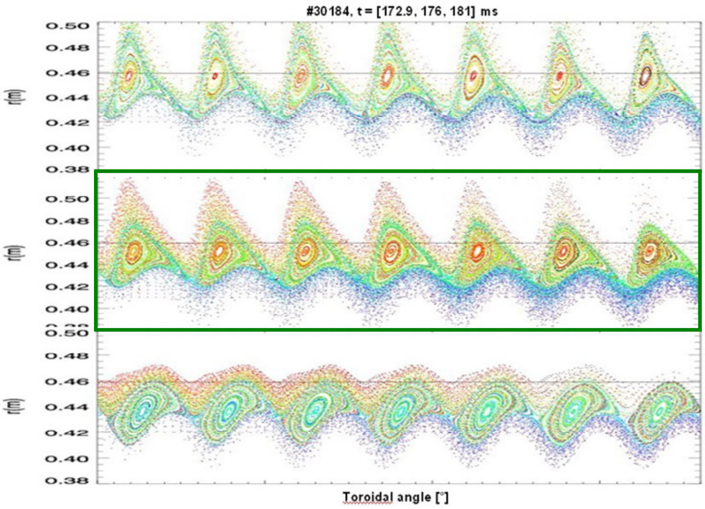

Figure 2. #30184. Poincaré plots on the external equatorial plane. Superposition of m=1/n=7 and m=0/n=7 eigenfunctions. Horizontal lines mark the position of the first wall.

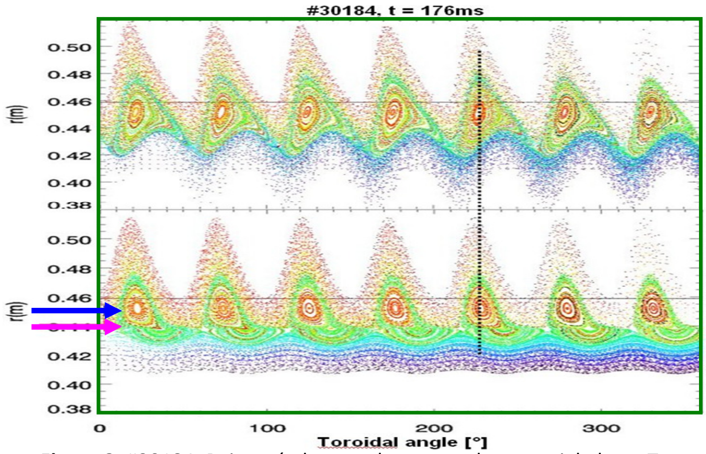

Figure 3. #30184. Poincaré plots on the external equatorial plane. **Top:** superposition of m=1/n=7 and m=0/n=7 eigenfunctions. **Bottom:** the contribution of only the m=0/n=7 mode.

We can distinguish between the contribution to the magnetic topology of the m=0/n=7 and the m=1/n=7 modes separately: the helical deformation of the plasma column due to the m=1 mode simply produces the n=7 edge modulation, while the contribution of the m=0 mode is plotted in fig.3-bottom (in fig.3-top one can see the 'whole' configuration for comparison). The contribution of the m=0/n=7 mode generates two chains of seven islands, at two different radii highlighted by the two arrows in the plot. The two island chains are associated to a jump in the phase profile of the m=0/n=7 eigenfunction, plotted in fig.4: the radii of the two island chains,

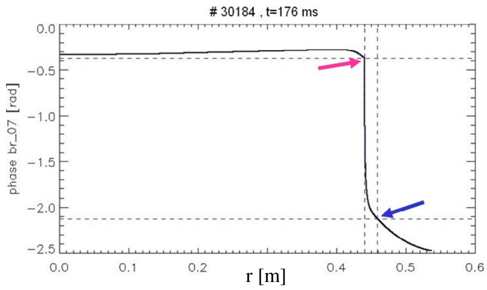

Figure 4. #30184. Phase profile of the m=0/n=7 eigenfunction

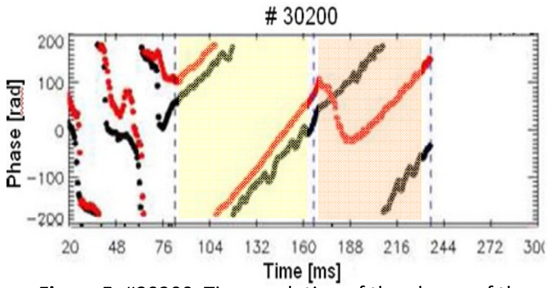

Figure 5. #30200. Time evolution of the phases of the m=1/n=7 (black) and m=0/n=7 (red) eigenfunctions at the q=0 reversal surface

marked by the two vertical lines, correspond to two different values of the phase, marked by the two horizontal lines. The blue arrow highlights the phase of the external chain and the pink one the phase of the internal chain. Once the contribution of the m=1 mode is superimposed to the contribution of the m=0 mode, the edge magnetic topology is characterized by the presence of only one of the two chains of seven islands. The black vertical line in fig.3 shows that this corresponds to the external island chain (marked by the blue arrow). As seen in fig.2, the phase of the external island chain is not affected by the external non-zero BCs - having always the same phase difference with the m=1 mode. Studying more into details the behaviour of the internal m=0 island chain, we can say that: 1) the O-points lie on the q=0 reversal surface, which is the theoretical resonant radius for all the m=0 modes; 2) it seems that with the externally applied non-zero BCs we can only act on the phase of the m=0/n=7 eigenfunction at the q=0 reversal surface. As an example we use the shot #30200, where two time windows with different phase difference (equal to 0 and 90 degrees) between the m=0/n=7 and the m=1/n=7 were externally imposed. In fig.5 we plot the time evolution of the phases of the two modes at the reversal q=0 surface, and coloured boxes mark the two time windows. As one can see the reconstructed phases at the reversal surface are in agreement with the imposed ones. Again, this is not true away from the q=0 surface, probably due to a too high toroidal coupling between the m=1 and the m=0 modes.

Conclusions: Phase modification appears more difficult than acting on the m=0 island amplitudes and the SOL volume by applying non-zero BCs to both the dominant modes. Other experiments are planned in order to study more into details the effects of the toroidal coupling between the two dominant modes at the edge and the role (and the origin) of the two m=0 island chains.

References

[1] R. Lorenzini et al., Nature Phys. **5** 570 (2009)
[2] P. Zanca and D. Terranova, Plasma Phys. Control Fusion, **46** 7 (2004)
[3] E. Martines, R. Lorenzini, B. Momo, Nucl. Fus. **50** 035014 (2010)
[4] L. Piron et al, 53rd Annual Meeting of the APS, Division Plasma Phys, 2011, oral session PO4 6
[5] P. Piovesan et al, Plasma Phys. Control Fus. **53** 084005 (2011)
[6] G. De Masi et al., 53rd Annual Meeting of the APS, Division Plasma Phys, 2011, oral session PO4 12