Characterization of Alfvén Eigenmodes in RFX-mod plasmas

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Alfvén Eigenmodes (AE) have been detected at the edge region of the RFX-mod reversed-field pinch (RFP) device (*R/a=2m/0.459m*) [1], in purely ohmically heated plasmas. The analysis of magnetic field fluctuations, measured by an insertable edge probe, shows the modes to occur at a frequency in the range 0.1÷1.5 MHz, strongly depending on the Alfvén velocity. Almost two kinds of AE are distinguished, one recognized as Global Alfvén Eigenmodes (GAE) [2] and the second, arising only during Quasi Single Helicity (QSH) states [3], whose nature is under study.

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 the total magnetic field and q the safety factor) and $v_A=B/(\mu_0\rho)^{1/2}$ the Alfvén velocity, ρ being the mass density [4].

The experimental observations of AE in RFX-mod are provided by the insertable U-probe, measuring the fluctuations of all the magnetic field components (toroidal B_t, radial B_r and poloidal B_p) in different radial and toroidal positions. It can be inserted in the edge plasma region up to 5 cm. The sampling frequency is set up at 10 MHz. A wide range of plasma conditions are considered in this analysis: the plasma current I_p varies in the range 0.3÷1.8 MA, the electron density n_e in the range

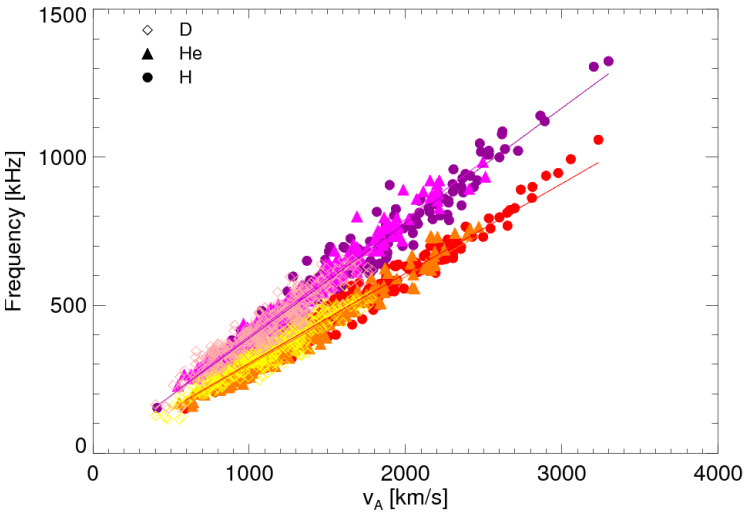

Fig. 1 GAE frequency *vs* the Alfvén velocity v_A for three different working gases and a wide range of experimental conditions.

$0.5 \div 10 \times 10^{19}$ m^{-3} and the reversal parameter $F=B_t(a)/\langle B_t \rangle$ up to quite deep values (F>-0.2), even dynamically by Oscillating Poloidal Current Drive (OPCD) [5], a method to reduce the spontaneous dynamo process in RFP plasmas by modifying the toroidal magnetic field at the edge. The last is in order to investigate the role of the equilibrium in the mode destabilization. Figure 1 exhibits the strong linear relation between the mode frequencies experimentally measured and the associate Alfvén velocities for the three kinds of gases, H, He and D. In the three cases, the modes detected present the same characteristics: they are two peaks at frequencies related by $f_1=1.25\ f_2$, lasting all the discharge time. Moreover, they all develop in correspondence to the minimum of the theoretical Alfvén frequency radial profile, characterized by (m,n)=(1,0) wave-numbers, thus with the same wave-vector (k≈1/a). On the other hand, the different working gas affects the estimation of the Alfvén velocity, since it depends on the ion mass density, evaluated in RFX-mod by the relation $\rho=Z_{eff}^{-1}\langle n_e \rangle A m_p$, where Z_{eff} is the effective ion charge, A the atomic mass number and m_p the proton mass. The measurement of the Z_{eff} in RFX-mod is not available at the moment, but collisional-radiative simulations states that $Z_{eff}=1.5$ for the Hydrogen case [7]. For He and D plasmas, the parameter has been evaluated fixing the wave-vector value and minimizing the angular coefficient of the linear relation with respect to the H case: $Z_{eff}(He)=3.45$ and $Z_{eff}(D)=1.72$. GAE are thus useful to extract information about Z_{eff} in RFX-mod plasma, technique known as MHD spectroscopy.

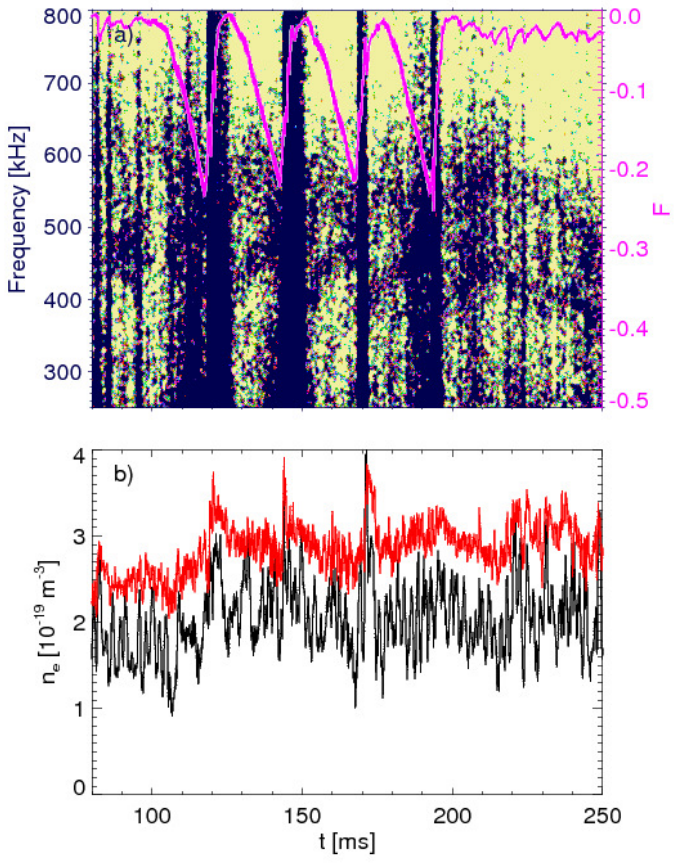

Fig. 2 a) Spectrogram of δB_p for a D discharge; the pink curve represents the F parameter. b) Electron density by an internal (black curve) and an external (red one) chord.

In the present contribution, particular attention has been devoted to discharges performed using Deuterium as working gas, recently adopted in the RFX-mod experiments instead of Hydrogen and Helium. Both of the AE branches above mentioned have been detected in D

plasmas, nevertheless the analysis presented here concerns the role of the equilibrium and of the density profile in the characterization of GAE. Further analysis is necessary to confirm that the experimental evidences observed for D discharges are present in H and He plasmas.

In Fig. 2a, a spectrogram of the poloidal component of the magnetic field fluctuation for a D discharge is shown. The reversal parameter behaviour (pink curve) highlights the nature of this discharge as OPCD.

In this case the frequencies of the modes are observed to oscillate in accordance with the F time evolution. As well known, the Alfvén frequency is mostly determined by the main magnetic field. Nevertheless, the oscillating behaviour of B does not justify the evident sweep in frequency: the role of the density is decisive. Fig. 1b shows the time evolution of the electron density $<n_e>$, taken as a line average on an internal (black curve) and an external (red curve) chord of the interferometric diagnostics. The density peaks, measured at the edge and caused by a strong plasma-wall interaction when F is very deep, are crucial to correctly reproduce the Alfvén frequency behaviour, since the modes are localized at the very edge. GAE are observed at any F value, nevertheless at deeper values, the magnetic spectrum is characterized by the presence of strong magnetic activities that could hide the weaker GAE fluctuations, if the frequencies are comparable (f≈50÷200 kHz) [6].

Moreover, the investigation of the edge plasma region by inserting the U-probe up to 5 cm, confirms the extremely edge radial position of the GAE fluctuation in RFX-mod plasma: no modes can be detected when the pick-up coil is inserted over *r/a=0.92*.

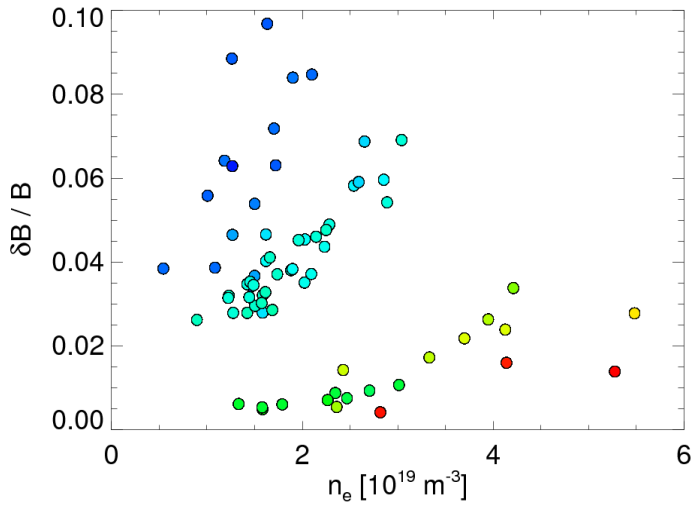

Fig. 3 Normalized AE amplitude *vs* electron density. The color indicates the relative plasma current: the blue dots represent the lowest values, around 400 kA, cyan ones are around 600 kA, green ones around 800 kA, yellow ones around 1000 kA and red ones around 1350 kA.

Some analyses have been performed to evaluate the role of the density profile and of the equilibrium in the characterization of GAE in RFX-mod. Beyond the known effect in determining the Alfvén frequency profile [2], the density profile plays an important role in the destabilization of the modes.

An analysis of the AE amplitude in D discharges shows a clear linear relation with the electron density and that the dependence is stronger at lower plasma currents. Fig. 3 summarizes the

experimental observation, where AE normalized amplitude, averaged over the plasma current flat-top phase, is plotted against the relative electron density. The dots color indicates the associate plasma current level: from 311 kA (blue) and 1351 kA (red dots). Despite the different magnetic topology, this experimental observation is in very good agreement with those emerged in TFTR tokamak plasma (in particular, Fig. 10a of Chang *et al.* [8]).

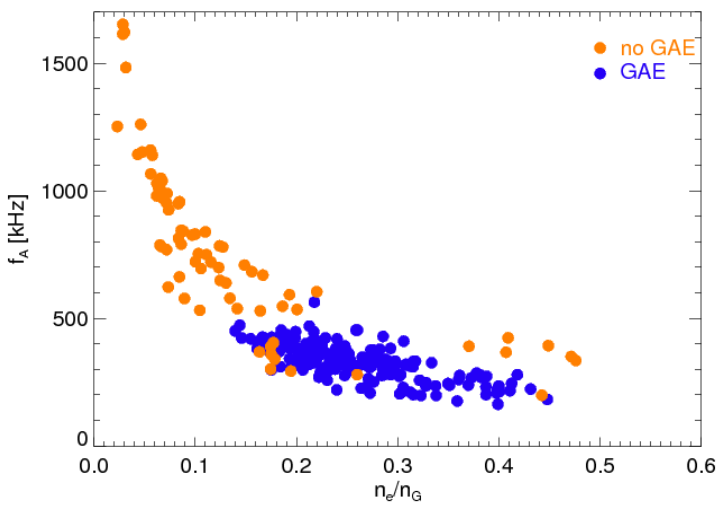

Fig. 4 Measured (blue) and expected (orange) Alfvén frequencies in D discharges vs n_e/n_G

Moreover, a sort of density threshold has been observed. A statistical analysis on about 300 D discharges has been performed to investigate this point. Fig. 4 shows the Alfvén frequencies measured (blue dots) and those theoretically expected but not observed (orange dots). It is worth noting that no GAE are observed at n_e/n_G values lower than 0.15.

These analyses highlight the fundamental role of the density, or of other physical quantities related to it e.g. collisionality, resistivity, in exciting these modes. This point is of particular interest since the RFX-mod plasma is exclusively ohmically heated, so the presence of fast particles, generally considered responsible to excite AE by inverse Landau damping, is not ensured by the neutral beam injectors. Experiments are in progress with the aim to estimate the contribution of magnetic reconnection events (at various scales) in the acceleration of particles to Alfvénic velocities. Some preliminary results obtained by measuring the neutral fluxes at different energies by the Neutral Particle Analyzer, showed the presence of a high energy tail during big reconnection events. Moreover, a new diagnostic tool has been recently installed in RFX-mod in order to gain the ion distribution function.

Acknowledgements: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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