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Electron pressure gradient analysis during QSH and SHAx states in RFX-mod

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This works addresses to a characterization of the plasma electron pressure profile in the RFX-mod reversed Filed Pinch device during QSH regimes, both DAX (Double Axis) [1] and SHAx (Single Helical Axis) [2] states, where an helical hot structure inside the plasma appears. Various diagnostics are combined through mapping on helical flux surfaces: their high time or spatial resolution over different covered regions allows a detailed reconstruction on the whole plasma radius. Electron temperature (T_e) and density (n_e) are obtained via main TS system [3], edge TS system [4], Thermal Helium Beam diagnostic (THB, [5]) and multichord double filter SXR spectrometer [6].

Main TS System resolves 84 spatial points with a repetition rate of 40 Hz along almost the entire radial midplane (-0.96÷0.84 r/a), and edge TS can measure up to two profiles per discharge, with 6 points each, in the outer radial region (0.83÷1 r/a). Edge TS absolute calibration is sufficiently stable in time to deliver also n_e data, while getting n_e from main TS requires a periodical cross-calibration with measurements from interferometer [7]. Double filter SXR multichord spectrometer provides line integrated T_e measurements sampled at 10 kHz in the outer radius. Further information on n_e and T_e at the very edge can be obtained with THB, whose profiles are available for 5 radial points (5 mm distanced), with a time resolution of 5 ms.

Helical flow mapping

As we are mainly interested in DAX and SHAx plasmas, both characterized by helical symmetry, we used the helical coordinates instead of cylindrical ones in the reconstruction of the profiles. This is based on the verified assumption [7, 8] that T_e and n_e are constant on flux surfaces. The helical flux function X is defined by $X= m\Psi+nF$, where Ψ and F are respectively the poloidal and toroidal fluxes, m and n the poloidal and toroidal number of the perturbation: in the cases considered in this work, as in most RFX -mod discharges, the dominant mode is the inner resonant mode, m=1 n=-7.

When the amplitude value of the dominant tearing mode exceeds a given threshold, the helical flux function shows a transition between a double minimum shape to a single minimum one (DAX-SHAx transition) [2,9]. The pressure profiles are analyzed as functions of the dimensionless quantity , which is an effective radius defined as by $= \sqrt{X/X_w}$, with X_w the helical flux value at the first wall.

Pressure profiles behaviour

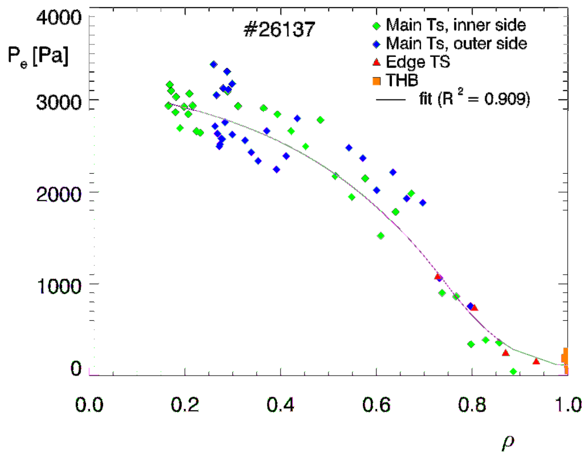


Fig1. Pressure profile in SHAx state; here THB data are available improving reconstruction quality in the edge region.

In RFX_mod, in absence of a density source inside the plasma (i.e. pellet), n_e profiles are not significantly modified by the presence of the hot magnetic island, and the p_e variations essentially reproduce T_e ones. The experimental pressure profile is usually well fitted by a curve composed by a 3rd degree polynomial function in the core joint to a 2nd degree function in the edge (an example is shown in fig.1).

Looking at the Te and pe profiles reported in Figure 2 it can be noticed that in DAX they are nearly flat, but for the hot island and the edge regions, while in SHAx conditions they remain slanted all over the plasma.

To quantify the mentioned differences in the RFX-mod SHAX and DAX pressure profiles the dimensionless parameter $P_{=0.4}/\nabla\ P$ has been evaluated in different discharges: it is found that it typically remains below 0.5 in a SHAX regime, while it takes typical values between 0.4 and 1.5 in DAX. In multiple helicity (MH), the equivalent parameter is just a function of plasma radius and results significantly higher (>2).

Thermal transport analysis

The considered helical states are particularly interesting because they show improved confinement features [2, 10]; this can be seen looking at confinement time or electronic diffusivity.

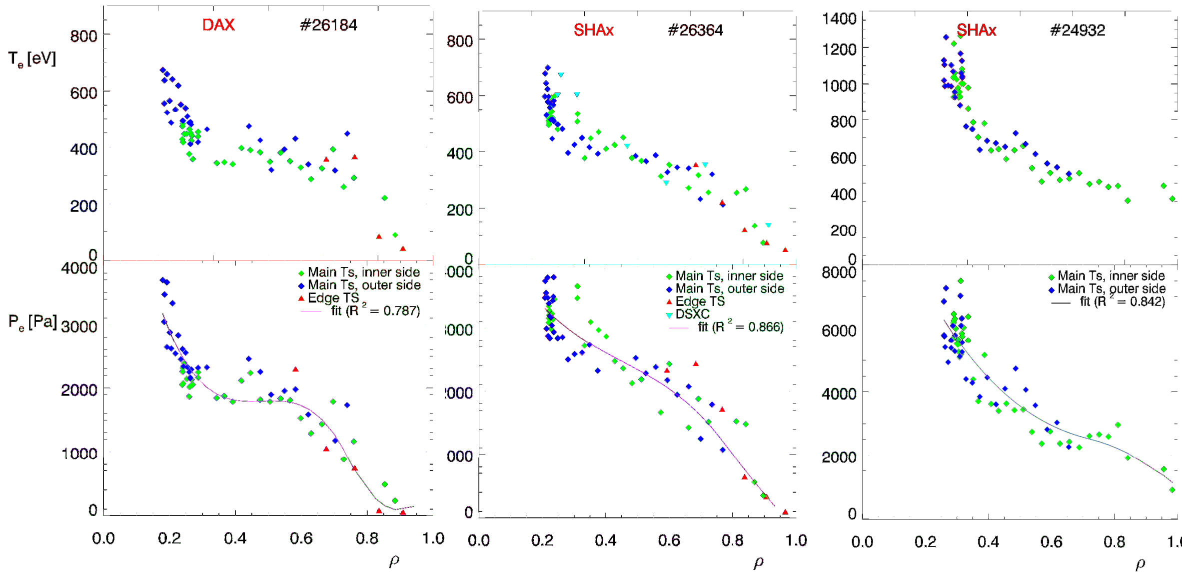
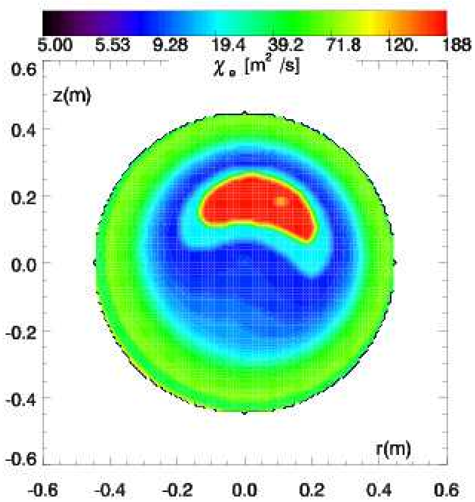


Fig2. Temperature and pressure profiles for typical DAX (left) and SHAx (center and right) shots; the variation in the pressure gradient at =0.4 is evident, corresponding to the increase in extension of the inner p_e gradient . The radial positions of DSXC points correspond to chords impact parameter; doesn't reach 0 because the island o-point is not on TS line of sight.

To evaluate the X_e profile toward the flux coordinates, all plasma parameters are computed on a 2D mesh corresponding to a poloidal section (fig.3). The local X_e value is determined by $X_e = \frac{1}{S}\int_{x,y(\ <\ 0)} (j_{tor}^2 + j_{pol}^2)\frac{1}{n_0 \nabla_r T_0}\, dxdy$ where j_{tor} and j_{pol} are the current components and S is the helical surface interested by heat flux; for the resistivity the Spitzer formula is adopted and X_e is averaged on levels. As far as the current density function profile is concerned, the available polarimeter data do not permit a detailed **J** reconstruction in the core, and zero order quantities coming from Bessel function model are used in the calculation. This seems to be a reasonable assumption since, in a SHAx state, **J** perturbations are some percents of the unperturbed current density



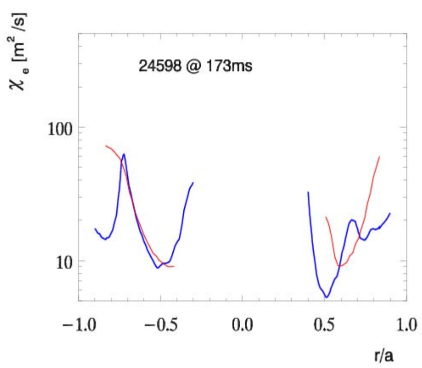


Fig3. Left, electronic diffusivity at TS poloidal section; right, comparison between 1D (blue) and 2D (red) models in a SHAx discharge.

Fig.3 shows a comparison with the electronic diffusivity obtained in cylindrical approximation (r instead of), a method used in previous analysis [11]. It has to be mentioned that, despite the cylindrical reconstructions of χ_e do not account for surface deformations and could be affected by significant uncertainties (quantitatively dependent on the island shape, extension and position respect to TS line of sight), the essential features of χ_e profiles are similar and the diffusivity values around the minimum are of the same order of magnitude.

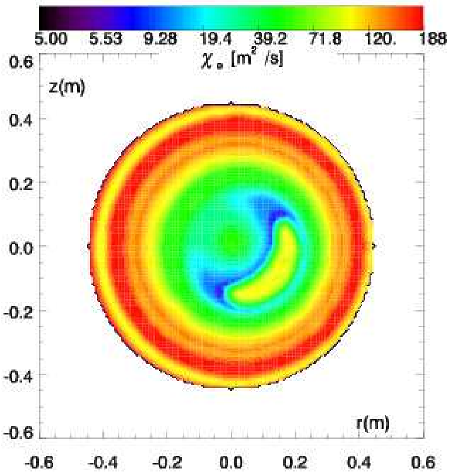


Fig 4. Electron diffusivity for a DAX shot (#24531); values on the island border are significantly lower than in the outer region

The electron thermal conductivity has been also evaluated in DAX states, for discharges with plasma current greater than 1MA. In these cases the typically measured increase in Te inside the island is on the order 300-500 eV, and the correspondent found χ_e is around 10 m^2/s, showing a consistency with [12].

The extension of the hot region is wider in SHAx with respect to DAX. This corresponds to a higher plasma energy content and it is related to an improvement in $_e$ up to 60 %. The electron confinement time in some cases can grow up to a factor 2 [11].

Conclusions

The electron pressure profile reconstructions in RFX-mod have been presented, using data from different instruments. In particular the pressure gradients in DAX and SHAX states have been analyzed and the electron thermal diffusivity profiles have been calculated in the two regimes.

Aknowledgements

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