Characterization of toroidal mode number of Edge Localized Modes in JET plasmas. Comparison between spontaneous and controlled ELMs

F.M. Poli[1], H.R. Koslowski[2], S.E. Sharapov[3], Y. Liang[2], and JET-EFDA Contributors[*]

JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK

[1]*University of Warwick, Coventry CV4 7AL, UK*

[2]*Association EURATOM-Forschungszentrum Julich, Institut fur Plasmaphysics, Trilateral Euregio Cluster, D-52425 Julich, Germany*

[3]*CCFE, Culham Science Centre, Abingdon OX14 3DB, UK*

1. Introduction

The foreseen operating scenario for ITER is the type-I ELMy H-mode [1]. Nevertheless, the energy load onto plasma facing components, caused by type-I ELMs is too high [1], calling for methods for controlling them, while maintaining adequate confinement. Several control mechanisms have been proposed and recently explored on JET, including ELM mitigation by resonant magnetic perturbations using the Error Field Correction Coils (EFCCs) [2], ELM pacing with shallow pellet injection [3], ELM magnetic pacing by fast movements of the plasma column with imposed radial electric fields ('vertical kicks') [4]. In this work, the magnetic perturbation spectra of ELMs during EFCCs control experiments on JET are compared with those of spontaneous type-I ELMs. The toroidal mode numbers of ELMs is extracted from the phase of the magnetic perturbations measured by edge Mirnov coils, on the low field side, toroidally separated by 10 degrees (maximum n=11) [5]. The method, based on the combination of wavelet functions and a two-point correlation analysis, allows the reconstruction of the power spectral density $P(n,f)$ over short time windows before and during the ELM crash [6]. For each ELM, $P(n,f)$ has been computed over time steps of 100 μs during a 10 ms window centred at the time of the crash. The n grid is constructed over unitary steps, Δn=1, in such a way that all wavenumber values (phase shift divided by coil separation) that fall between $n\pm0.5$ are associated to n.

[*] *See the Appendix of F. Romanelli et al., Proceedings of the 22nd IAEA Fusion Energy Conference 2008, Geneva, Switzerland*

2. Spontaneous ELMs

The power spectral density associated with a spontaneous ELM in a reference discharge (no application of EFCCs) is shown in Fig.1. The *P(n,f)* has been integrated over different frequency ranges, between 0.25 kHz and 125 kHz. Below the lower limit, wavelet spectra are dominated by edge effects close to the ELM crash, while above the upper limit the amplitude and frequency response of Mirnov Coils is modified and toroidal mode number spectra over short time windows are not reliable. The chosen intervals are not regular in frequency, but they have been selected to isolate the background MHD activity at n=1 and n=2 present in these plasmas during inter-ELM phases. Magnetic perturbations below 2 kHz typically peak at low toroidal mode numbers, typically n=1. Above 2 kHz spectra are localized at intermediate values of $|n|$, between 2 and 6. The negative value of n is consistent with the observation of magnetic turbulence propagating along the electron diamagnetic direction, usually measured on JET in H-mode plasmas and present in these discharges. The absolute value of n is seen to increase with frequencies approaching the ELM crash. Above 20 kHz spectra are contaminated by aliasing in the toroidal mode number value, within a short time window of 100 μs during the crash and no conclusions can be made on the value of n, which may be much higher than the maximum measurable with this pair of coils.

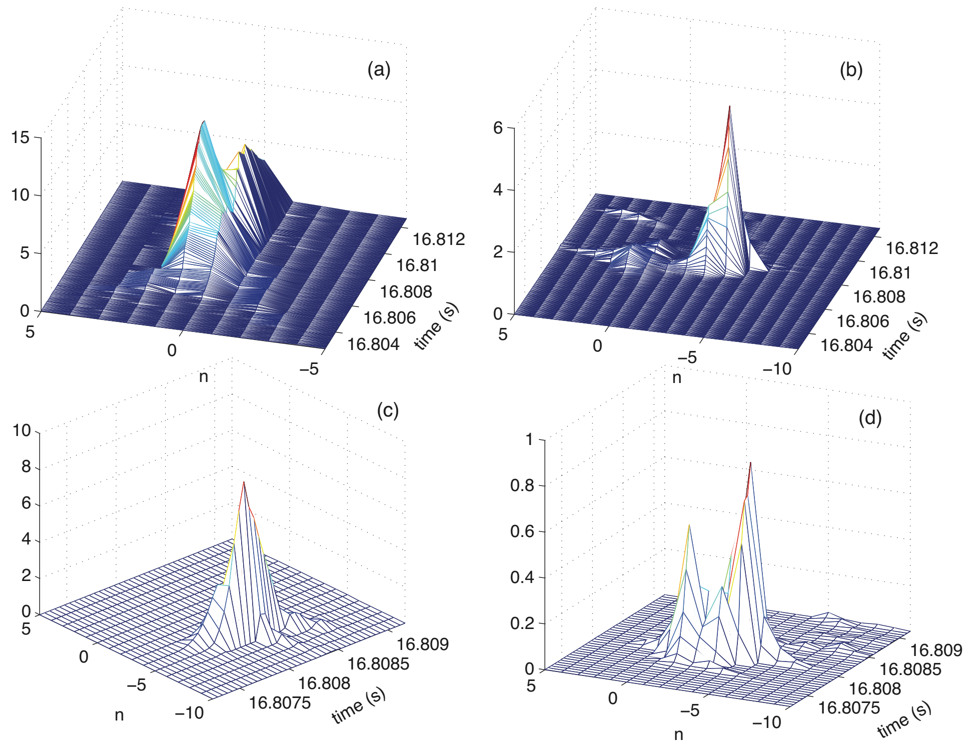

Figure 1. Power spectral density associated with magnetic perturbations in the frequency range of (a) [0.25,1] kHz, (b) [1,4] kHz, (c) [4,8] kHz, (d) [8,16] kHz, in the case of a spontaneous ELM (shot 72524).

3. Controlled ELMs

Experiments of ELM control have been run on JET with EFCCs for plasmas in a wide range of q_{95}, from 3.8 to 5 [7]. It was found that even a small variation of q_{95} from 4.5 to 4.8 may result in an increase of the ELM frequency by a factor up to four [7]. A possible explanation of this *multi-resonance* effect has been investigated using the ideal external peeling mode model [8]. Figure 2 shows the time evolution of *P(n)* in the range of frequencies [4,8] kHz during the EFCC phase, for experiments with n=1 and n=2. The qualitative features, i.e. spectra peaked at negative toroidal mode numbers (see Fig.2), are similar to what observed for spontaneous type-I ELMs, independently on the phase of the EFCCs. A total of 35 ELMs for the plasma at q_{95}=4.8 and 21 for the plasma at q_{95}=4.5 have been analyzed during RMP experiments with n=1, for which the measured magnetic perturbations do not reach saturation level during the ELM burst.

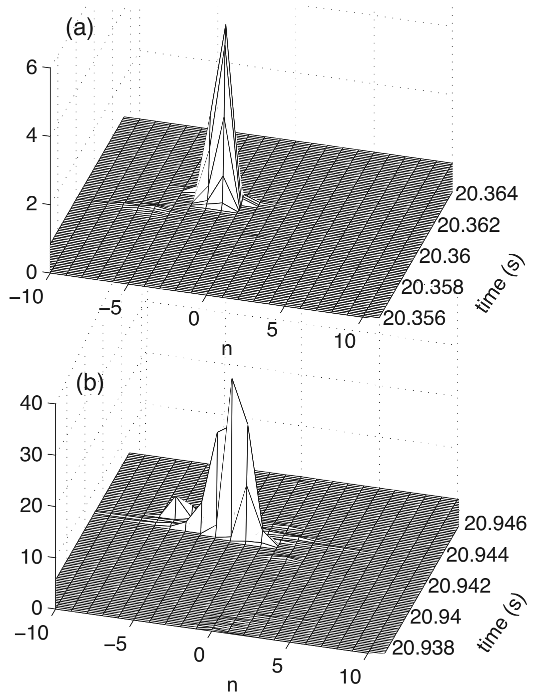

Figure 2. Power spectral density associated with magnetic perturbations in the frequency range of [4,8] kHz,in the case of an ELM mitigated by RMPs with n=1 (shot 76963) (a) and n=2 (shot 72273) (b).

The two plasmas exhibit differences in toroidal mode number distribution, as shown in Fig.4. The histogram shows the value at which spectra in the range of [1,4] kHz peak. These frequencies also correspond to the maximum spectral amplitude. For larger frequencies the toroidal mode numbers can be larger, but the spectral amplitude is lower. In the plasma at higher value of q_{95}, for which the ELM frequency is higher, spectra peak dominantly at n=-2, and the distribution is quite narrow, while in the plasma at lower q_{95}, where the ELM frequency has only increased by a factor two during the RMP phase, the mode number distribution appear wider.

4. Conclusions

The measurement of the toroidal mode number spectra of modes dominantly unstable during an ELM crash is important for a comparison with MHD stability analysis codes. In particular, the comparison between toroidal mode number spectra during spontaneous ELMs and those

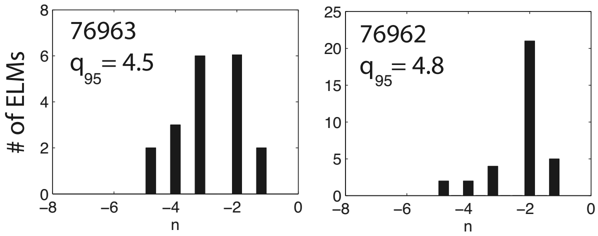

Fig. 3. Histogram of measured n at maximum power.

triggered and/or mitigated in controlled experiments, could give a better insight on the nature of the MHD instabilities that may trigger an ELM. Previous work on experiments with shallow pellet injection have shown that pellet-triggered ELMs and spontaneous type-I ELMs have similar features [6]. In both cases two components are detected, one at low frequency and low mode number, typically n=1, the other at higher frequencies, with n values typically negative. The value of n at which the spectrum of triggered ELMs peaks saturate to approx n=6, while in spontaneous type-I ELMs, the value of n may be higher. In experiments with RMPs no evident differences in the time evolution of the n<0 component have been observed compared to spontaneous ELMs for the cases analyzed so far. Also, the maximum measured oroidal mode number is likely larger than the Nyquist value for the chosen set of coils, similarly to spontaneous ELMs.

A dependence of the toroidal mode number distribution on the value of q_{95} is found, with the wider distribution corresponding to the plasma with lower ELM frequency. As demonstrated in the experiments run by Liang *et al* [7], the ELM frequency depends on q_{95}. The multi-resonance model [8], which can explain the observed frequency features, also predicts a dependence of the toroidal mode number of the most unstable mode on q_{95}. Further analysis on a more extended database is ongoing to verify experimentally this dependence.

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