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Confinement properties in RFX-mod with active control of the boundary magnetic field

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Introduction: The establishment of the scaling laws of the global confinement properties of fusion devices in stationary conditions is a crucial point both to design new experiments than to propose improvement to the operating devices. In that prospect the modified RFX (RFX-mod) experiment provide new information for the RFP devices thank to the thin shell, the active control of the boundary radial magnetic field[1] and a good set of magnetic and kinetic diagnostics. The thin shell confinement properties with and without radial field active control can also be directly compared to those of the previous thick shell operation since RFX-mod keeps the previous magnetic and geometric parameters.

RFX confinement database: To perform reliable scaling studies, a database has been realised and, to reduce errors, all kinetic quantities are carefully qualified. In particular Thomson Scattering[2] measurements are used for electron temperature profiles, electron density profiles are computed from multi-chord interferometer measurements[3] and medium radius ion temperature is deduced by Doppler broadening of OVII lines. Poloidal beta (β_p) and energy confinement time (τ_E) are computed integrating temperature and electron density profiles, while the ion temperature profile is assumed equal to the electron temperature profile.

In fig.1 the allowable data-points are plotted for the three main RFX operation modes: the old thick shell experiments and the new thin shell experiments without and with active control of boundary radial field (Virtual Shell). The figure shows that the new experiments do not completely overlap the previous one in the (I_p,I_p/N) parameters space ($N=\pi a^2<n>$ is the line density), in particular

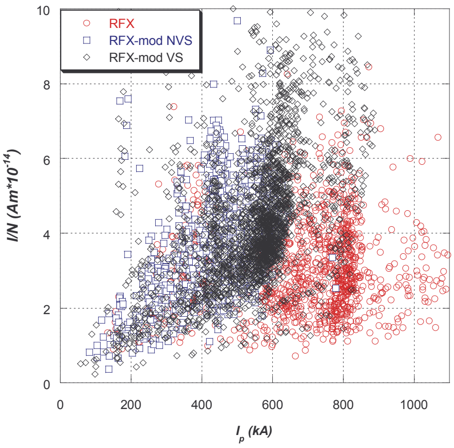

Fig. 1 Confinement data-points for RFX thick shell, RFX-mod standard operation (NVS) and RFX-mod with radial field active control (VS).

allowable in it. The following average values are obtained: $\langle\beta_p\rangle$=3.4 %, $\langle\beta_p\rangle_{NVS}$=4 % and $\langle\beta_p\rangle_{VS}$=4.6 % for poloidal beta and $\langle\tau_E\rangle$=0.58 ms, $\langle\tau_E\rangle_{NVS}$=0.36 ms $\langle\tau_E\rangle_{VS}$=0.80 ms for energy confinement time.

Scaling laws: To get some insight on the phenomena underlain present results we study the dependence of the confinement from the main plasma parameters.

The β_p presents the strongest scaling of the two confinement quantities, all the virtual shell data of stationary discharges can be fitted by a single I_p/N parameter exponential fit (fig. 5). The same fit reproduces very well the RFX-mod standard discharges also. The situation is slightly different for the RFX thick shell discharges: those with a plasma current lower than 700 kA (the same explored by the RFX-mod experiments) are better described by a two parameters fit $\beta_p(\%)=7.2\cdot10^{-9}I_p^{-0.51}(I_p/N)^{-0.55}$ (A,Am).

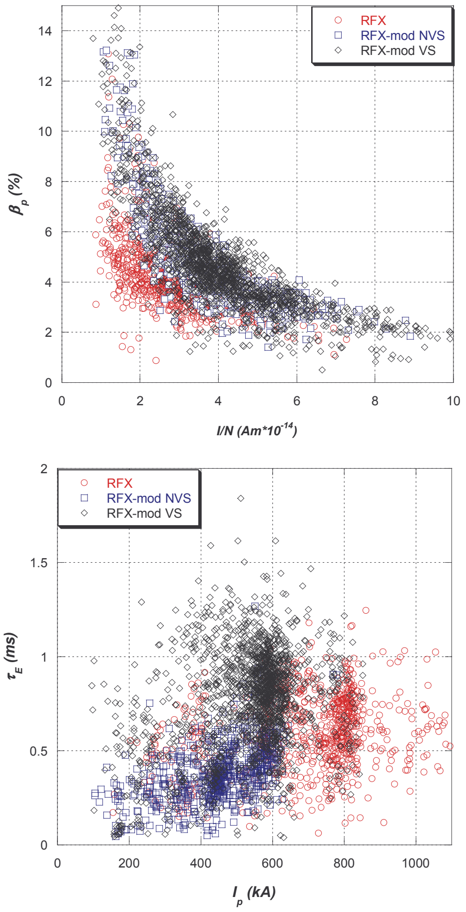

Fig. 4: Poloidal beta and energy confinement time for all the tree experimental conditions.

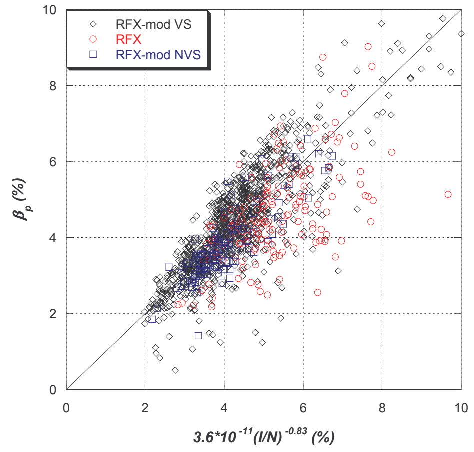

Fig. 5: Poloidal beta single parameter least square fit of the virtual shell experiments. The same fit is used for RFX-mod standard discharges and RFX discharges.

Less evident is the scaling law for the energy confinement time, the data of the three RFX configurations are not compatible with the Connor-Taylor[4] scaling law: $\tau_E=ca^2I_p^3/N^{3/2}$ (where c is a constant theoretically equal to 10.2) which was derived assuming that resistive fluid turbulence (g-modes) limit the energy confinement. The inability of the Connor-Taylor to fit RFX data was expected since the same scaling law predicts also a constant poloidal beta. Indeed it has to be mentioned that the RFX-mod energy confinement times of the better discharges is not far from the value expected from Connor-Taylor scaling law with c obtained fitting the energy confinement time of smaller RFP devices[5].

A good scaling law has been obtained for the VS data by a three parameters fit using I_p, I_p/N and the square of the normalized internal radial field $b=<b_r^2(r)/B_p(a)^2>^{1/2}$ of modes with m=1 and n=-15÷-8. For F=-0.23÷-0.18 the least square fit of τ_E is drawn in figure 6. In the same figure RFX-mod standard discharges results are plotted using the fit obtained with the VS data only. It is possible to see that the fit is able to describe relatively well both situations although there is a factor of about 5 in *b* between standard and VS discharges. For RFX-mod similar, but less good fit, can be obtained for other F intervals, while for RFX only worst correlations can be found. The beneficial effect of the boundary control to the internal plasma apparent from the explicit dependence of τ_E from *b* is confirmed by the peaking of the temperature profile lowering *b* as shown in figure 7.

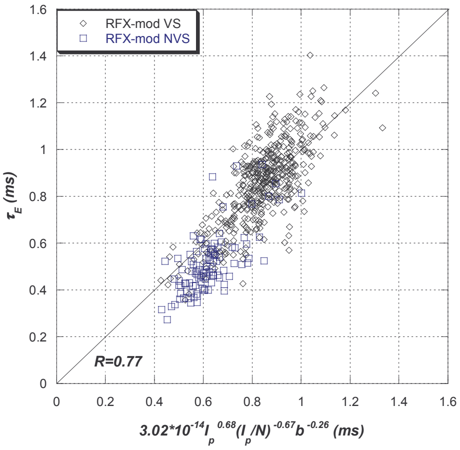

Fig. 6: Three parameters fit of τ_E of VS discharges applied to both VS and standard RFX-mod discharges.

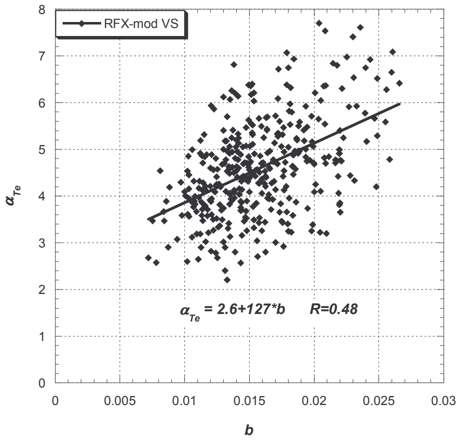

Fig. 7: Profile exponent of the electron temperature profile $T_e(r)=T_{eo}(1-r^{\alpha})$.

Conclusions: The first statistical analysis of RFX confinement properties has been presented, first results confirm that the thin shell solution supplemented by a feedback system to control edge radial field improves confinement properties while allowing in principle stationary discharges. First scaling law of the new configuration provide better plasma current dependence than the thick shell RFX, allowing also a large poloidal beta, probably thank to a better first wall.

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