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MHD analysis of Beta Collapses in AT JET discharges

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**See the Appendix of F. Romanelli et al, Proc. of the 25th IAEA FEC, Saint Petersburg, Russia, 2014*

Introduction. Advanced Tokamak (AT) experiments aim at identifying favorable conditions for stable plasmas at high normalised pressure (β_N>3) in view of extrapolating to next step fusion devices. Higher values of β_N are limited by the onset of MHD activity [1, 2]. In experiments performed at JET with Carbon Wall (CW), large collapse events [3] have been observed to suddenly reduce the β_N value, and were referred to as beta collapses (BC). BCs were observed to be ELM-like events but involving a larger plasma volume and triggered by a global kink-like MHD mode [3].

Recent experiments were performed in JET with ITER-Like Wall (ILW) using up to 26MW NBI power in plasmas with B_T from 1.7T to 2.4T, with I_P from 1.9MA to 1.5MA (q_{95} from 3.5 to 5.5). The initial q-profile was varied by changing the start time of the high heating phase, with q_{min} from 1.2 to 2.5. All q-profiles have positive magnetic shear. Contrary to the observations in CW, BCs found in ILW experiment did not show any clear oscillatory precursor in the usual fft based analysis of magnetic signals. An analysis of the MHD activity before the BC is here addressed by application of Singular Value Decomposition (SVD) [4,5] to a toroidal array of Mirnov coils.

Resonant Field Amplification (RFA) measurements were performed in JET experiments by application of non-axisymmmetric magnetic field from four Error Field Correction Coils (EFCCs) arranged symmetrically around the outside of the vacuum vessel, each spanning

70º toroidally. This measure allows to probe the plasma stability, using the so-called MHD spectroscopy technique [6].

Singular Value Decomposition. Magnetic crashes associated with BC are very fast events, with durations of ~0.5ms similar to ELM ones. MHD analysis is here carried out by application of SVD to a toroidal array of six Mirnov coils in time windows of 0.5ms. SVD [4] decomposes a matrix in a collection of singular values $\{SV_i\}$ (the strength of the mode), of Principal Components $\{PC_i\}$ (the mode timeline), and of Principal Axes $\{PA_i\}$ (the spatial periodicity of the mode). In order to evaluate the toroidal order number n of the dominant SVD mode, the n's likelihoods L_n [5] are calculated as: $L_n = \left|PA_1 \cdot V_n\right|^2$; where V_n is the expected PA_1 calculated from numerical signals with n periodicity [5]. Amplitudes A_n of perturbations with n periodicity is calculated from the amplitude A_x of the fluctuations sensed by a given Mirnov coil, by

$$A_n = \frac{A_x \sum_i SV_i^2 \left|PA_i \cdot V_n\right|^2}{\sum_i SV_i^2}.$$

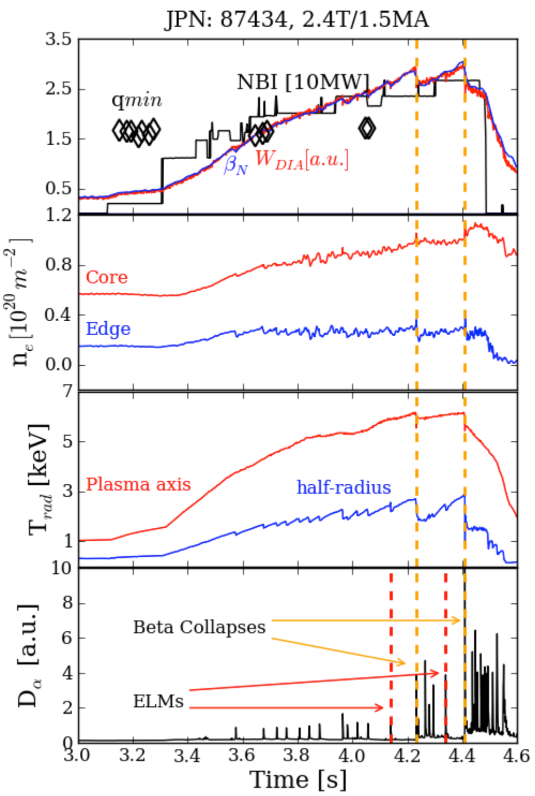

Figure 1. From top to bottom: q_{min} values from MSE constrained EFIT, NBI power normalized to 10MW, W_{DIA} normalized to 1.76MJ; core and edge line integrated electron density; electron temperature near plasma axis and at half radius; Dalpha. Beta Collapse events are indicated by vertical dashed orange lines while ELMs analyzed in Fig.2 by red dashed lines.

Detailed analysis of JET ILW #87434. The time traces for this pulse are reported in Fig.1 where two BCs occurring at t=4.23s and 4.41s are indicated by vertical dashed orange lines. Differently from ELMs (dashed red lines in Fig.1, bottom panel) such events affect the electron temperature profile from edge to near the plasma axis, (3rd panel in Fig.1) and produce sudden relative losses of Wdia (stored diamagnetic energy) of 10 and 17% respectively, reducing β_N from 3 to less than 2.5.

In Fig.2, the SVD results for 40ms around each event highlighted in Fig.1 by vertical dashed lines are shown. For each case the peak frequency of the PC_1, the L_n values, and the A_n are shown from top to bottom. L_n>0.5 indicates the presence of a mode with a given n order number.

A weak n=4 mode is present both before the ELM at 4.14s (Fig.2a) and before the BC at 4.23s (Fig.2b), while in the larger BC at 4.41s (Fig.2d) a n=5 mode is found to suddenly grow in about 20ms and to undergo to three frequency-amplitude cycles before the BC. Such a mode is located at R~3.44m (CXS), where q~1.8±0.2 from MSE-EFIT.

a) b) c) d)

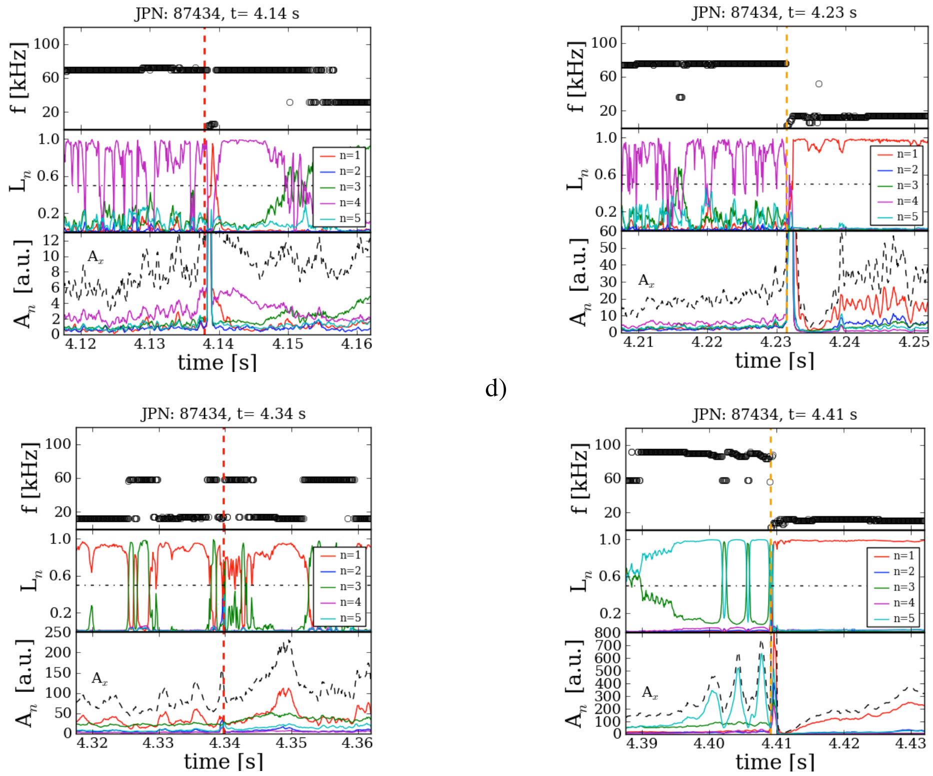

Figure 2. Results from SVD analysis (top to bottom): mode frequency; n order number; amplitudes of the modes. Results are shown in four cases: a) ELM before the first BC; b) first BC; c) ELM before the second BC; d) second BC (see also figure 1).

In both cases shown in figure 2, SVD is not capable of identifying a clear toroidal periodicity when the crash happens, but in all cases it indicates the presence of a low frequency n=1 mode immediately after the crashes. The main difference between ELMs and BCs is the presence of an n=1 mode that develops as a 2/1 mode.

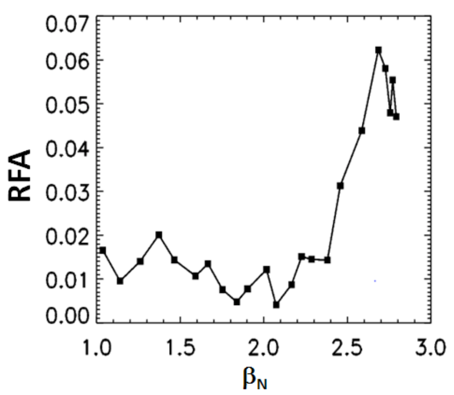

Figure 3. RFA measurements in pulse #87434.

Results of RFA measurements are shown in Fig.3 as a function of β_N. Toroidally opposite EFCCs are connected in series with oppositely directed currents to produce a n=1 magnetic field. RFA is defined as $RFA = \frac{B_r|_{rsensor} - B_{r,ext}}{B_{r,ext}}$. In Fig.3 for β_N>2.5 the strengthening of the RFA is a sign that the plasma pressure is approaching the no-wall beta limit.

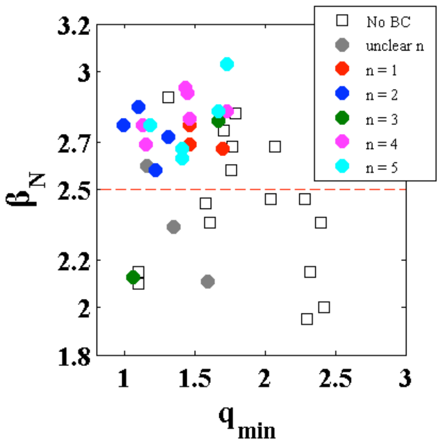

Figure 4. Maximum $ß_N$ in AT pulses with (circles) and without (squares) Beta Collapses. Colors refer to the dominant mode n resulting from SVD analysis. q_{min} from MSE-EFIT.

SVD results. SVD analysis has been performed in 24 events found in 19 JET AT ILW pulses. Such events were selected only taking into account the relative losses of ΔW_{dia}>8%. Results of such analysis are shown in the q_{min}-$ß_N$ diagram of Fig.4. Circles in Fig.4 are the q_{min}-$ß_N$ values just before the BC, colors are related with the n of the dominant SVD mode before the BC. Values of n from 1 o 5 are found before BCs, but only in some cases with n=3,5 such activities behave as a precursor growing exponentially in few tens of ms before the BC. n=1,2,4 modes are usually already present and with constant amplitude before the BC. A weak dependence is found between q_{min} and n (n=2 for q_{min}=1.45, and n=3,5 for 1.45<q_{min}<1.75).

It is noticeable that BCs are mainly concentrated in (q_{min}<1.75, $ß_N$>2.5) region of operational parameters. Furthermore, in 20 cases out of 21 for $ß_N$>2.5 a strong 2/1 is triggered after the BC, while only 1 out of 3 for $ß_N$<2.5. The black squares in Fig.4 refer to ($q_{min}(ß_{Nmax})$, $ß_{Nmax}$) of 16 pulses clearly unaffected by BC with $ß_N$>1.9 and NBI>20MW.

Summary. MHD analysis before BCs has been carried out by SVD. Such analysis showed that modes with high n up to 5 are present before the BC and in certain cases they act as precursor (Fig.2 and 4) showing a fast growth in ~10ms. This is in contrast with previous CW observations of a BC triggering by a n=1 kink like mode [1,3]. RFA enhancement (Fig.3) for $ß_N$>2.5 shows that plasma pressure is approaching the no-wall beta limit. This is found in good agreement with the concentration of BC in the q_{min}-$ß_N$ diagram (Fig.4).

Acknowledgments

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