INSTABILITIES OF BEAM-HEATED L-TYPE AND H-TYPE ASDEX PLASMAS

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INTRODUCTION

This paper summarizes the investigations on MHD modes occurring in beam-heated ASDEX plasmas and supplements them by some new observations and discussions of the mode structure. Particular attention is given to the connection between oscillatory mode activity and relaxation phenomena, namely sawteeth, disruptions and ELMs, the latter occurring only in the H-regime. The relaxation processes, however, are not the main topic of this paper. For the understanding of the mode behaviour to be discussed in what follows it is important to note that in no case the onset of neutral injection leads immediately to H-type behaviour. Rather, an L-type phase extending over at least ~ 30 ms preceeds the L to H transition.

Discussion of mode structure and mode propagation.

It is generally accepted that Mirnov oscillations with the poloidal and toroidal mode numbers m and n, respectively, are created by currents flowing parallel to the field lines on rational magnetic surfaces $q=m/n$. In a torus, the slope of the field lines varies poloidally which leads to a variation of the poloidal wavelength: it is larger at the outside of the torus according to $\cos m\,(\Theta-\lambda \sin \Theta)$ /1/. Furthermore, model calculations performed by one of the authors /2/ have shown that the mode amplitude is larger at the outside, too; typical out-in ratios range between 2 and 5. Formally, this variation can be ascribed to sidebands $m = \pm 1$ whereas the current creating this structure is flowing on just one rational surface.

The analysis of the ASDEX data has shown that the mode structure agrees to the conception exposed above as far as the phases are concerned; the amplitudes, however, fit into this model only in rare cases. The out-in amplitude ratio varies between 20 and 0.5, apparently depending on the mode type (in addition, an up-down asymmetry exists which is nearly the same for all modes and is not discussed in this paper.) These experimental findings can be ascribed to the simultaneous occurrence of different modes i.e.currents flowing on different rational surfaces. In lowest order a mode cluster m-1,m,m+1 is sufficient to describe the observations. It has to be postulated then that the leading mode which defines the m number of the observed structure imposes its frequency onto the sideband or satellite modes.

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The field perturbation $\tilde{\underline{B}}$ is frozen within the plasma i.e. it moves at the velocity

$$\underline{v}^* = \underline{v} + \nabla p_i \times \underline{B} / (en_e B^2). \qquad (1)$$

Here, $\underline{v}$ denotes the macroscopic motion which in the case of ASDEX is the toroidal rotation caused by the unidirectional neutral injection. The second term is the contribution of the ion pressure gradient to the diamagnetic drift velocity /3/. This equation allows for determining the mode frequency via $v_{pol} = \omega_{pol}\, r$ and $v_{tor} = \omega_{tor}\, R$. In the case of co-injection (the only scenario treated here), both terms tend to cancel each other. From a discussion of the profiles /3/ it can be taken that modes located near the magnetic axis propagate according to the toroidal rotation while modes located near the boundary tend to move in the opposite direction. Thus, the study of mode propagation and frequency provides a very valuable tool in investigating MHD phenomena.

Sawteeth, m=1 oscillations and satellites.

The OH target plasmas of the ASDEX device are generally subject to sawteeth preceded by m=1/n=1 oscillations. The application of neutral injection leads always to an increase of the sawtooth period. In both confinement regimes, a critical power level is found above which sawtooth activity vanishes in the course of the NI pulse: After the first relaxation, the m=1/n=1 mode develops again but it attains a more or less stationary level without giving rise to sawteeth. The further temporal evolution depends on the confinement regime: If the plasma remains in the L-type state the mode may continue up to the end of the injection pulse or it may develop into fishbone-like bursts. After an L- to H-transition, however, the amplitude of the continuous m=1 mode always decreases drastically but it revives repetitiously in a fishbone-like manner indicating that the q value on axis remains close to unity.

The mode frequency of typically 10 to 30 kHz is clearly governed by the toroidal rotation of the central plasma as is shown by Doppler measurements. Regardless on the waveform - precursor of sawtooth, continuous mode of fishbone-like burst - and regardless on the confinement regime the m=1 mode is always accompanied by a satellite, i.e. an n=1 Mirnov oscillation with exactly the same frequency and similar temporal behaviour of the amplitude.

The poloidal mode number m - preferrably 4 or 5 - exceeds always the q value at the boundary (separatrix effects not included); hence an external kink is a plausible candidate. The out-in ratio of the amplitudes is extremely large and may amount up to 20 or more which indicates a cluster of modes coupled such that the maxima coincide at the outside of the torus. Presumably, such cluster comprise all mode numbers between 1 and the dominant m value which would explain the mode coupling satellite extending over the total plasma cross section.

Most puzzling, in some cases, this structure is superimposed by an m=0/n=1 component at same frequency which - due to the large amplitude ratio of the m > 0 satellite - is most prominent at the inside of the torus. Thus the signals from the Mirnov coils located in a poloidal plane at the high field side of the torus are in phase while those from the outer coils exhibit the well-known picture of a propagating mode. On the basis of plausible assumptions it is possible to separate the m=0 component /3/. It is difficult to comment on the significance of this phenomenon since its occurrence cannot be attributed to characteristic parameters such as q, $\beta_p + l_i/2$ etc.

m=2 modes and disruptions.

L-type plasmas in ASDEX are not susceptible to disruptions below the density limit. If q approaches 2, a large m=2/n=1 mode develops which usually persists over hundreds of milliseconds without leading to disruptions. Frequently, the island size is appreciable and impairs the confinement. In H-type discharges, disruptions preceded by large m=2 oscillations occur preferrably if the β limit is approached. The way the m=2 mode is initiated is reported in ref. /4/.

The moderate amplitude ratio of the order 3 fits into the picture of just one mode. The direction of propagation is still that of the toroidal rotation while the frequency is appreciably smaller than that due to the central rotation velocity which indicates the enhanced competing effect of the diamagnetic drift.

Localized m ≧ 3 modes and their relationship to the confinement regimes.

The m=1/n=1 and m=2/n=1 modes discussed in the preceding sections are localized in that they propagate according to eq. (1). Another localized n=1 mode was first observed in the L regime by one of the authors /5/. The m number is $m^* = 3$ or 4, where m^* is smaller than but close to the boundary q value (separatrix effects disregarded). This mode propagates in the diamagnetic drift direction at a frequency which is typically below 10 kHz, i.e. less than that of the m=1 mode. In favourable cases, the double frequency feature is clearly seen in the raw data. Using an ideal filter method /5/ the two components can be separated.

Surprisingly, in contrast to the behaviour of the satellite mode, the out-in ratio of the amplitudes is nearly unity or even less which corresponds to a cluster of modes coupled such that the maxima coincide at the inner side of the torus.

All these features indicate the occurrence of a mode originating near (but inside) the separatrix which apparently is decoupled from the central m=1 activity. Unfortunately, this statement has to be qualified according to the following experimental findings: In sawtoothing L-type discharges, there is generally an interval between sawteeth, in which the m=1 oscillation and its satellite is not detectable. This behaviour, however, holds also for the m* mode, apart from a short period after the sawtooth crash. Furthermore, there is a puzzling connection between the number m* of the mode discussed here and the mode number m_s of the satellite governed by the m=1, namely

$$m^* = m_s - 1 \qquad (2).$$

Simple relationships, however, between the frequencies of both modes or the sums or differences of them were not found.

It was already stated that the m* mode is observed in the L regime. After the L to H transition, it vanishes rapidly, i.e. within a few milliseconds. It reappears on the same time scale if, after the termination of the NI heating pulse, the plasma returns into L-type behaviour. During the H phase, the m* mode occurs only during the so-called edge-localized modes or ELMs which in general is masked by the signals due to the inward motion of the plasma column caused by the rapid decrease of β_p. Using particular evaluation techniques /6/, however, it is possible to separate both types of signals. It is seen that the m* mode and the ELM relaxation develop simultaneously. Hence, this mode is no precursor to the ELM other than the characteristic precursors of sawteeth and disruptions.

In the L phase, the m* mode develops at rather low β values. Furthermore, there is no threshold for the onset of ELMs. From this it is inferred that this mode is driven by current density rather than by pressure.

SUMMARY

The variety of MHD oscillations in beam-heated ASDEX plasmas can be systemized to some extent: rules can be established. The underlying physics, however, are not yet understood.

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