*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-5.051 (2005)*

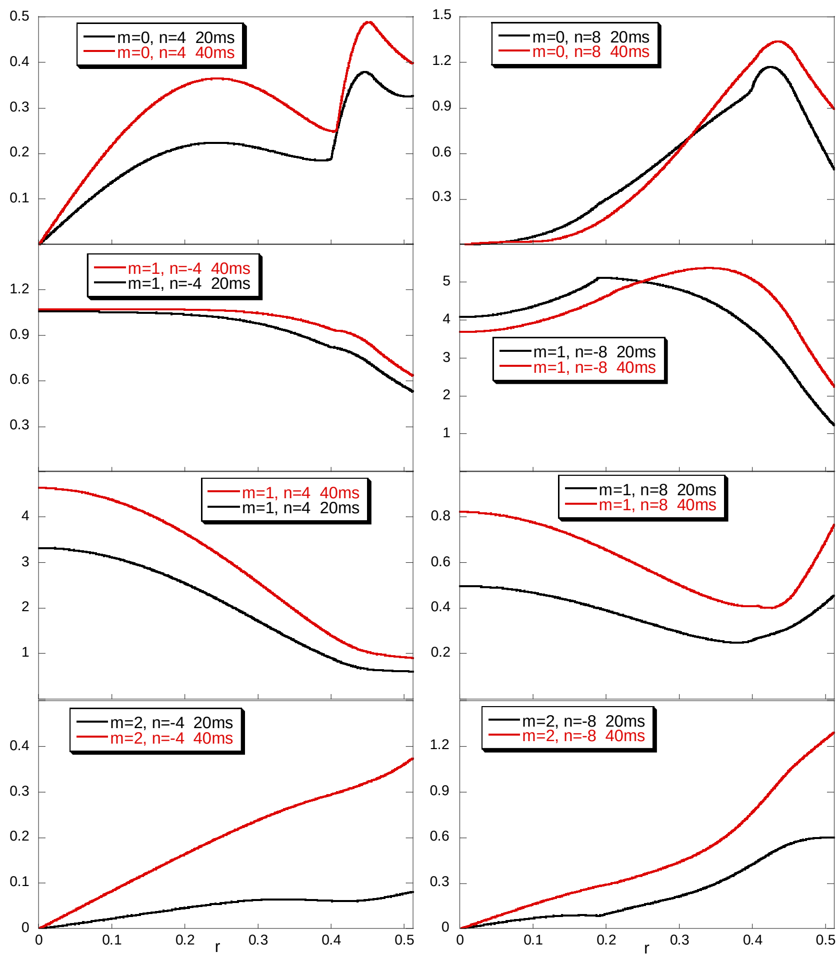
First results on the analysis of magnetic fluctuations in toroidal geometry and comparison with numerical simulations for the RFX-mod reversed field pinch

D.Terranova, P.Zanca, R.Paccagnella, T.Bolzonella, S.Martini
Consorzio RFX, Euratom-ENEA Association
Corso Stati Uniti 4, 35127 Padova, Italy.

The reversed field pinch (RFP) is a magnetic configuration, which, according to Cowling's theorem, cannot be axisymmetric in stationary conditions [1]. The magnetic profiles are in fact sustained by magnetohydrodynamical (MHD) modes, mainly tearing modes [2] resonant inside the reversal surface (the q=0 surface), having poloidal mode numbers m=1 and a broad spectrum of toroidal mode numbers n. In principle it should be possible to sustain the configuration with just one single m=1 mode [3], and indeed the shrinking of the n-spectrum is sometimes observed in RFP experiments. The m=0 modes resonant at the reversal are also present, with a rich content of toroidal n-harmonics. They are particularly sensitive to the plasma-shell distance [4], and provide part of the non-linear coupling between the m=1 modes [5]. It is customary to study RFP plasmas by assuming cylindrical geometry. Nonetheless in the actual experiments the aspect ratio is not so large as to make the toroidal effects completely negligible. The toroidicity produces poloidal harmonics in the equilibrium quantities (at the leading order m=±1, n=0), which act as mediators between modes with the *same* toroidal number and *different* poloidal numbers. A method to study the toroidal coupling in circular shaped, force-free plasmas (a good approximation of the RFP equilibrium) has been developed in [6], and its application [6, 7] to the RFX experiment [8] has put into evidence the toroidal generation of m=0, 2 sideband from the dominant m=1 modes. The purpose of this work is to apply the toroidal mode analysis to the RFX-mod experiment in order to characterize the typical magnetic perturbations. Moreover we will try a comparison with the simulations provided by the *cylindrical* DEBS code [9]. The RFX-mod experiment (a=0.45m, R=2m) is equipped with a rich magnetic probes layout, including 4 toroidal arrays of 48 pick-up coils measuring the toroidal field and 4 toroidal arrays of 48 saddle coils measuring the radial magnetic field. These arrays, which are used for the present analysis, are both placed between the vacuum vessel and the conducting shell. In comparison to the previous layout, this configuration allows a better spectral resolution of the poloidal harmonics. Moreover RFX-mod has a new shell thinner (shell time 100ms) and closer to the plasma. Due to the reduced magnetic screening of the thinner shell, we expect the appearance of the plasma resistive wall modes (RWM) [10], and of some externally produced error field. These perturbations can complicate considerably the phenomenology of magnetic fluctuations present in RFX-mod. In this analysis we solve the harmonics m=0 $0<n<24$, m=1 $-24<n<24$, m=2 $-24<n<0$, where the convention $n<0$ for the modes with the same helicity of the equilibrium field inside the reversal and $n>0$ for the modes with the same helicity of the equilibrium field outside the reversal is adopted. We present both the Fourier spectrum of the edge magnetic signals, and the b_r radial profile obtained by solving a system of toroidally coupled Newcomb's equations [6]. Both analysis are performed in toroidal geometry with the adoption of flux-coordinates ('r'= radius of the unperturbed circular flux surface, 'ϑ'= poloidal-like angle, therefore not the machine one, 'ϕ'= machine toroidal angle). The system of Newcomb's equations is solved by finding a basis of independent solutions, which are combined with coefficients determined by the edge measurements.

In figure 1 the b_r amplitude radial profiles (in mT) for the modes corresponding to n=±4 and n=±8 are shown at t=20ms, and t=40ms (the flat-top of the shot; I=600 kA) for the shot 16126. The profiles are plotted up to the radius r=0.5115m which corresponds to the location of the conducting shell. Since the shell is not ideal, the edge value of the radial field is different from zero. The reconstructed profile for the internally resonant m=1, n=-8, and the non-resonant m=1, n=4 are in good qualitative agreement with the simulation performed by DEBS, and reported in figure 2 (here a resistive shell is considered; b_r is shown after 2 shell times, and it is normalized to the equilibrium toroidal field on axis). The fact that in the simulation the m=1, n=4 turns out to be a RWM would suggest such identification also for the experimental harmonic of figure 1. Nevertheless a detailed analysis of the growth rates is required to draw any conclusion. Moreover it is interesting to note that the appearance of potential RWMs is clearly visible adopting flux-coordinates, while it is not so evident in the same analysis performed using cylindrical machine-coordinates.

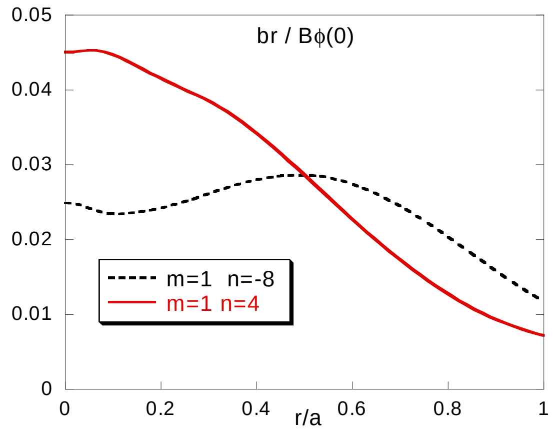
fig.1



In figures 3 and 4 a statistical analysis made on several shots with similar characteristics is considered at t=40ms: figure 3 shows the edge radial field amplitude obtained from the measurements; figure 4 shows the maximum amplitude of the radial field profile, which in general is reached at a point inside the plasma (the data in fig.3 are not the edge values of the reconstructed b_r profiles, because the latter are obtained with both b_r, b_ϕ measurements). The red bars are the average values, while the green bars are the standard deviation. Note in figure 3 the toroidal contribution, coming from the dominant *m*=1 *n*≤-7 resonant modes, to the *m*=0 *n*≥7 (≡ *m*=0 *n*≤-7), *m*=2 *n*≤-7, *m*=1 *n*≥7 (≡ *m*=-1 *n*≤-7). Those portions of the spectrum are in fact very similar in shape with a dominat *n*=7-8 and a broad tail extending up to high *n* numbers. In figure 4 this effect, though still present, is partly hidden by the fact that the maximum amplitude is reached at different points for the various modes.

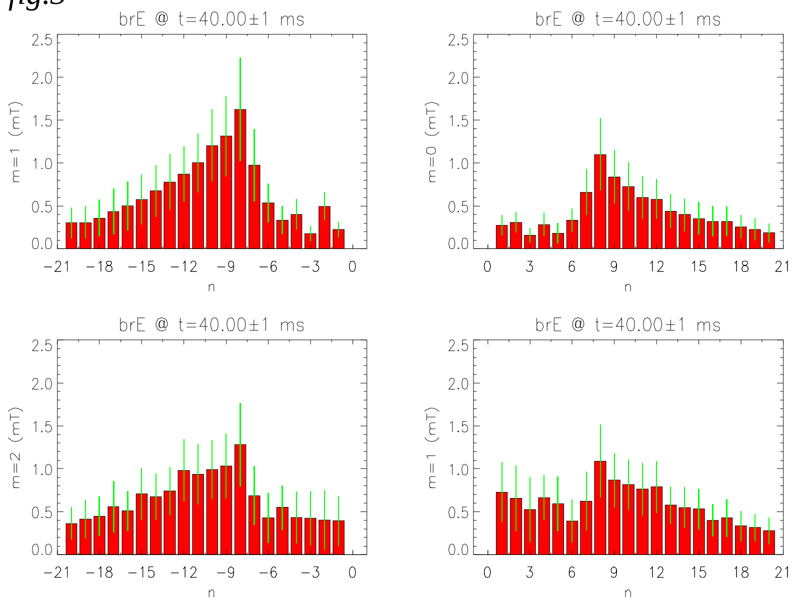
In figure 4 the amplitudes of the *m*=1 1≤*n*≤5 harmonics are very high compared to the edge value reported in figure 3 for the same modes: this implies a decreasing *br* radial profile, like that of the *m*=1 *n*=4 mode shown in figures 1,2, and suggests that these harmonics could be RWMs.

fig.2



Note that the *m*=1 amplitudes of figure 4 look like the spectrum predicted by DEBS, reported in figure 5 (here the volume integrated energy for *br* is shown; the values are normalized to the maximum one). The theoretical spectrum is narrower than the experimental one, possibly due to the low $S=10^4$ (the Lundquist number), the discard of pressure effects, and the absence of any external error field in the simulation. In particular the latter could be an important source of energy for the modes in the real situations. In figure 4 the *m*=2 spectrum highlights the internally resonant *n*=-14,-15,-16 modes. In fact, when the *m*=2 harmonic is resonant, its radial profile is peaked at the resonance with a value much greater than the edge one. Note that the *m*=2, *n*=-14,-16

fig.3



harmonics share the same resonant surfaces of the dominant *m*=1 *n*=-7,-8 dynamo modes respectively (so they are their non-linear overtones), and that the resonance of the *m*=2, *n*=-15 lies between them. These *m=2* harmonics are predicted also by DEBS though with smaller amplitude.

As final observation we underline that at t=10ms the edge *br* is negligible, while the *br_max* spectrum already shows important modes with amplitudes about 2-3mT, in particular the internal *m*=1 tearing modes and the *m*=1, *n*=4 non resonant mode.

fig. 4

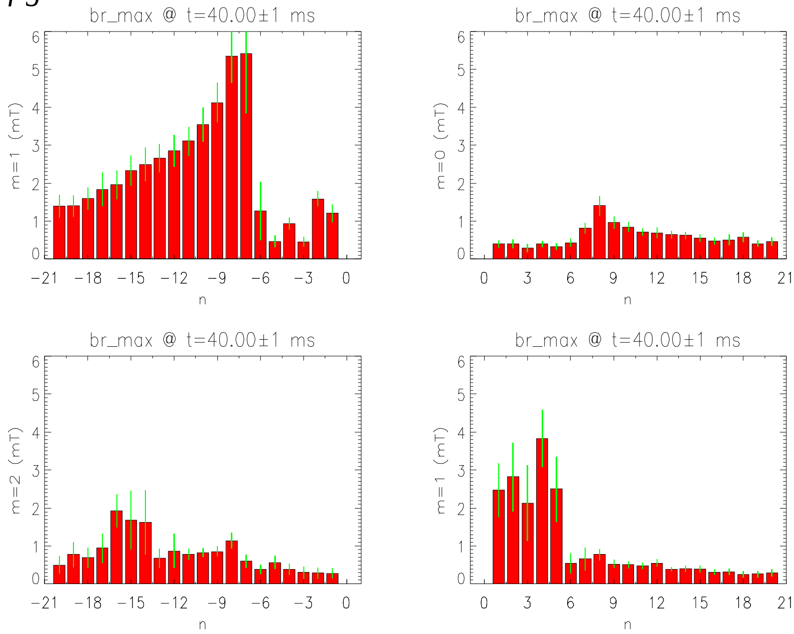
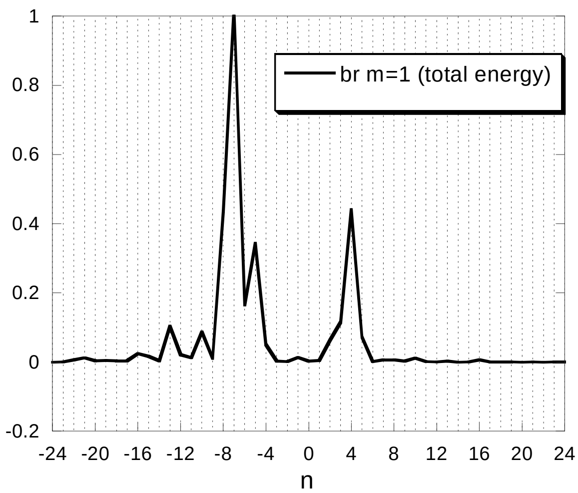


fig 5



References

[1] S. Ortolani and D.D. Schnack, *Magnetohydrodynamics of Plasma Relaxation*, (World Scientific, Singapore, 1993)

[2] H.P. Furth, J. Killen and M.N. Rosenbluth, *Phys. Fluids* **6** (1963) 459

[3] J.Finn, R.Nebel, C.Bathke, *Phys. Fluids* B **4** (5) (1992) 1262; S.Cappello, R.Paccagnella, *Phys. Fluids* B **4** (3) (1992) 611

[4] Z.X.Jiang, A.Bondeson, R.Paccagnella, Phys.Plasmas **2** (2) (1995) 442

[5] R. Fitzpatrick, P. Zanca *Physics of Plasmas* **9** (2002) 2707

[6] P. Zanca, D. Terranova *Plasma Phys. Control. Fusion* **46** (2004) 1115

[7] D.Terranova, P.Zanca, Proceedings ICPP (2004)

[8] G. Rostagni, *Fusion Eng. Design* **25** (1995) 301

[9] D.D.Schnack, *et al*, *Comput. Phys. Comm.* **43**, 17 (1986)

[10] C.Gimblett, *Nuclear Fusion* (1986). B.Alper, *Plasma Phys. Control. Fusion* (1989)

Acknowledgement This work was supported by the European Communities under the contract of Association between EURATOM/ENEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission