*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-5.021 (2005)*

Analysis of transient MHD modes of Wendelstein 7-AS by coherence techniques

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Introduction

Bursts in the Mirnov-coil signals are frequently observed on the Wendelstein 7-AS stellarator in otherwise MHD inactive plasmas. We have mostly analysed pure ECRH discharges near the confinement transition at 1/3 edge rotational transform [1]. The magnetic bursts in these shots have a modulated sinusoidal temporal structure and quite often they possess a well defined spatial mode structure. As neither fast ions nor steep pressure gradients are available for driving these modes, we believe that they are stable modes excited by some transient deviation of the plasma from the MHD equilibrium. It is supposed that such deviations can be caused by transient transport events detected as transient flattenings in the temperature profile measured by ECE. Figure 1 shows the cross-correlation functions (CCFs) between temperature variations and the RMS amplitude of magnetic fluctuations. It can be seen that the bursts in the Mirnov-coils correlate with a positive change in temperature on the periphery of the plasma and a negative change in the core, which indicate a flattening caused by transient transport event. An analysis of the link between transient MHD modes and transport relevant fluctuations can be found in [2,3,8].

Transient MHD modes also have a density component besides the magnetic one, consequently they can be observed in the Lithium Beam Emission Spectroscopy (LiBES) signals as well. [4] The autocorrelation functions (ACF) of the LiBES show that the transient MHD modes have a clear sinusoidal structure indicating a true wave contrary to a rotating flux tube.

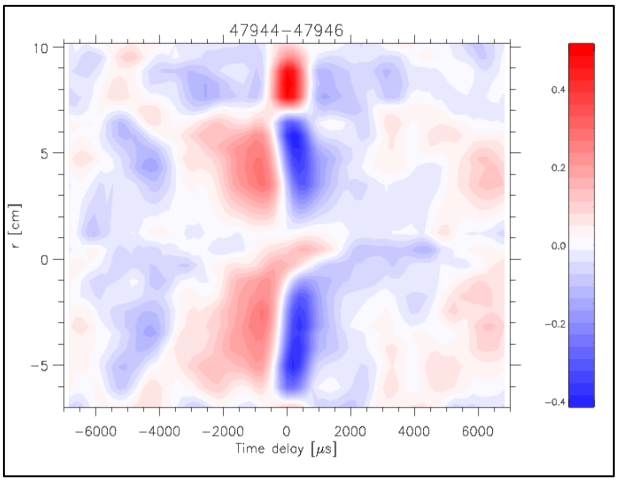

Figure 1: CCFs between ECE signals and Mirnov-coil RMS

Being stable, these transient MHD modes are rapidly damped, the duration of the bursts is typically on the 100μs timescale.

The characteristic frequencies of the transient MHD modes are in the frequency range of 10 to 110 kHz. Consequently for the lowest frequencies we see only a few oscillations in one transient. By analysing the properties of the transient MHD modes we aim to infer some information about the events exciting them.

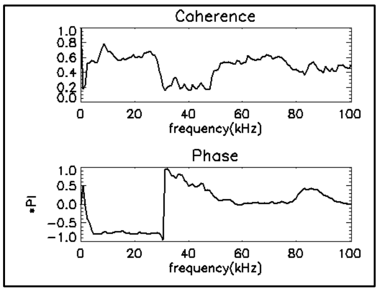

Figure 2: Typical coherence and phase function between Mirnov-coil signals

Spatial structure

In order to reveal the spatial structure of the transient MHD modes, coherence and phase functions were calculated between the signals of the 16 Mirnov-coils of the MIR-1 poloidal array. The average coherence function between non-adjacent coils has broad peaks around the characteristic frequencies of the transient MHD modes, and the corresponding phase function is typically constant in these intervals. (Figure 2)

At the frequencies where coherences between all pairs of coils are relatively high, phase between the coils can be plotted as a function of the poloidal location of the coils. In some cases we do not see a structure in these phase diagrams, but in most cases the phase distribution is consistent with a mode number equal to $1/\iota_a$, where ι_a is the edge rotational transform. [4,9] We have detected both m=3 and m=2 (in case of $\iota_a \sim 1/2$) modes (Figure 3). Poloidal ExB rotation of the mode is indicated by the reversal of the direction of the rotation with the change of the sign of the toroidal magnetic field. For characteristic frequencies at around 4 kHz other types of phase diagrams are typical, that may be the result of the rapid modulation of the fluctuation or a LFS-HFS wobble of the plasma.

In order to fully understand the results of our analysis, we made a simple simulation reproducing the basic properties if the coherence and phase functions. Results from an earlier attempt to simulate Mirnov-coil signals were already published. [5] That simulation assumed GAE-like modes [6] at given frequencies and used realistic geometry. Phase diagrams could be reproduced quite precisely, but no temporal modulation of the modes were included. Our new simulation includes waves amplitude-modulated by burst-like envelopes travelling with the poloidal ExB drift in simple slab geometry with periodic boundary condition. Despite the simplicity of the model, basic properties of the coherence, phase functions and phase diagrams could be reproduced by tuning the time constants of the envelope, the characteristic frequency of the wave, the speed of rotation and the non-

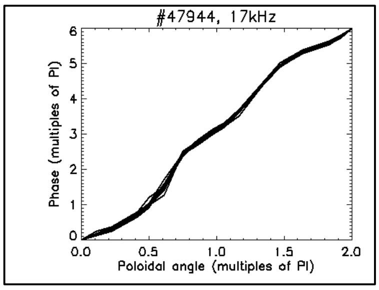

Figure 3: Phase diagram of m=3 mode

correlated noise level. (Figure 4) Combining the two models we hope to be able to fit the various parameters of the transient MHD modes onto the measurements.

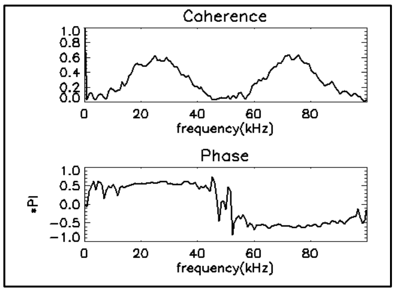

Figure 4: Simulated coherence and phase functions

Temporal structure

Investigation of the temporal structure of the transient MHD modes is based on the short-time Fourier transform. As it does not produce interference patterns between signal components, its absolute value squared can be directly interpreted as time-frequency power-density distribution, which is called spectrogram. The power variation of the different transient MHD modes can be recovered from the signal by integrating the spectrogram in frequency between the limits of their frequency ranges. This way we calculate the bandpower signal, which is subject to further statistical analysis. Earlier analysis based on correlation functions found, that cross-correlation between bandpowers tends to be stronger, if temperature transients have larger radial extent. [5,7]

We have observed some minuscule time delays in the central peaks of the CCFs, but we had doubts about their being significant. That is why we calculated the coherence and phase functions between the bandpowers (Figure 5). Time delays have been estimated from the slope of the phase function. Significant time delays were found in very few cases, when the power variation of MHD transients at higher frequencies seemed to be delayed by some 10 μs.

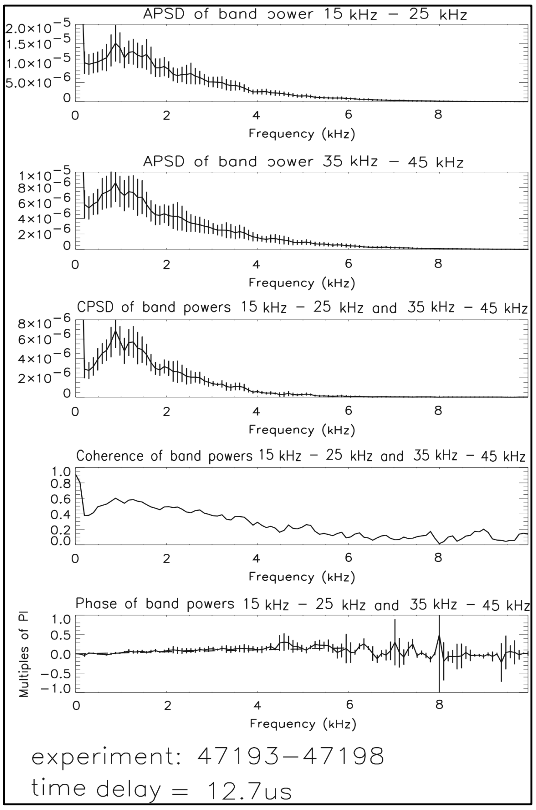

Figure 5: Auto-spectra, cross-spectrum, coherence and phase function of Mirnov-coil bandpowers

Transient MHD modes in LiBES

During discharges, in which there is a ruling frequency component in the Mirnov-coil signals, CCFs between the Mirnov-coil signals and LiBES channels measuring inside the LCFS show a periodic oscillation with the frequency of the transient MHD mode and a decay time of about 100 μs. [4] This proves, that the transient MHD modes have a density component.

By calculating the coherence between the Mirnov-coil signals and the LiBES signals, we can radially localize the transient MHD modes

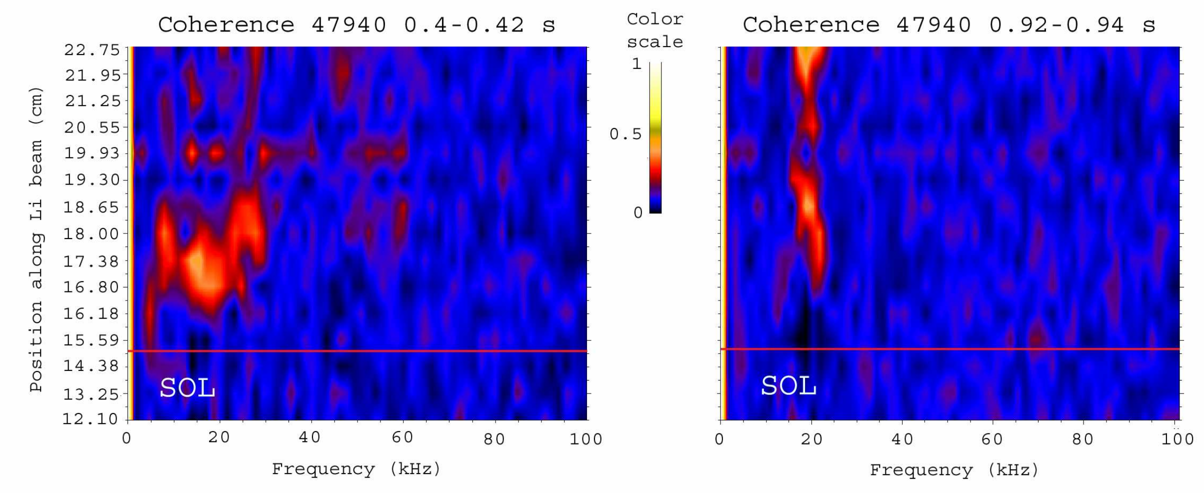

Figure 6: Coherence between magnetic fluctuations and LiBES signals at ι_a=0,345 and ι_a=3,6 respectively

within the range of the LiBES diagnostic. Slow current ramp shots were analysed this way, and it was found that at around ι_a=0,345 transient MHD modes were localized typically just inside the LCFS, and at around ι_a=3,6 transient MHD modes appear even at the deepest positions of the measurement range of the LiBES. (Figure 6) This change coincides with an increasing radial extent of the temperature profile flattenings.

Conclusions

Magnetic bursts in pure ECRH shots in the W7-AS near a rational edge rotational transform were identified as transient MHD modes. Besides the Mirnov-coils, these modes can be observed in the density fluctuations measured by the LiBES diagnostic. Characteristic frequency, autocorrelation time, radial localization and other properties change sensitively with the magnetic geometry and parameters of the heating, which often coincide with a change in global confinement. The power modulation of the transient MHD bursts is linked to transient transport events seen as flattenings in the ECE temperature profiles. Further analysis of the MHD transients may reveal some properties of the transport events [2] exciting them.

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