MHD activity during the recent divertor campaign
at the Wendelstein 7-X stellarator

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Introduction

The magnetohydrodynamic (MHD) activity during the recent operational phase OP1.2 (parts a and b) at the stellarator Wendelstein 7-X (W7-X) is studied. A number of installed diagnostics are suitable for the estimation of frequencies, phases and amplitudes as for example poloidally and toroidally arranged Mirnov coils and Rogowski coils [1, 2], a soft X-ray tomography system [3], an electron cyclotron emission diagnostic [4], a phase contrast imaging diagnostic [5], divertor Langmuir probes [6] as well as movable magnetic and Langmuir probes located on the probe manipulator [7]. This contribution focuses on the measurements of the magnetic diagnostics (Mirnov probes and Rogowski coils). Two main topics have been selected for discussion. First, typically measured broadband Alfvénic activity and mode analysis results based on the observations of 40 poloidally arranged Mirnov probes are discussed in comparison with theoretical predictions. Second, initial investigations of the nature of fast plasma current crashes, i.a. detected by a Rogowski coil, are presented. The importance of both aspects for future operation phases at W7-X is briefly described.
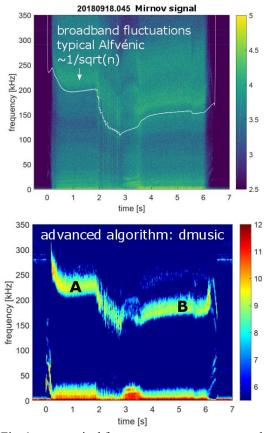

Fig. 1: *top:* typical frequency spectrum measured by a selected Mirnov coil; *bottom:* same data as above, but calculated using the advanced spectral analysis tool DMUSIC.

1. Typical Alfvénic activity

Independent of magnetic configuration and heating mechanism/power during most plasma experiments of OP1.2 distinct broadband MHD activity in the range of ~200 kHz has been observed by the Mirnov diagnostic. Fig. 1 (top and bottom plot) shows a typical spectrogram of a plasma experiment (here example: PID 20180918.045) measured by a Mirnov coil (QXM10CE040, half module 10 (HM10)).

The observed fluctuations around ~230kHz during the initial plasma phase drop down to ~170kHz after pellet injection [8] between 2-2.8s. The trend follows ~ $Cn^{-1/2}$, where C is an adapted constant and n is the electron plasma density from interferometer data [9] (as indicated by the white line in Fig. 1, top plot), which suggests its Alfvénic nature. The top plot in Fig. 1 has been calculated using a standard FFT algorithm, whereas the bottom plot is the result of an advanced spectral analysis method, so-called DMUSIC (damped multiple signal classification [10, 11]). The regions of interest, mentioned above, are much better visible within the spectrogram. This is used for determining two pronounced frequency ranges, marked with **A** (~230 kHz) and **B** (~170 kHz) before and after a high plasma energy phase (3.2-3.4s, ~1MJ), respectively. At 1.48s (**A**) and 5.02s (**B**) the corresponding Alfvén continua (Fig.2, 1.48s top plot, 5.02s bottom plot) using CONTI [12] have been calculated, based on plasma density and temperature profiles measured by the Thomson scattering system [13].

The EAE gap shifts to lower frequencies between **A** and **B**. The shift as well as the frequency range are both found also within the experimentally observed spectra. A mode number
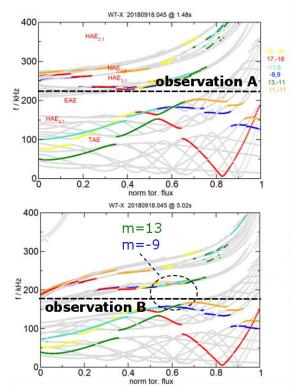

Fig. 2: Alfvén continua calculated using CONTI for PID 20180918.045 at two time points 1.48s (*top*) and 5.02s (*bottom*) Expected poloidal mode numbers are indicated for a direct comparison with experimental results (n = 1 mode family).
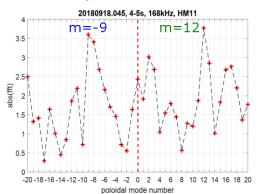

Fig. 3: Experimentally observed poloidal mode numbers for PID 20180918.045 during the time period of 4-5s. The mode number analysis was done using the SSI-method on the measured data of the poloidally arranged Mirnov coils in HM11.

analysis using the SSI-method (Stochastic System Identification [14, 15]) based on the measurement of 40 poloidally arranged Mirnov coils located in half module 11 (HM11) within the time interval 4-5s (observation range **B**) reveals pronounced poloidal mode numbers *m = -9* and *m = 12* (Fig. 3). That is comparable to theoretical predictions as indicated in the bottom Alfvén continuum in Fig. 2. In summary, using advanced spectral and mode analysis methods, it is possible to determine type, location and mode numbers of observed MHD modes in comparison with theoretical predictions. This will be important in future experiments incorporating much stronger drive mechanisms for instabilities, which can lead to enhanced transport phenomena, substantial loss of plasma energy and shorter confinement times. It is noted that the calculation of the Alfvén continua strongly depends on plasma pressure and iota profiles. A possible Doppler shift is also not taken into account here.

2. Fast plasma crashes

During plasma experiments with a strong electron cyclotron plasma current drive (ECCD [16]) sudden, unwanted plasma terminating collapses ('plasma crashes') have been observed, usually, if the total plasma current reaches 15kA or more. The determined current decay times are found to be significantly faster (~ order of a few ms) than respective confinement times
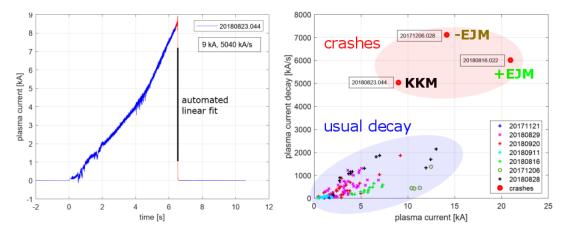

Fig. 4: Comparison of usual plasma current decay times with much faster plasma terminating crashes. *Left:* example linear fit (black line) of plasma current (blue line) during a plasma terminating crash (final phase of PID 20180823.044 indicated in red); *Right:* Overview of major plasma terminating crashes (indicated red area) occurring in standard (+EJM), reversed standard (-EJM) and high mirror configuration (KKM) and selected usual current decay times during planned shutdown of discharges (indicated blue area).

~150 ms. Automated linear fitting of the plasma current during the crash (Fig.4, *left*, example PID 20180823.044, plasma current measured by a Rogowski coil in HM11) clearly shows much higher decay rates of the plasma current (Fig. 4, *right*, plasma crashes, indicated in red,

observed in three magnetic configurations) and the energy (not shown here), when compared to the decay times of a planned plasma heating shutdown (Fig. 4, *right*, usual decay times indicated in blue). These crashes represent a potential risk for save machine operation due to high induced currents in adjacent in-vessel machine parts and strong resulting mechanical forces. Therefore it is important to study the nature of these probably MHD-linked phenomena. Ongoing investigations including fast measurements of the plasma electron temperature, soft X-Ray tomography and Mirnov coil mode analysis have not been conclusive so far. A preliminary hypothesis describes the occurring crashes as reconnection events of inner and outer island chains due to a localized increase of the rotational transform iota crossing the value 1 [17].

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