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ELM-related High Frequency MHD Activity in ASDEX Upgrade

T. Bolzonella[1], E. Martines[1], M. Maraschek[2], H. Zohm[2], S. Günter[2], S. Saarelma[3],
and ASDEX Upgrade Team

[1] *Consorzio RFX, Associazione Euratom-ENEA sulla Fusione, I-35127, Padova, Italy*
[2] *Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748, Garching, Germany*
[3] *Helsinki University of Technology, Euratom-TEKES Association, FIN-02015 HUT, Finland*

Introduction: Edge-Localized Modes have been identified since the discovery of H-modes in tokamak plasmas. ELMs can be seen as a temporary breakdown of the edge transport barrier typical of Hmodes leading to fast expulsion of plasma particles and energy [1, 2]. Several models have been proposed to explain the main characteristics of the ELM cycle [3], including the interpretation of fluctuating quantities observed in conjunction with ELMs. ELM-related magnetic fluctuations play an important role in these models since they can act as trigger or precursor of the fast transport phase. We present a systematic study of fast ($0.1< f <1.2$ MHz) magnetic fluctuations that were found to be related to type I ELMs on ASDEX Upgrade.

Experimental setup: A new set of magnetic pickup coils has been recently installed at ASDEX Upgrade to study fast MHD phenomena. It is made by 14 Mirnov coils measuring the fluctuations of the radial magnetic field component, and sampled at frequencies up to 10 MHz. The coils are located on the low field side of the vessel, covering an angle of approximately 60° centered on the outer equatorial line. They are then a very useful diagnostic tool to improve the understanding on high frequency MHD phenomena related to the ELM cycle, where fast time scale are expected as well as high local poloidal mode numbers. For this study the sampling was set to 2.5 MHz (5 MHz for a smaller set of discharges), allowing the investigation of modes with frequencies up to 1.25 MHz (2.5 MHz); the acquisition time window was correspondingly set to 400 ms (200 ms). Tests at higher frequencies showed a substantial filtering effect of the acquisition chain and of the metallic boundaries close to the location of the coils.

Other diagnostic systems are used in this study to correlate magnetic data to the ELM cycle and to calculate plasma stability properties, mainly data from edge Thomson scattering system for electron temperature and density, DCN interferometer for electron density, and diode arrays for H_α signals in the divertor region. Very promising results were obtained from preliminary comparisons between fast magnetics and reflectometry data [4].

ELM type I-related MHD activity during the H-mode Standard Shot: Medium frequency (*f* ≈ 75-120 kHz, *n* ≈3 - 6) coherent magnetic fluctuations prior to type I ELMs were already described during co-injected discharges in ASDEX Upgrade [5]. For this study we choose to characterize first a well-known and reproducible experimental situation. In ASDEX Upgrade the best choice is the so called “H-mode Standard Shot”, a discharge that is run at the beginning of every experimental session to test day to day changes on the machine conditions. The setup of the discharge was studied to provide data on the L-H transition and on confinement properties at different densities. Typical values of plasma and heating parameters are: I_p=1 MA, B_t=2 T, $q_{95} \approx 3$, low triangularity ($\delta_{bot} \approx 0.35$, $\delta_{top} \approx 0$), single-null configuration, 2 steps in NBI power injected (2.5 and 5 MW), a “normal” and a high electron density phase, with average values of respectively 4 10^{-19} m^{-3} and 7-9 10^{-19} m^{-3}. The reproducibility of this discharge allowed us to move the acquisition time window in order to obtain a detailed description of fast magnetic fluctuations in the different phases of the discharge.

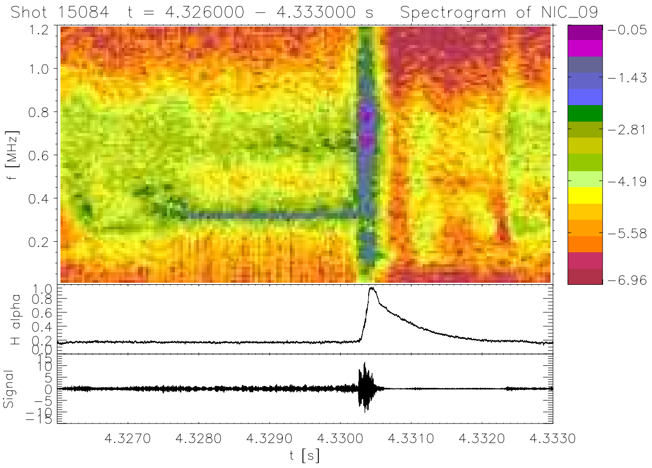
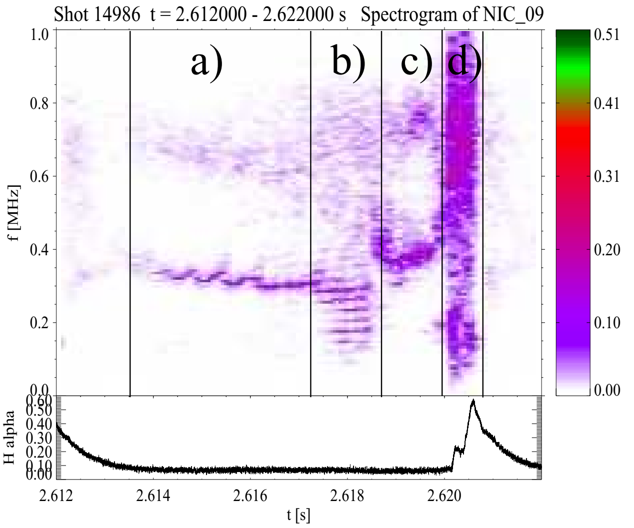


Figure 1. From the top: spectrogram of one high frequency magnetic signal (logaritmic scale and a.u. are used in the color bar), divertor H_α signal, and raw magnetic signal.

New types of fast MHD events clearly related to the ELM cycle are evident when spectrograms are plotted for the signal of a single probe. As an example, in Fig. 1 a time window of 7 ms centered on a type I ELM is shown. The spectrogram is presented together with a divertor H_α and the raw magnetic signal. A coherent mode at 320 kHz developing 3 ms before the H_α rise is clearly visible. Phase analysis of the whole set of probes gives for this discharge a poloidal mode number *m* ≈ 10-15. The transport phase is characterized by a turbulent spectrum where very high frequencies in the 600-800 kHz are dominant. During the slow decrease of the H_α signal, a phase of very low magnetic activity level is present. In general it is found that also less defined high frequency magnetic fluctuations centered around 400 kHz can be detected during the “normal” density phase and related to the type I ELM cycle. This kind of MHD activity appears more frequently when P_{NBI} = 2.5 MW, while well-defined modes are more common when the heating power is increased. No MHD events clearly related to ELMs are seen in the high density phase.

Other phenomenologies: A somehow different, more complex phenomenology is observed in discharges where some neutral beam heating power is already applied during the rise of the plasma current. In these shots the sequence of events shown in Fig. 2 is observed. Four different phases have been evidenced: a) the development of a sequence of up-chirping coherent modes, with frequencies around 300 kHz; b) a multi-mode phase, where several coherent modes, with constant frequency spacing, are present simultaneously, at frequencies up to 400 kHz; c) development of a 400 kHz broadband pre-ELM mode, similar to the one already described above for standard H-mode discharges; d) transport phase of the ELM. The modes observed in the multi-mode phase have been found to be internally resonant, with a ratio m/n ≈ 1.5. This result suggests a possible interplay between core (phases a and b in figure 2) and edge (phases c and d) MHD activity. These modes display a linear relationship between wave number and frequency, and have *m* numbers typically ranging between 2 and 7. They propagate in the electron diamagnetic drift direction.



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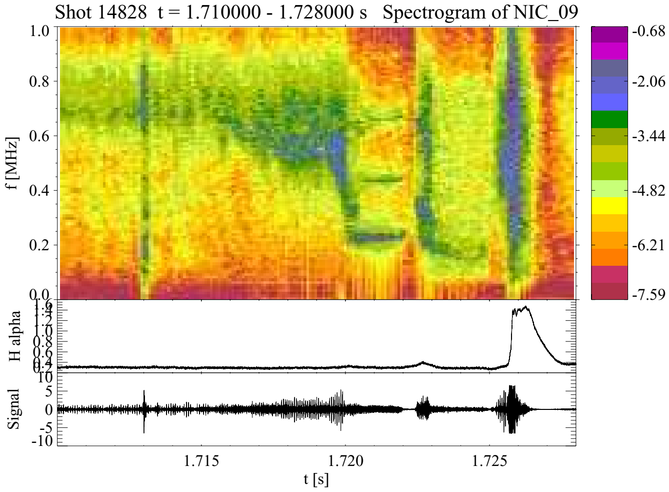

Figure 3. Spectrogram from shot 14986 (log. scale).

The edge safety factor has also important effects in determining the features of the pre-ELM events. In Fig. 3 is shown a spectrogram of the data measured in shot 14828, which was the only one in the database having q_{95} = 2.7 (all other discharges had $q_{95} \geq 3.1$). It is possible to see a large number of coherent modes, with constant frequency spacing. These modes at some point decay, giving rise to three modes that culminate in a sort of small transport phase (seen also on the H_α signal) preceded by a short very quiet phase. After this, the event is not over, and in fact after a while the real ELM occurs, as if only a small part of the stored energy had been released in the first transport event. The multiple modes observed at the beginning of the sequence can in fact be divided into two groups: low frequency (50-200 kHz) ones, which are similar to the ones described in previous paragraph, and propagate in the electron diamagnetic drift direction; and high frequency (300-700 kHz) ones, which have m=3-9 and propagate in the ion diamagnetic drift direction. The different direction could indicate that the second group is due to fast particles excitation.

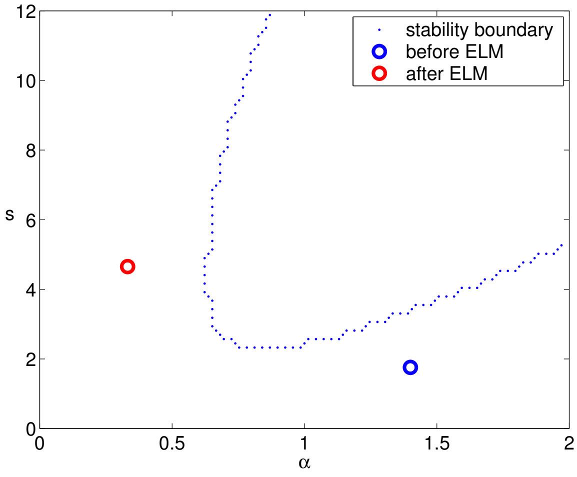

Figure 4. Ballooning stability at normalized poloidal radius ρ = 0.975 before (blue) and after (red) a type I ELM (shot # 15875).

Stability: Stability properties of the discharges under study were also investigated. Cross-checking data from fast magnetics spectrograms and edge Thomson scattering, time samples before the ELM crash, when the MHD modes are visible, and after, when coils signal reaches a minimum, were selected. The ballooning stability at the edge changes significantly as a result of an ELM (Fig. 4). Before the ELM, a narrow part of the edge plasma can access the 2^{nd} stable region due to lowered shear by the bootstrap current. This allows a very steep pressure gradient. After the ELM, edge plasma returns to first stable region. Consequently, also the pressure gradient is limited by the ballooning mode. Peeling mode stability calculations showed that peeling modes are no longer unstable just after the ELM.

Conclusions: A new class of fast MHD instabilities related to type I ELMs in ASDEX Upgrade is described and compared to ballooning stability calculations. More detailed comparison with other fast diagnostics and a better theoretical interpretation are in progress. Measurements of magnetic activity related to type II and III ELMs are at present under analysis.

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