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First results on Reversed Field Pinch plasmas with new magnetic boundary in the RFX-mod experiment

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Introduction

Reversed Field Pinch experiments resumed in December 2004 in the modified RFX device (RFX-mod) [1]. Magnetic boundary is now made by a thin (3mm) Cu shell with a 50 ms penetration time τ_w for vertical magnetic field, B_v. The shell has one overlapped poloidal gap and one toroidal gap and the shell/plasma proximity has been decreased from b/a = 1.24 to 1.1. Toroidal equilibrium is feedback controlled [3] using the field shaping coil system. New power supplies provide a more flexible control of the toroidal field coils. A new full graphite tile coverage of the vacuum vessel has been installed, which should prevent highly localized power deposition on the tile edges thanks to the new design of the tiles [1]. A set of 48x4 saddle coils outside the thin shell [2] will be controlled by a digital feedback system [3], which will allow a variety of operation modes [4] to act both on field errors, radial field components due to dynamo modes and resistive wall modes (RWMs). A greatly enhanced set of internal and external magnetic pick up coils, internal electrostatic probes and thermocouples is available [5], which, along with detailed measurements of temperature, density and impurity emission profiles, permit to do a complete characterization of the pulses, both in terms of MHD mode dynamics and of plasma confinement. The paper presents the first experiments at currents of 300-600 kA, which have been done to assess the performance of the new machine front-end before commissioning the MHD mode control system, which is expected to start operating shortly after the Conference.

Experiments

The previous machine had a 6.5 cm thick aluminium stabilizing shell with a $\tau_w \cong 500$ ms, which guaranteed both mode stabilization and toroidal equilibrium through the 100÷150 ms pulse length. Hence, the first issue to face in RFX-mod was RFP setting-up and equilibrium control with a shell whose time constant is comparable to pulse length. Actually this was not particularly difficult and, after a brief optimization of magnetic field programming, density and equilibrium control, we have been able to produce RFP discharges using aided reversal, matched mode and current ramping with characteristics similar to those of the past (figure 1).

As for toroidal equilibrium, because of the short shell time constant, feedback control has indeed proven necessary, but also very effective. Indeed we find that it is possible to keep the plasma shift Δ at a constant preset value within a few mm. Optimum plasma performance is obtained with Δ =0÷5 mm. This up to now allowed us to obtain well sustained pulses with duration in excess of 130 ms, that is, more than twice the shell time constant. An example of such pulses is given in fig. 2, where it can be seen that actually the plasma terminated for lack of volt-second.

The plasma performance of these discharges has been benchmarked versus reference pulses of the previous database. As shown in fig 2 and 3 the RFX-mod plasmas have field reversal and pinch parameter ($F \equiv B_\phi(a)/\langle B_\phi \rangle$, $\Theta \equiv B_\theta(a)/\langle B_\phi \rangle$), loop voltage, density and temperature comparable to those of the reference pulses. Mode dynamic is also relatively benign, with amplitudes and spectra similar to the past ones [7,8]. On the other hand the penetration of the

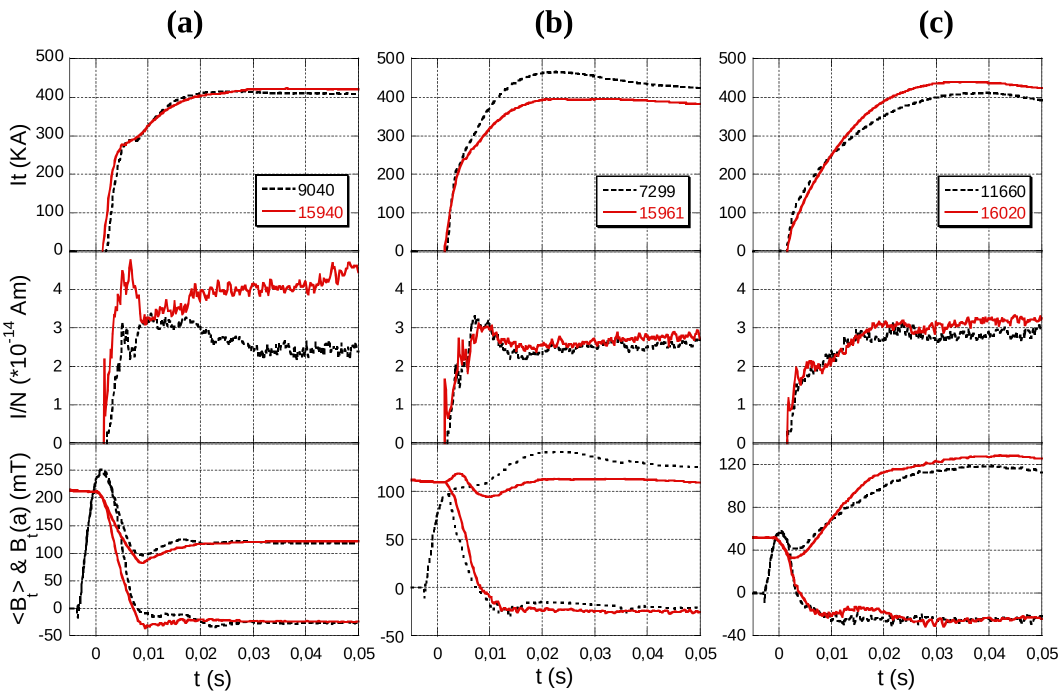

Fig.1 Plasma current, I/N ratio, toroidal field (mean and edge) for pulses with different RFP setting-up in RFX (black line) and RFX-mod (red line): (a) aided, (b) matched and (c) ramped. In all cases both the time evolutions and the final states are very similar.

mode radial field component through the thin shell is relatively fast, which leads to enhanced plasma wall interaction. The improved graphite tiles design has countered this negative effect by spreading the power deposition over the tile central section rather than on their edges. This is confirmed by CCD images of plasma wall interaction taken during the pulses [6] and by periodic in vessel inspection. The latter in particular, showed that, contrary to the past, after several hundred pulses no damage has been done to the tile edges.

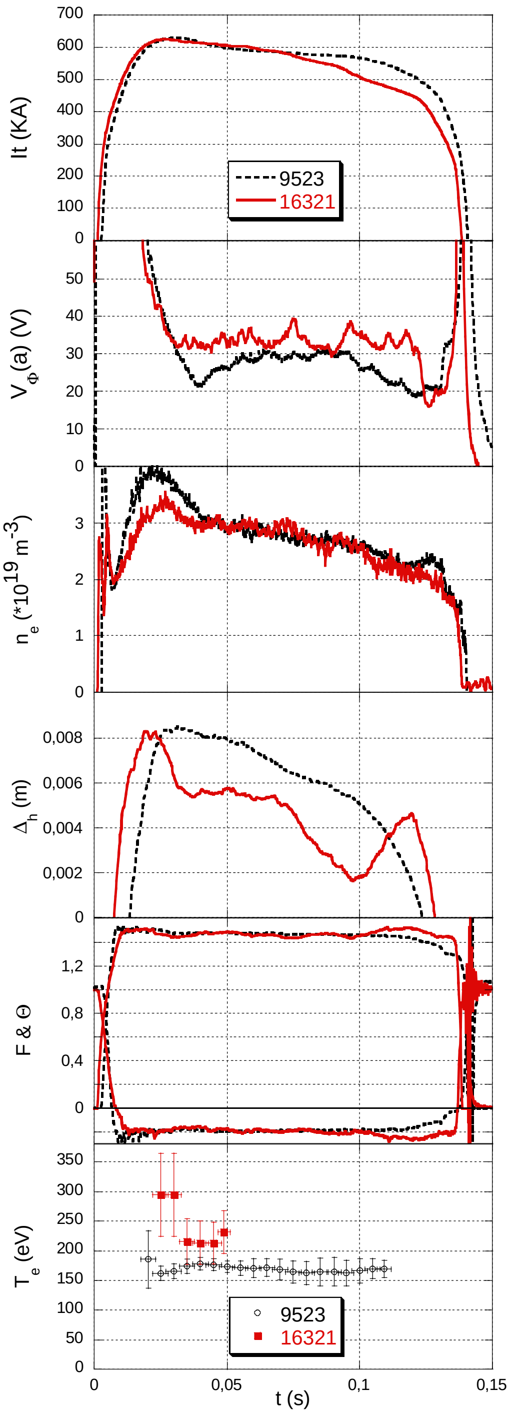

Fig.2 Reference "long pulses" in RFX (9523) and RFX-mod (16321). Both discharges terminate because of the turning off of the voltage at 0,11 and 0,12 s respectively.

Despite the improved shell proximity in RFX-mod, no evidence of spontaneous rotation of the dynamo tearing mode is seen even at low currents (200÷300 kA) and low density ($1\cdot10^{19}$ m^{-3}). In fact, similarly to the previous experience, m= 1 and m= 0 dynamo modes are systematically locked in phase and to the wall. The statistical distribution of the locking angle is concentrated around two positions at 180° toroidally from each other. Such positions correspond to the poloidal gaps of the stainless steel shell which has replaced the previous thick aluminium shell to work as a support structure for the RFX-mod coils. Such structure has time constant of ~ 15÷20 ms for B_v penetration, and is outward shifted by 5 mm relative to the inner copper shell. Hence it seems that the structure acts as a secondary shell and generates field errors at its gaps, which penetrate through the inner shell and influence the mode locking position.

Evidence of RWM growth is seen in the longest pulses [7]. Their amplitudes and growth rates are compatible with theoretical predictions [8], which, according also to the results obtained on

T2 [9], should allow us to control them by the new RFX-mod feedback system.

Conclusions

The initial operation of RFX-mod without active mode control has been very encouraging, since performance similar to that of the thick shell machine has been readily achieved both in terms of pulse length and main plasma parameters. The plasma loop voltage is still higher by 2-3 V compared to the best pulses of the past, but this is likely caused by the enhanced plasma-wall interaction due to the faster penetration through the thin stabilizing shell of radial field components of locked tearing modes. Moreover a role is played also by the systematic field errors. Both such field errors, along with errors due to the growth of RWM, should be adequately corrected with the new RFX-mod MHD digital feedback system. In this way we expect on the one hand to further improve the performance, demonstrating the possibility of operating a large RFP without a thick conducting shell, and, on the other hand, to obtain easier and better controlled access to enhanced RFP scenarios, such as QSH [10], OPCD [11], and Intelligent Shell [9].

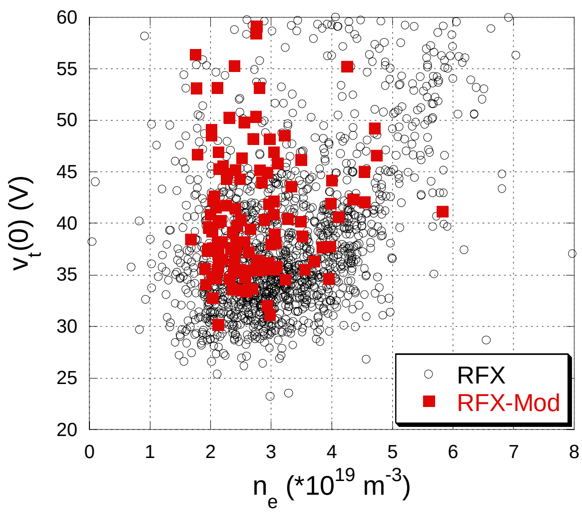

Fig.3 Resistive loop voltage versus density for pulses at 600 kA

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References

[1] P. Sonato, G. Chitarin, P. Zaccaria et al., Fus. Eng. and Des. **66-68** (2003) 161
[2] G. Chitarin, S. Dal Bello, L. Grando, S. Peruzzo, Fus. Eng. Des. **66-68** (2003) 1055
[3] M. Cavinato, A. Luchetta, G. Manduchi, and C. Taliercio, *Real time control environment for the RFX experiment*, to be publ. Fus. Eng. Des.
[4] P.Sonato, R.Piovan, A.Luchetta, and RFX Team, *Control of non-axisymmetric magnetic fields for plasma enhanced performances: the RFX contribution*, to be publ. Fus.Eng. Des.
[5] G. Serianni, T. Bolzonella, R. Cavazzana, et al, Rev. Scien. Instrum. 75 (2004), 4338
[6] L.Carraro, A. Cravotta. E. Gazza, et al., this Conference
[7] T. Bolzonella, D. Terranova, P. Zanca et al., this Conference
[8] D. Terranova, , P. Zanca, R. Paccagnella et al.,this Conference
[9] P. R. Brunsell, D. Yadikin, D. Gregoratto, et al., Phys. Rev. Lett. **93**, (2004) 225001
[10] P.Martin, S.Martini, V.Antoni et al, Nucl. Fusion **42** (2002) 247
[11] T. Bolzonella, P. Martin, S. Martini, et al. , Phys. Rev. Lett. **87**, (2001) 195001