Alfvén Eigenmodes and magnetic reconnection in the RFX-mod reversed-field pinch plasma

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Reversed-field pinch (RFP) plasmas in the RFX-mod device [1], the largest RFP machine presently operating, have been recently shown to exhibit long wavelength (n=0) Alfvén eigenmodes (AE) in the MHz frequency range [2]. Indeed, the study of edge magnetic fluctuations, measured by means of an insertable probe housing arrays of three-axial magnetic coils, revealed the presence of coherent activity emerging as peaks from a turbulent background mainly in the power spectra of the poloidal field signals. The Alfvénic nature of these peaks was deduced by the linear relation between their frequency and the Alfvén velocity v_A (= $B/(\mu_0\rho)^{1/2}$, ρ being the mass density) in a wide range of plasma parameters, in terms of plasma current I_p (0.3 -1.8 MA) and electron density n_e (0.5 – 8 x 10^{19} m^{-3}).

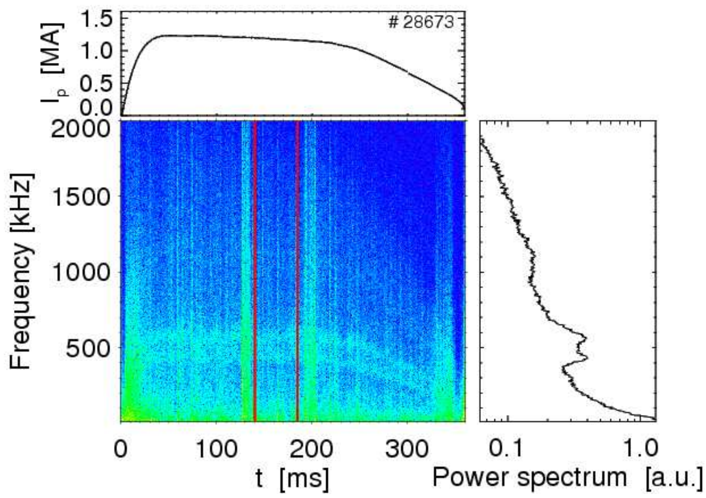

Figure 1*: Typical spectrogram (colour coded) of a dB_p/dt signal (left panel; right) power spectrum of the same signal evaluated in the time window delimited by the vertical (red) lines over plotted in the spectrogram; top) time trace of I_p.*

In particular, in the magnetic fluctuation spectra, two (broad) coherent peaks are found to be present simultaneously, as can be seen in the example proposed in Figure 1, where a spectrogram (i.e. frequency power spectrum *vs* time) of a poloidal field sensor signal (dB_p/dt) is shown in a colour coded contour plot. The power spectrum, evaluated in the time window delimited by the vertical red lines, where the frequency of the modes remains almost constant) is also given. The experimental wavevectors k_1 and k_2 for the two modes, deduced as $k_{i=1,2}=2\pi f_{i=1,2}/ v_A$, being f_1 and f_2 the two mode frequencies, had been estimated to be about 2 and 2.5 m^{-1}, respectively [2]. The relation between the time behaviour of the coherent magnetic activity and I_p in the top panel of Figure 1 (i.e. the magnetic field strength at the edge of a RFP) is also clearly visible.

Previous measurements [2], based on the use of the two-points technique on two signals from toroidally closely spaced probes, allowed us to associate to the observed modes a toroidal mode number n=0, and a good agreement was found between the observed frequency and the minimum of the shear Alfvén continuum $\omega(r)=k_{//}(r)v_A(r)$ for a m/n=1/0 mode structure. In such plasma region the continuum damping would not be effective. On the basis of this result an interpretation of the observed modes in terms of global Alfvén eigenmodes (GAE) had been proposed [2].

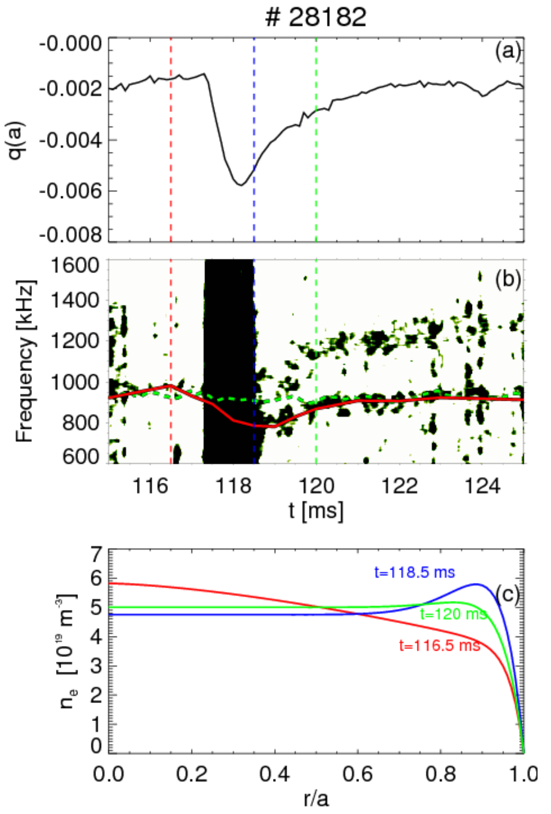

Figure 2: a) time behaviour q(a) during a single reconnection event; b) spectrogram of dB_p/dt. The green dashed line represents the frequency expected for a m/n=1/0 mode by considering the density value averaged over central chord in the calculation of v_A. Red line is the time behaviour of the minimum of the Alfvén continuum; c) density profiles at three different time instants.

In the present work, a detailed analysis of the effect of the discrete magnetic reconnection events characterizing RFP plasmas on Alfvén eigenmodes is presented.

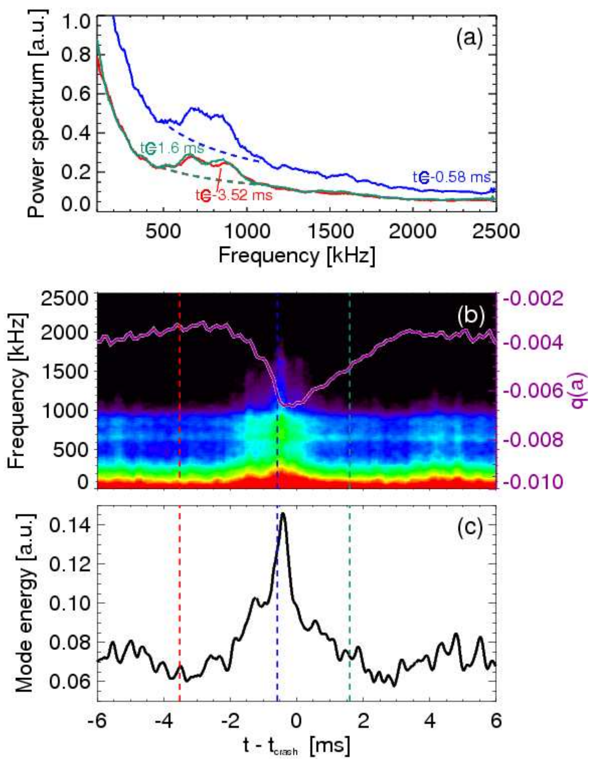

Figure 3: a) Power spectra of a dB_p/dt signal at three instants. b) Spectrogram obtained by averaging different time intervals centred on reconnection events (the solid line represents the averaged q(a) referring to the y-axis on the right). c) Time evolution of the mode energy.

Indeed, RFP plasmas are known to be characterized by the cyclic occurrence of discrete magnetic reconnection events, associated to a relaxation of the magnetic profiles (crashes) and the rapid generation of poloidal current sheets at the plasma edge [3]. Such current sheets have been observed to form in toroidally localized positions and then to rotate along the torus at about 20 km/s. In their movement, current sheets have been observed to strongly affect both the magnetic and the kinetic (n_e and T_e) edge plasma properties.

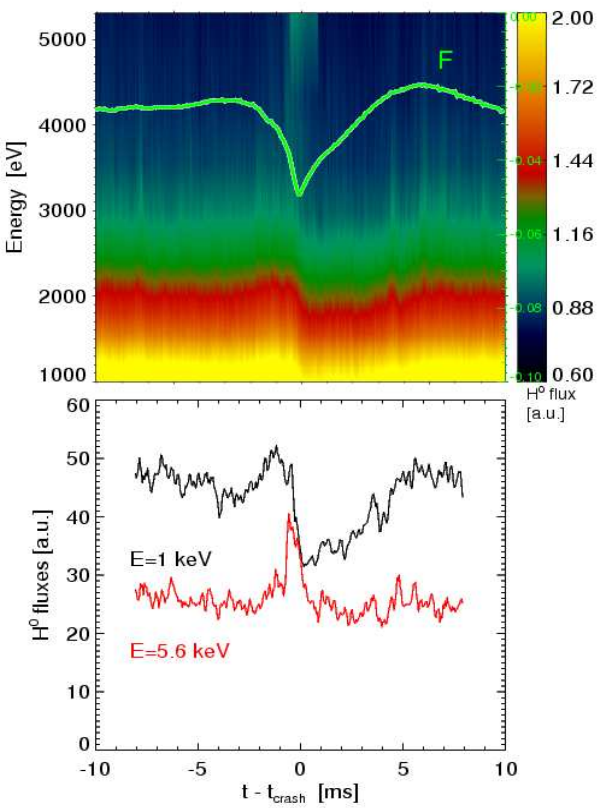

Figure 4: *Contour plot of the H^0 fluxes collected by the NPA during magnetic reconnection events. Bottom: time trace of two signals of the NPA.*

The occurrence of a discrete reconnection event is here shown to have strong impact also on the Alfvénic fluctuations, as can be deduced by Figure 2, where a detailed variation with time of the mode frequency is well correlated to the edge safety factor *q(a)* behaviour for a single event. In particular, modes frequency immediately after the reconnection event is considerably lower than that measured before it, and a recovering of the original frequency values occurs only after few milliseconds. In Figure 2b) the dashed green line indicates the frequency value $f = (k/2\pi)\ v_A$, estimated by using in the evaluation of v_A, for the density value, the quantity $<n_e>$, averaged over a central chord. The dynamical behaviour of the frequency at reconnection seems to be not well represented by such a quantity. The red line, which, instead, is in perfect agreement with the experimental frequency, is the value expected by the evaluation of the minimum of the Alfvén continuum for the m/n=1/0 GAE, when the time variation of the density profile is also taken into account. Actually, as can be seen in Figure 2c) density profiles are mostly affected at the plasma edge, r/a=0.9 (as already previously described in the RFP literature [4]), where a peak in the density profile appears in coincidence of the reconnection event. This evidence, while suggesting a radial localization of the AE close to the plasma edge, further confirms the validity of the GAE hypothesis.

Reconnection events have been observed not only to have an influence on the modes frequency, but also on their amplitude. In particular, as shown in Figure 3c) as the result of conditional averaging process over a number (~10) of reconnection events a strong time correlation is found between the maximum of modes energy and the minimum of *q(a),* plotted in Figure 3b) along with a spectrogram of a magnetic signal. The energy associated to Alfvén activity has been evaluated by integrating the power spectra at each time instant over the frequency of the two peaks. As reconnection processes induce a (yet not understood) growth of the fluctuation at all frequencies, such integration has been performed after subtracting the fluctuation background, represented by the dashed lines obtained by an interpolation of the spectrum-broad-band in terms of a frequency power law (Figure 3a). The growth of AE energy, above the turbulent background, indicates that reconnection is likely to stimulate a driving mechanism for this kind of magnetic instability.

Further, interesting, information in this sense derives by the analysis of the neutral H^0 fluxes leaving the plasma, collected by the NPA (Neutral Particle Analyzer) recently installed in RFX-mod [5]. In particular, as can be seen in Figure 4, reconnection events induce important modifications in the distribution function of the particles. At reconnection the lowest energy flux component is reduced, while a high energy (> 5 keV) tail forms. The origin of the generation of a non-Maxwellian H^0 fast population (deriving from charge-exchange processes with accelerated protons), is still under debate, but it is worth to note that such fast particles, being in some cases super-Alfvénic, could, in principle, be able to induce an inverse Landau damping mechanism for AE destabilization.

Further analysis and experimental investigation of the neutral fluxes at higher energy levels, along with theoretical modelling, would be, however, mandatory in order to support this hypothesis and to investigate the relation of such phenomenon with the ion heating due to reconnection observed in the RFP plasmas of the MST device [6].

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