Alfvén Eigenmodes in the RFX-mod reversed-field pinch plasma

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High frequency magnetic activity has been detected at the edge region of the RFX-mod reversed-field pinch (RFP) device (*R/a=2m/0.459m*) [1]. The analysis performed by means of an insertable edge probe, measuring the magnetic field fluctuations, shows coherent modes at a frequency in the range 0.1÷1.5 MHz, depending on the Alfvén velocity. Almost two kinds of modes have been distinguished in the experimental observations and a preliminary interpretation in terms of n = 0 Global Alfvén Eigenmodes and Reversed-Shear Alfvén Eigenmodes is proposed.

In the analyzed discharges, the plasma current I_p has been varied in the range 0.3÷1.8 MA and the electron density n_e in the range 0.5÷10×10^{19} m^{-3}. An insertable edge probe, named U-probe, measures the fluctuations of all the magnetic field components (toroidal B_t, radial B_r and poloidal B_p) in different radial and toroidal positions. For the measurements here presented, the probe was located at r/a~1.04 and the sampling frequency set up to 10 MHz.

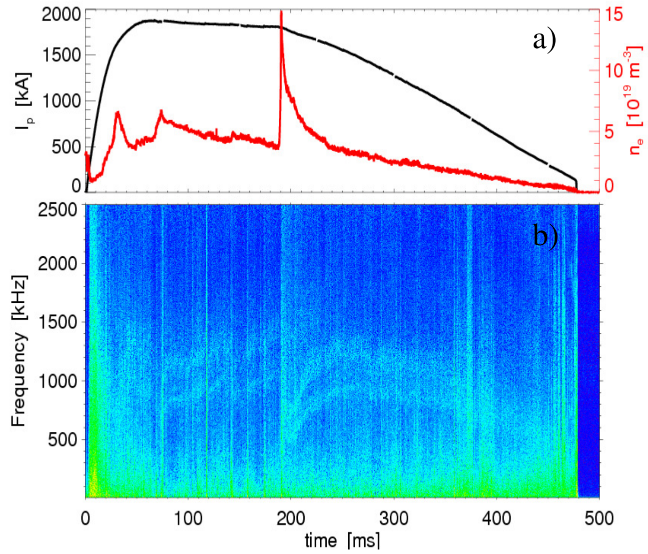

Fig. 1: a) the time evolution of plasma current (black line) and electron density (red line); b) the spectrogram of $\dot{B}_p$ signal (two coherent magnetic activities are found).

As well known by ideal MHD, shear Alfvén waves in an inhomogeneous plasma have a continuous spectrum, whose dispersion relation takes the form $\omega_A(r)=k_{//}(r)v_A(r)$, r being the radial coordinate, $k_{//}=(m+nq(r))B_p/(rB)$ the wave vector component parallel to the magnetic field (where m and n are the poloidal and the toroidal mode numbers respectively, $B=(B_p^2+B_t^2)^{1/2}$ the total magnetic field and q the safety factor) and v_A the Alfvén velocity $v_A=B/(\mu_0\rho)^{1/2}$, ρ being the mass density. Wave energy is usually absorbed in the plasma by the *continuum damping* mechanism [2]; nevertheless a large variety of Alfvén Eigenmodes (*gaps* in the continuum) can be destabilized in non-uniform plasmas. In particular, shear Alfvén Eigenmodes can rise at the location of the frequency crossing of counter-propagating waves (e.g., TAE, EAE, HAE), or in the proximity of an extremum of the continuous spectrum (e.g., GAE, RSAE).

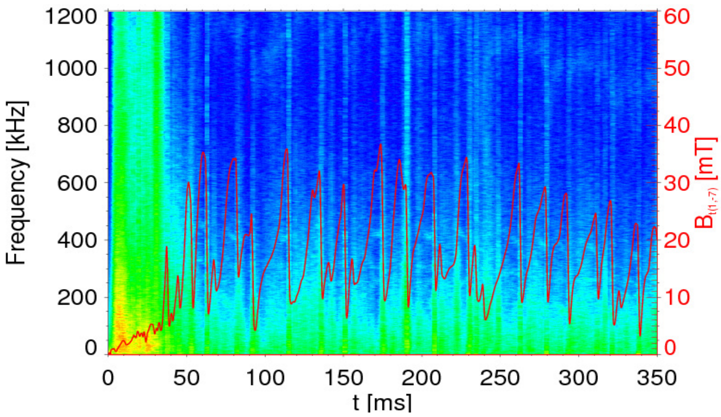

Fig. 2: The spectrogram of $\dot{B}_p$ signal. The red line is the (m,n)=(1,-7) toroidal magnetic field component.

The spectrogram of the time derivative of the poloidal magnetic field $\dot{B}_p$ shows some coherent magnetic activities: two close peaks enduring all the discharge at a frequency around 1 MHz (Fig. 1b) and one, whose appearance depends on the amplitude of the (m,n)=(1,-7) toroidal magnetic field component (Fig. 2), at a lower frequency. Observing the time evolution of the activities in Fig. 1, a clear dependence of their frequency on I_p ($\propto$ B(a)) and n_e is found,. The Alfvénic nature, suggested by the previous observation, is confirmed by an analysis performed in various experimental conditions (different I_p, n_e and working gases, H and He). In particular, as shown in Fig. 3, a linear relation is found between the measured frequency and v_A (i.e., $\omega=k\cdot v_A$). It is worth noting that the points group around three distinct k coefficients: this observation suggests that the three modes can be interpreted as Alfvén Eigenmodes [2]. One of the key elements to distinguish different Alfvén modes is the polarization of the magnetic field fluctuations. In particular, shear Alfvén waves are marked by a transverse polarization, which, for the RFP configuration, imply to observe B_t fluctuations larger than B_p ones; in our case instead, the coherent activity is observed only on the B_p component. In this respect, it must be said that the B_t component is characterized in RFPs by a large fluctuation level (mainly due to resistive kink-tearing and interchange [3] modes), so that it is difficult to recognize in the spectrum a coherent, but relatively weak, Alfvén mode; nevertheless, an interpretation as magnetoacoustic waves, that are longitudinal waves, cannot, in principle, be excluded.

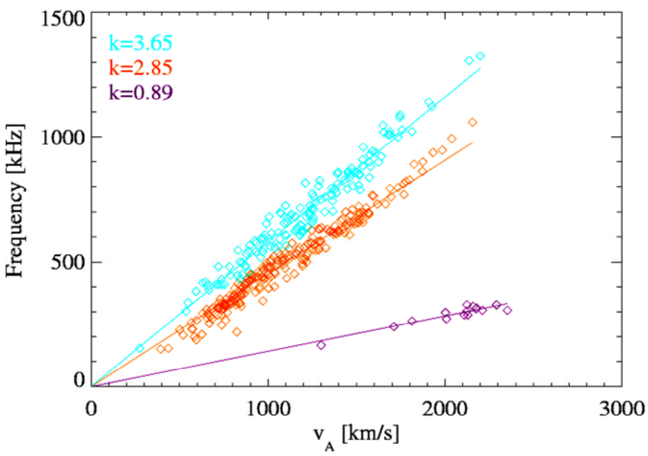

Fig. 3: Frequency of the three modes *vs* the Alfvén velocity v_A for a wide range of experimental conditions.

At this point, a preliminary analysis of the two modes having higher frequency in the $\dot{B}_p$ spectrum, that, despite their weakness, are one of the most common MHD activities observed in routine RFX-mod discharges, is presented. For the two highest frequency modes (the lower mode frequency is about 75% of the larger one), it has been seen (Fig. 3) that k~3 m^{-1}. For these modes a $n=0$ toroidal periodicity has been measured by means of two B_p probes located in two different toroidal positions, so that it can be deduced that the poloidal periodicity (not measured) associated to the peaks is likely to be $m=1$ (in the hypothesis $k=k_{//}$). The radial profile of the continuum of the shear Alfvén waves, in the form $f_A=\omega_A/2\pi=(k//v_A)/2\pi$, can be deduced using the radial profiles of the safety factor q, of the electron density n_e, and of the magnetic fields B_p and B_t, which are all shown in Fig. 4 for a typical RFX-mod discharge. A minimum in the $f_A(r)$ profile is observed, for the $(m,n)=(1,0)$ case, at a very edge position ($r/a\approx0.9$) and at a value close to the frequencies of the two experimental peaks (marked by the horizontal lines); at this site, strong continuum damping vanishes and an effective potential well can trap a wave. Despite the different magnetic topology, the experimental observations obtained are in very good agreement with those observed in TFTR [5] and theoretically explained in terms of Global Alfvén Eigenmodes (GAE) by L. Villard and J. Vaclavik in [4]. Finally, as explained in [4], the presence of a double $(m,n)=(1,0)$ peak is due to the quantization condition of the wave vector radial component k_r, the two eigenfrequencies being localized in different radial positions.

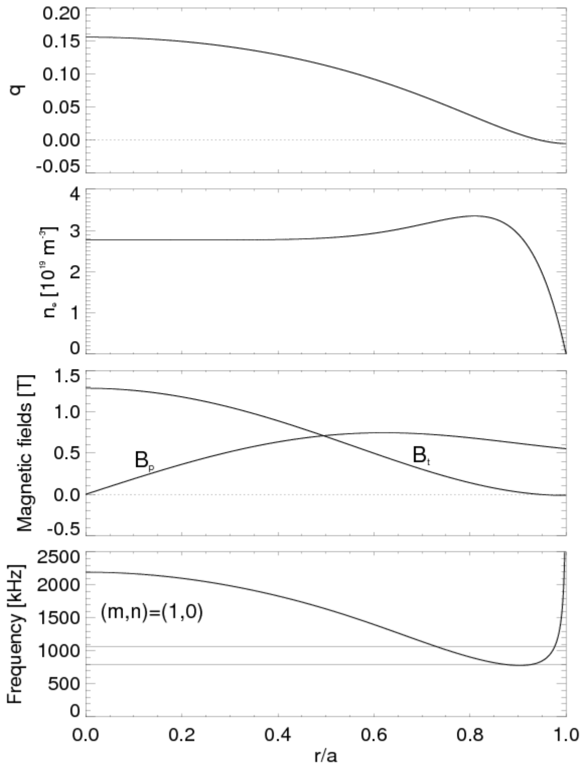

Figure 4: Radial profiles of the safety factor *q*, of the magnetic fields B_t and B_p, of the electron density n_e, and of the Alfvén frequency f_A for the *(m,n)=(1,0)* periodicity (continuous horizontal lines represent the measured mode frequencies).

The other Alfvénic activity, characterised by a frequency (~ 400 kHz) lower than those of the aforesaid modes, has been found only in high plasma current discharges. As it is evident from Fig. 2, the presence of the mode is discontinuous in time, being strictly related to the time evolution of magnetic equilibrium. High plasma current discharges in RFX-mod are characterised by the spontaneous transition to a helical equilibrium, the Single Helical Axis state (SHAx) [6], characterized by one MHD mode, *(m,n)=(1,7)*, dominating over the other (secondary) ones, and by a reduced magnetic chaos. The SHAx states are not continuous, but intermittently interrupted by rapid transitions to the so called multiple helicity state (MH). In Fig. 5 two power spectra of $\dot{B}_p$ are shown obtained in different magnetic topologies (MH and SHAx). It is worth noting that, while the modes interpreted as GAEs are continuously present during the discharge, the peak at 400 kHz appears only in the SHAx states. An interesting observation is that SHAx states are associated to the presence of a maximum in the *q* profile, plotted in Fig. 6 against the proper spatial coordinate in a helical equilibrium, ρ, the square root of normalized helical flux, χ. In this case, the absence of magnetic shear at q_{max} recalls the condition of the reversed shear tokamak plasmas, where the *q* profile has a minimum. It is well known that in reversed shear plasmas, the so-called Reversed Shear Alfvén eigenmodes (RSAE) can rise at the location of the minimum of the *q* profile [2]. It is interesting to note that in RFX-mod, during the SHAx states, a minimum in Alfvén frequency profile is found, whose spatial position correspond to the maximum of *q*, and that for some proper helical mode number values (at the moment not measured), the frequency of the minimum is comparable to that experimentally observed (Fig. 6).

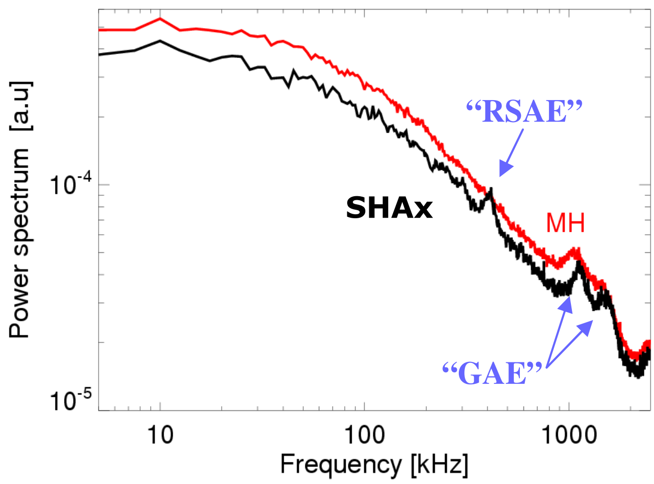

Fig. 5: Power spectra of $\dot{B}_p$ for the different topologies.

In conclusion, a variety of coherent Alfvénic modes have been observed for the first time in RFX-mod by means of insertable edge probes. Further efforts are needed to confirm the proposed interpretation in terms of GAE and RSAE.

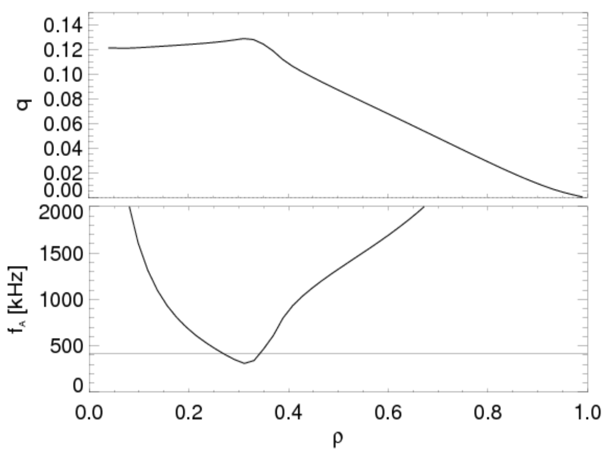

Fig. 6: The *q* profile (a) and the Alfvèn frequency (b) *vs* ρ in SHAx state

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