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MHD fluctuations in a Reversed Field Pinch with different magnetic boundaries produced using an active feedback coils system

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Introduction:

The RFX-mod experiment (a=0.459 m, R=2 m, I = 1 MA) has been equipped with 192 active saddle coils, arranged in 4 toroidal arrays of 48 coils each located on the external surface of the shell (the shell time constant for the penetration of a vertical field is $\tau_b/2$= 50 ms, and its average radius is b=0.5125m). The layout is designed to interact with the broad spectrum of magnetic perturbations, mainly instabilities with poloidal numbers *m*=0 and *m*=1, characteristic of the RFP plasmas.

By coupling the system in a feedback scheme with the input signals of the magnetic sensors located inside the shell at the radius r_{sens}=0.505 m, a variety of magnetic boundaries can be realized. In particular it has been proven possible to cancel the radial field measured by the sensors, thereby realizing an ideal boundary, i.e. a 'Virtual Shell' (VS) at $r=r_{sens}$. The beneficial effects of this kind of operation, mainly the resistive wall mode suppression, the mitigation of the plasma first-wall interaction and the global reduction of the perturbation amplitude inside the plasma, are presented. Moreover we derive a cylindrical model which is able to extrapolate the measured radial field at the sensors to the radial field at the plasma edge. In this way it is possible, in principle, to build feedback schemes where the VS can be produced at any intermediate radial position from the plasma edge to the sensors.

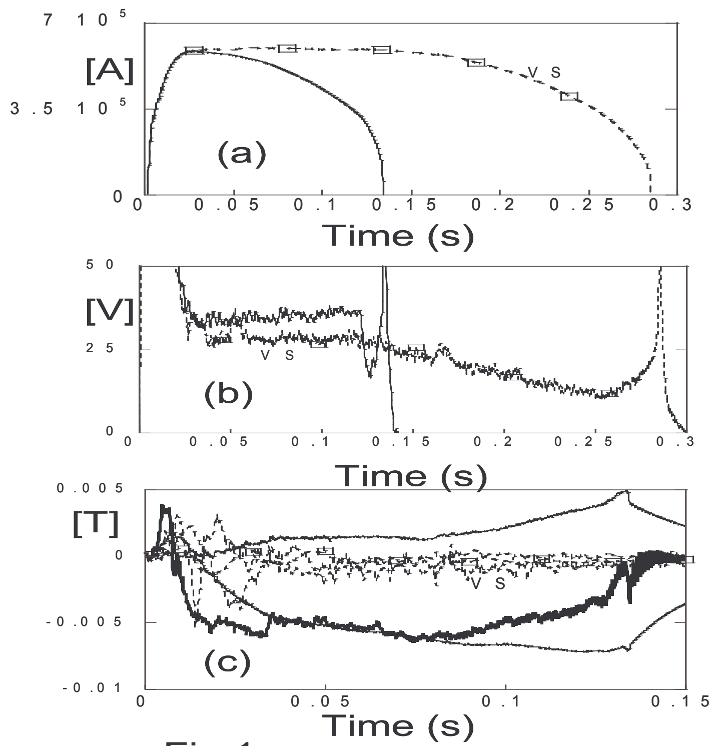

Fig.1

Results of the VS operation:

In Fig.1 the comparison in terms of plasma current (a) and toroidal loop voltage (b) between a VS and a reference uncontrolled discharge is shown.

A very clear prolongation of the pulse and lowering of the loop voltage is seen. As an example of the effectiveness of the feedback control, in Fig.1(c) the measured radial magnetic field (at three toroidal positions) for the same two shots is shown. The radial field amplitude at the radial sensors is much lower in VS controlled discharges.

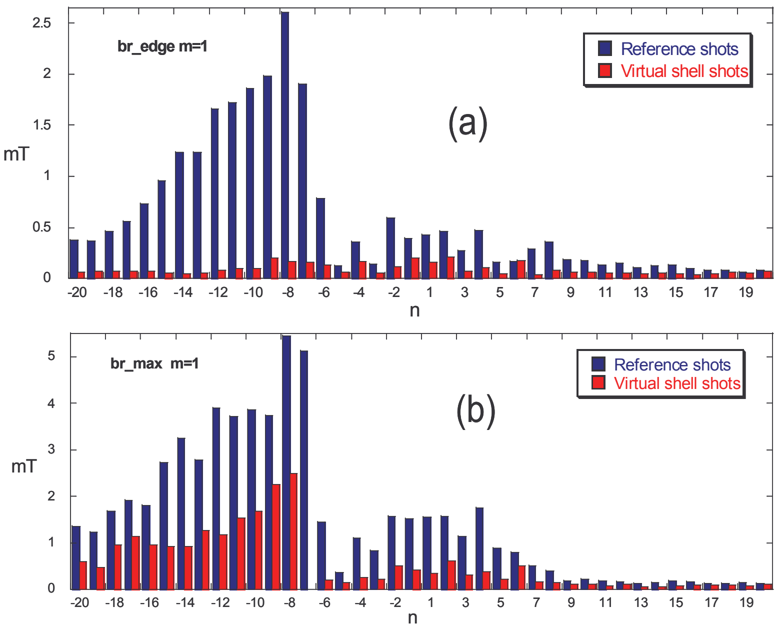

Fig.2

In Fig.2 the comparison between the standard and VS m=1 spectrum (reconstructed in toroidal flux coordinates [1] is shown for a set of selected discharges, both at the edge (a) and in the core (b). To evaluate the fluctuations inside the plasma an equilibrium reconstruction , the edge radial and toroidal field measurements and a Newcomb's equation describing the perturbed fields in the plasma are used. Fig.2(b) shows the maximum radial field amplitude for each harmonic.

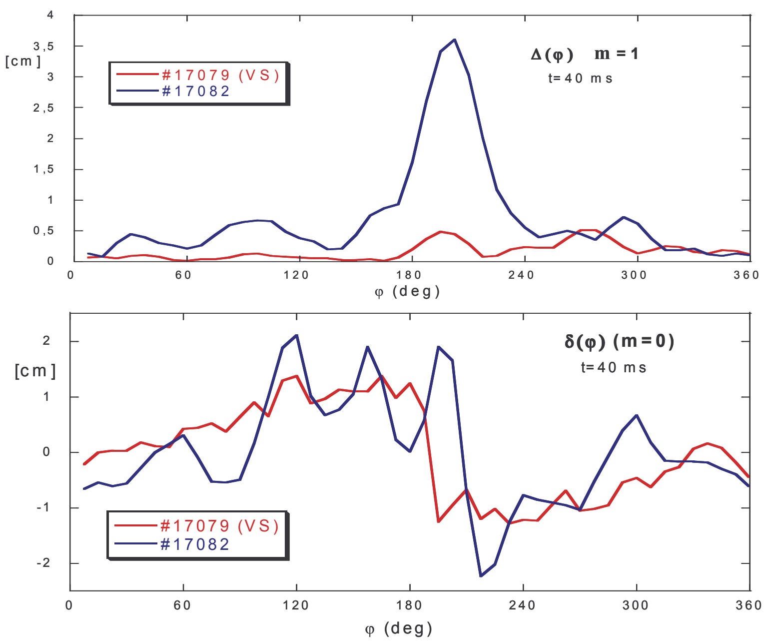

Fig.3

This maximum corresponds to the on-axis value of the eigenfunction for the non-resonant modes, while it is representative of a value close to the resonance surface in the case of resonant modes. The n=-7 mode is not shown due to difficulties in its reconstruction since it is resonant very near to the magnetic axis. The use of a Newcomb's equation is justified by the fact that the linear and nonlinear eigenfuctions (in cylindrical geometry) for both RWMs and resonant tearing modes show, in numerical simulations, similar magnetic field radial profiles [2]. It is clear, from our reconstruction that the mode amplitudes are reduced by the VS for all n's, both at the sensors position and, more important in the core. Resistive Wall Modes (RWM) are stabilised [3] and, on the other hand, the resonant tearing mode amplitudes are significantly reduced by the VS operation. The average radial perturbation amplitude (over all n's) is lowered by a factor of about 3 in the plasma region. The reduction of the tearing part of the spectrum is a consequence of the fact that the VS mimics an ideally conducting wall, which has a stabilising influence on the whole spectrum of unstable modes, but also the reduction of the error fields play an important role.

In fact error fields can act as seeds for the tearing modes growth to higher amplitudes and also can facilitate the phase locking process. Under this respect, as a consequence of the mode amplitude reduction, the m=1 locking is also considerably mitigated in VS discharges. A residual toroidally localised structure is still present, but it corresponds to a radial shift of the last closed magnetic surface lower than 0.5 cm (to be compared to 3-4 centimetres in the absence of control).

A 2-4 centimetres m=0 local deformation (see Fig.3), in this case almost of the same magnitude as in not controlled discharges, is instead still detected, because of this the plasma-wall interaction is still severe in some cases.

A closer Virtual Shell:

In [4] a theoretical plasma response cylindrical model for a feedback system realized with a finite number of active coils was derived for the specific case of RWMs.

The theory needs to be generalized in the case of resonant modes. Neglecting the effect of the finite number of coils, an equation can be derived that links the radial field at the plasma edge with the radial field measured at the sensors and the field produced by the coils. For each harmonic we have:

$$\tau_b \frac{\partial}{\partial t} b_r^{m,n}(a) - A^{m,n}\, b_r^{m,n}(a) = -B^{m,n}\, b_{r,sens}^{m,n} + C^{m,n} \tau_b \frac{\partial}{\partial t} b_{r,sens}^{m,n} - D^{m,n}\, b_{r,coil}^{m,n} \qquad (1)$$

where:

$$A^{m,n} = \frac{m^2 + \left(\frac{nb}{R}\right)^2}{\left(\frac{nb}{R}\right)^2} \frac{K'_m\left(\frac{|n| r_{sens}}{R}\right)}{K'_m\left(\frac{|n| b}{R}\right) F^{m,n}(r_{sens}, b)} \qquad B^{m,n} = \frac{m^2 + \left(\frac{nb}{R}\right)^2}{\left(\frac{nb}{R}\right)^2} \frac{K'_m\left(\frac{|n| a}{R}\right)}{K'_m\left(\frac{|n| b}{R}\right) F^{m,n}(r_{sens}, b)}$$

$$C^{m,n} = \frac{F^{m,n}(a,b)}{F^{m,n}(r_{sens},b)} \qquad D^{m,n} = \frac{m^2 + \left(\frac{nb}{R}\right)^2}{\left(\frac{nb}{R}\right)^2} \frac{F^{m,n}(r_{sens},a)}{K'_m\left(\frac{|n|b}{R}\right) I'_m\left(\frac{|n|r_{coil}}{R}\right) F^{m,n}(r_{sens},b)}$$

$$F^{m,n}(x,y) \equiv K'_m\left(\frac{|n|x}{R}\right) I'_m\left(\frac{|n|y}{R}\right) - K'_m\left(\frac{|n|y}{R}\right) I'_m\left(\frac{|n|x}{R}\right)$$

a, b are the plasma and shell radii respectively.

Eq.(1) reduces to eqs.(6,9) of Ref.[4] for the RWM branch.

Therefore, in principle, Eq.(1) can be used for every mode, resonant or non resonant, to extrapolate from known quantities (Bessel Functions and measured fields) the radial field close to the plasma boundary. In this way, theoretically, the coils current can be adjusted to produce a VS just at the plasma edge. However since Eq.(1) involves also time derivatives, it is not guaranteed that this scheme can be realized in practice. We leave this point for future investigations.

For the moment we want to show that the cylindrical model gives good predictions for some measurable quantities, which can be calculated [5], such as the penetration times in vacuum for different harmonics, as shown in Fig.4.

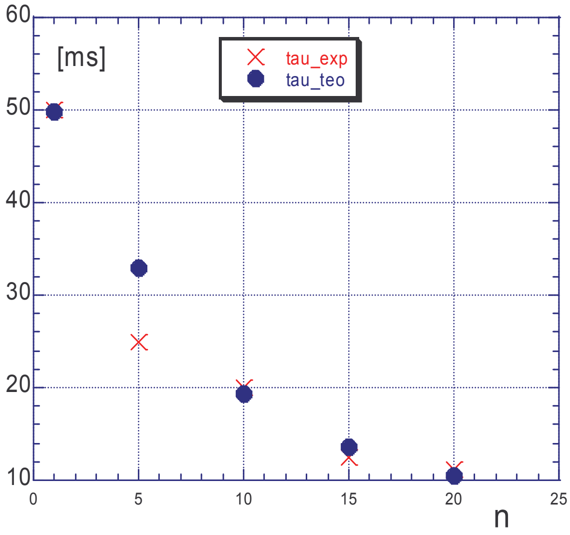

Fig.4

Conclusions:

The VS concept has been experimentally proved to reduce fluctuations amplitude and to enhance plasma performances.

Cylindrical theory compares favourably with the RFX-mod experiment and new control schemes, like the Close VS can be in principle implemented in the attempt to further improve the plasma conditions.

References

[1] P. Zanca and D. Terranova, Plasma Phys. Contr. Fusion **46** (2004) 1115.
[2] R. Paccagnella, D. Schnack, M.S. Chu, Phys. Plasmas **9** (2002) 234.
[3] T. Bolzonella et. al. Poster P..at this Conference.
[4] R. Paccagnella et. al. , Nuclear Fusion **42** (2002) 234.
[5]D. Gregoratto et. al., Phys. of Plasmas **12** (2005) 092510.