COMPARISON OF PLASMA CONFINEMENT PROPERTIES IN THE RFX AND MST EXPERIMENTS UNDER SIMILAR STATIONARY CONDITIONS

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1. Introduction

RFX [1] in Italy and MST [2] in the United States are at present two of the largest reversed field pinch devices in operation. They have similar geometrical plasma dimensions (RFX: R=2 m, a=0.457 m; MST: R=1.5 m, a=0.51m), can operate at similar plasma currents, but are characterised by rather different boundary conditions. In particular, they differ for the plasma-shell proximity (RFX: b/a ≈ 1.17; MST: b/a ≈ 1.04) and first wall material (in RFX the inconel vacuum vessel is entirely covered by graphite tiles while in MST the thick aluminium wall acts also as vacuum vessel and only about 10% of the internal surface is covered by graphite limiters). Thus, a comparison between plasma confinement in the two experiments offers the possibility of addressing the question of the importance of these different machine features. The aim of this work is the study of the confinement properties in the two devices during standard operations keeping comparable as many external parameters as possible. We will also briefly discuss the results recently obtained during different enhanced regimes (pulsed poloidal current drive operations, enhanced confinement periods) in both MST and RFX.

2. Standard operations

Two sets of discharges were executed for the purpose of studying standard operations during the summer-fall 1997 period in the two laboratories using particular attention to the completeness and the reliability of the diagnostics systems in order to get as much information as possible about electron density and temperature profiles, impurity content and magnetics. To avoid differences in the definitions of derived quantities or in the treatment of data, the same analysis programmes were applied to both RFX and MST raw data. Unfortunately, the discharges in the MST set were determined to be degraded, showing a high incidence of locking and increased Ohmic input power relative to optimized MST discharges. However, because the approach described here was designed specifically to compare RFX and MST operated as similarly as possible, we proceed with the caveat that the data for MST do not represent its optimal performance. We discuss below the impact on our conclusions.

We choose as reference parameters for the discharges the plasma current I, the F parameter ($F = B_\phi(a)/\langle B_\phi \rangle$) and the ratio of plasma current to line averaged electron density I/N. Experimental operation were under controlled conditions at values: I = 400 kA, F = -0.2, I/N = 4-6 10^{-14} Am. We used the same filling gas (hydrogen), the same parameters and the plasma current was well sustained for a significant time interval in order to eliminate the uncertainty related to inductive corrections in the calculations of resistive loop voltage and of

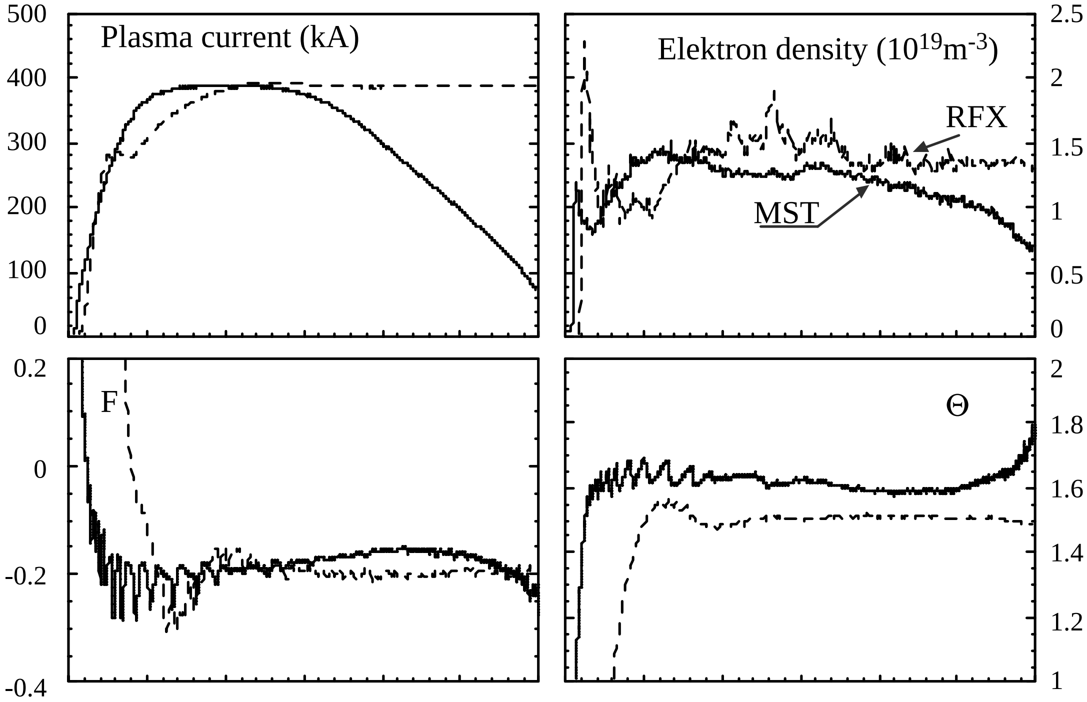

Fig. 1. Flat-top phase of two typical RFX (dashed line) and MST (continuous line) shots.

energy confinement. In RFX the horizontal shift was limited by a proper value of vertical field to $\Delta_H < 1$ cm, while in MST the equilibrium, provided only by the close fitting shell, has a resulting shift of the same order. The time behaviour of the main plasma parameter during the flat-top phase for two typical RFX and MST discharges is shown in figure 1 where the dotted line represents RFX data and the continuous line represents MST data.

To compare standard MST and RFX plasmas we averaged each shot data over a period of at least 6 milliseconds during the current flattop (more than one MST sawtooth period). The experimental values obtained using this procedure for the control parameters I, I/N and F are shown in figure 2. Electron density profiles were obtained for both MST and RFX by a multichord interferometer and were found to be similar and very flat. Electron temperature profiles are measured at present only in RFX by a single pulse, 10 points Thomson scattering diagnostic. We used in the calculations the same pressure profile for both sets of data assuming, in good agreement with experimental data, the density profile to be proportional to a function $[1-(r/a)^6]$ and the electron temperature profile to a function $[1-(r/a)^4]$.

The results of the analysis show that the confinement properties of stationary discharges of the two experiments are nearly equivalent in terms of derived quantities such as volume averaged resistivity, poloidal beta and energy confinement time (see figure 3). The similarity

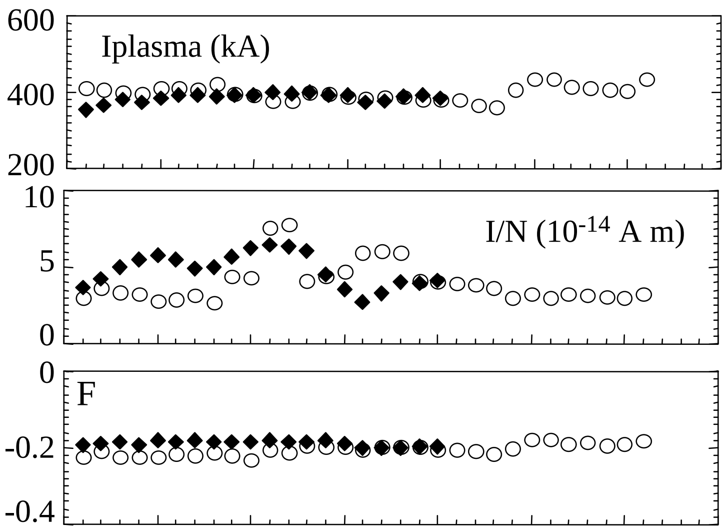

Fig. 2. Experimental values obtained for plasma current, I/N and F parameter for the two sets of shots are shown. Empty circles represent RFX data while black diamonds represent MST data. Each point is a flat-top average over several milliseconds.

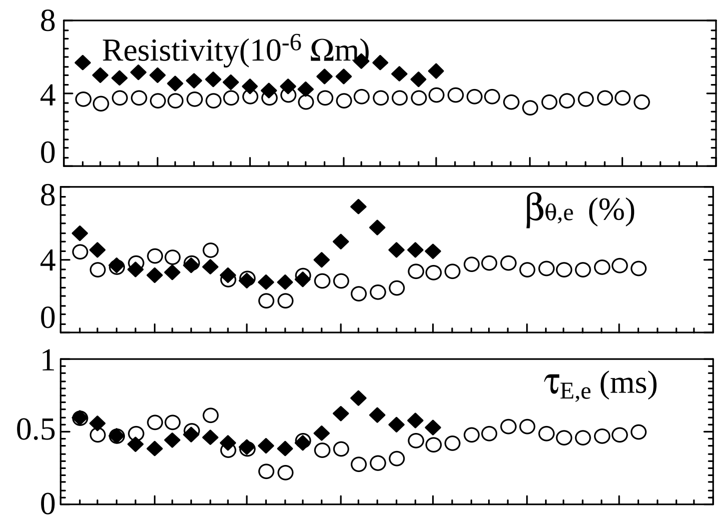

Fig. 3. Plasma resistivity, electron poloidal beta and energy confinement time for RFX (circles) and MST (diamonds).

of beta and confinement in MST and RFX suggests the different boundary conditions do not profoundly affect plasma performance. Typical values obtained are 4 10^{-6} Ωm for the resistivity ($\eta=a^2V(a)/2RI$) , 4% for the electron poloidal beta, $\beta_{\theta e}$ and 0.5 ms for the electron energy confinement time, $\tau_{E,e}$. MHD modes locked in phase and to the wall were present in each RFX discharge and in most of the MST discharges included in this comparison. Their occurrence does not change the values of confinement parameters for MST shots, at least at this plasma current level.

To assess whether or not the degraded nature of the MST discharges in figure 3 affect these conclusions, we compare a set of well-diagnosed, I/N~$4{\cdot}10^{-14}$ Am plasmas [3] known to be representative of MST's typical performance, but with different operation than specified for the controlled comparison above. These discharges were collected prior to recent improvements in the MST current flattop circuitry, and so they have a slowly decaying current waveform. Also, they were formed with deuterium and with slightly deeper reversal F~-0.25. The main differences between these plasmas and those in figure 3 are that the volume average resistance is ~3 10^{-6} V/Am (~30% lower than in figure 3) and the fraction of locked shots was ~30%. The confinement is no more than a factor of 1.4 higher in optimized MST plasmas, mostly as a result of the lower resistance. Improving confinement beyond that observed in RFX and MST is a necessary development step for RFP research.

3. Enhanced confinement regimes

Recent RFP experiments showed that major improvements in confinement are possible in transient conditions with non standard operation which can be related to changes in magnetic profiles: enhanced confinement periods (EC, [4]) in MST, improved high-theta mode (IHTM, [5]) in TPE RM-20, pulsed poloidal current drive (PPCD) in MST [6] and RFX [7]. During these periods magnetic fluctuations are greatly reduced suggesting a modification of the sustainment mechanism of the RFP configuration, the so-called magnetic dynamo.

It is interesting to note that when the same techniques are used, as in the case of PPCD operations, qualitatively similar plasma behaviours are found in both MST and RFX. The similarity in edge properties such as plasma potential profiles [8,4] and plasma flow [9,10] during standard operations, suggest, following the interpretation in [11], that also flow related enhanced confinement regimes could be accessible in RFX as indicated by recent measurements [12].

4. Conclusions

RFX and MST reversed field pinch plasmas during standard operation under similar controlled conditions show similar macroscopic behaviour and confinement properties. The very different magnetic boundary conditions and the differences in some features such as large sawtooth oscillations and rotating MHD modes in most MST plasmas versus modes always locked to the wall in RFX do not seem to influence this result. Finally, the differences between these two machines do not appear to influence the accessibility to new improved confinement regimes such as those obtained during PPCD.

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