Dynamo and Superthermal Electrons in RFX

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1. Introduction.

In the Reversed Field Pinch (RFP) configuration [1] the toroidal magnetic field at the wall $B_t(a)$ is in the direction opposite to the on axis toroidal field $B_t(0)$ and this B_t reversal can be achieved spontaneously and maintained against resistive diffusion. The sustainement of the magnetic field profiles implies the existence of a toroidal flux Φ regeneration mechanism internal to the plasma. The most important models that have been proposed and developed to describe this regeneration mechanism, usually called "dynamo", fall under two main categories; the kinetic dynamo theory (KDT) [2] and the MHD dynamo [3]. The KDT relies on the diffusion of energetic electrons, which escape from the core of the plasma following the wandering field lines of that highly stochastic region; once these so-called superthermal electrons reach the edge, they carry a substantial part of the current required to sustain the configuration [4]. According to the MHD dynamo, on the contrary, the configuration is the result of the dynamic interaction of a wide spectrum of low frequency coherent magnetic fluctuations, which create an electromotive force along the magnetic field through their non-linear coupling with the fluctuations of the plasma velocity; in this context the superthermal electrons could be generated in the regions where the reconnection of the fields, associated with the resistive tearing instabilities, takes place [5].

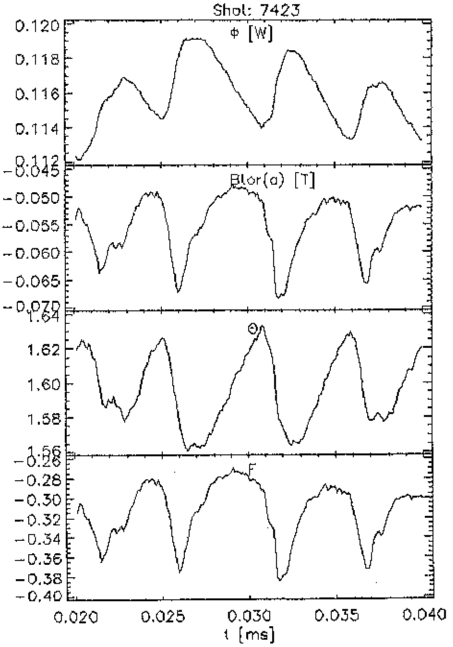

Fig.1: Discrete dynamo events in RFX

Discrete dynamo events (fig.1) have been detected in various RFP machines, particularly when they are operated at high Θ, a parameter defined as $\Theta = \pi a^2 \; B_p(a)/\Phi$ (here

$B_p(a)$ indicates the poloidal component of the magnetic field at the wall) and that is normally used together with the parameter $F = \pi a^2 B_t(a)/\Phi$ to describe the RFP configuration. The main purpose of this paper is to present the results of a high Θ experimental campaign of the RFX experiment [6] dedicated to the investigation of these discrete dynamo events. The trends of the various plasma parameters during the periodic oscillations have been studied with the help of several diagnostics: a set of 72 external magnetic coils, a 48 channels soft X rays (SXR) tomography, a 36 channels bolometric tomography calibrated absolutely, an electrostatic Electron Energy Analyzer (EEA) [4] and Langmuir probes. It is worth mentioning that all the discharges of the present database were affected by local stationary deformations of the main magnetic field normally referred to as "locked modes" [7]; on the other hand, since the discrete dynamo is generally less strong and therefore more difficult to detect in normal RFX discharges ($\Theta \cong 1.45$) [8], during this campaign the machine has been operated at high Θ (about 1.6). The obtained measurements provide a quite complete description of the evolution of the magnetic profiles and of its effects on the thermal quantities and also allow to insert the superthermal electrons behavior in the global picture of the discrete dynamo oscillations.

2 Experimental Evidence.

Evolution of the Magnetic Quantities

The typical time evolution of the magnetic quantities during a 600 kA, high Θ discharge of RFX is shown in fig.1, where several quasi-periodical oscillations of the quantities Φ, $B_t(a)$, Θ, and F are presented. The diffusion phase, which is characterized by a reduction of the total flux Φ and of the reversal ($B_t(a)$ becomes less negative) on a time scale of a few ms, is followed by a sudden (of the order of 1 ms) regeneration of the toroidal flux (often called relaxation phase) and the deepening of the reversal ($B_t(a)$ becomes more negative).

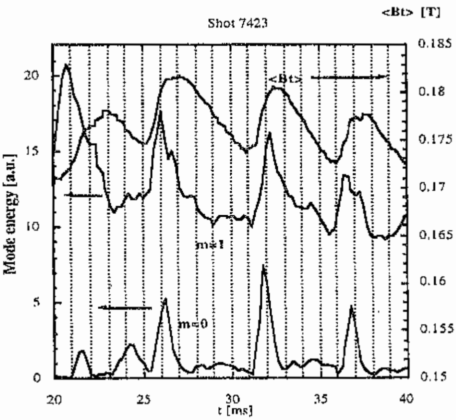

Fig.2: Evolution of the mode energy

With regard to the evolution of the MHD instabilities (fig.2), the energy in the toroidal component of both the m = 0 and the m = 1 modes, measured in the frequency range between 100 Hz and 5 kHz and between 0 and 5 kHz respectively, remains quite stationary during the diffusion phase and presents a sudden positive jump when the flux is regenerated. It is worth mentioning that at slightly lower values of Θ (around 1.55), the m = 0 modes show the tendency to increase after the m = 1 modes, whereas in the more common case of Θ ranging between 1.45 and 1.5 the phenomenology is more varied.

The oscillations of the m = 1 modes, which do not rotate in the laboratory frame and are the ones that form the static local distortion of the main field, constitute an interesting new piece of evidence, proving the role played by locked modes in the discrete dynamo events. On the other hand, the strong dynamic evolution of the m = 0 modes at the moment of the flux regeneration confirms the assumption that the edge region, close to the presumable resonance location of these modes, is strongly affected during the relaxation phase.

Radiation and Temperature

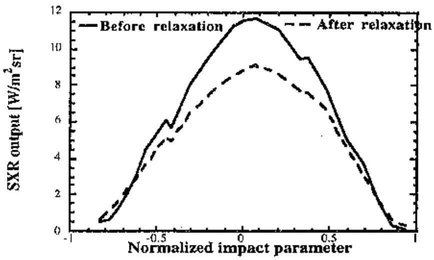

Fig.3: Integrated SXR profiles

As far as the thermodynamic quantities are concerned, the on axis electron temperature $T_e(0)$, determined with the double-foil technique, increases during the diffusion phase whereas the total radiation remains quite low (between 5 and 10 % of the input power); a sudden drop of the on axis temperature and a simultaneous increase of the total radiation are on the contrary typical of the interval in which the magnetic flux is regenerated [8]. With regard to the measured profiles, the SXR emission is higher and more peaked at the center during the first stage of the cyclical evolution (see fig.3 where a simple linear fit of the raw data is shown), whereas at the moment of relaxation the profiles are flattened and in several cases there is some evidence of an inversion radius at the plasma edge, where several instabilities are believed to resonate. The total radiation profiles are also remarkably modified by the discrete events; after relaxation indeed, even if the emissivity remains strongly peaked at the edge, the profiles appear more symmetric poloidally (the peak in the outer region of the equatorial plane is less relevant) and the emission from the plasma core can be higher than in normal stationary conditions.

Superthermal Electrons and Edge Density

The regeneration of the total magnetic flux coincides with a strong rise of the superthermal electron flux, as shown in fig.4, where the signal measured with the EEA at fixed repeller voltage is reported: the current associated with these superthermal electrons is estimated to increase up to a factor of two above a stationary level, which is always present also in the absence of periodic oscillations. The strong variation of the superthermal electron flux during the regeneration proves that these electrons are deeply influenced by the dynamics of the discrete dynamo. On the other hand the present experimental evidence does not allow to

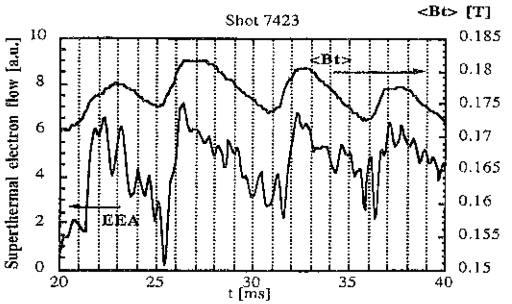

Fig.4: Flux of superthermal electrons

determine if they are generated locally or transported from the core. In any case, the rapid jump of their flux at the moment of relaxation seems to suggest a strong emission of particles toward the wall, an interpretation that is also sustained by the increase of both the H_α emission and the electron density at the edge. Moreover these measurements confirm that the superthermal electrons can play a significant role in the power balances of RFX, particularly during the regeneration phase of the coherent oscillations, when they can constitute a significant loss channel.

Conclusions.

The reported measurements allow a phenomenological description of the global magnetic and thermodynamic behavior of RFX plasmas during the cyclical oscillations. The usual phenomenology of both the magnetic and the thermodynamic quantities ([3], [8]) has been proved to coexist with locked modes. In particular it has been shown that the m = 1 modes, which form the stationary deformation of the mean fields, are strongly involved in the discrete dynamo events. On the other hand, the strong dynamics of the m = 0 modes indicates that, unlike tokamak saw-teeth, the edge region is deeply affected during the regeneration of the toroidal flux. Besides, the relaxation phase is contemporary to a remarkable increase of the flux of superthermal electrons, whose origin on the other hand has not been identified yet, leaving open the issue whether they are the result of the kinetic or the MHD dynamo. In any case, the superthermal electrons could constitute a significant power loss channel, particularly at low density operation, when their energetic role is believed to be higher.

References

[1] H.A.B.Bodin, Nucl.Fusion **29**, 1717 (1990)

[2] A.Jacobson and R.Moses Jr., Phys.Rev. A **29**, 3335 (1984).

[3] S.Ortolani and D.Schnack, *Magnetohydrodynamics of plasma relaxation*,.World Scientific, Singapore, 1993.

[4] Y. Yagi, V. Antoni, M. Bagatin et al., *Proc. 23rd Eur. Conf. on Contr. Fusion and Plasma Phys*, Kiev, 1996 (European Physical Society, Geneva, 1996), **20C**, **Part II**, p.707.

[5] M.Erba et al., Nucl.Fusion **33**, 1577 (1993).

[6] R.Fellin et al., Fusion Engineering and Design, **25**, (1995).

[7] V.Antoni et al.*in Proc. 22nd EPS Conf. on Contr. Fusion and Plasma Physics*, **19 C part IV**, 181, Bournemouth, UK (1995).

[8] L.Marrelli, P.Martin, A.Murari et al, Int. Conf. on Plasma Phys., Nagoya, **1**, 974 (1996).