MHD-EFFECTS WITH NI AND ICRF HEATING ON ASDEX

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Introduction

With high power auxiliary heating at increased plasma pressure many new MHD phenomena occur which can be studied most suitably by observation of the soft X-ray ("SX") radiation. In the plasma centre NI excites large m=1, n=1 oscillations, the detailed behaviour of which depends on external parameters. In divertor discharges with NI power $\lesssim$2 MW their occurrence is repetitive and terminated by sawteeth. When NI is combined with ICRH the m=1 mode often disappears after a first strong sawtooth which is followed by "precursor-free" large sawteeth.

The hot spot model

Detailed studies of the m=1 mode and of sawtooth activity have been made in ASDEX mainly based on the analysis of the signals of two SX diode cameras. In the case of a toroidal rotating plasma and disregarding a possible poloidal rotation these signals represent the projection of an asymmetric and helical radiation profile into the viewed poloidal cross section. From comparison with ECE measurements we conclude that the oscillating SX signals are mostly caused by varying electron temperatures.

Figure 1 shows an example of an m=1 mode during NI rotating opposite to the electron drift direction. The behaviour of the signals (doubled frequency, phase relations) can be well described by a rotating hot spot with an extension 2D, which is much larger than the distance Δ of its centre to the magnetic axis (Fig. 2). The hot spot centre describes a circle with radius Δ around the magnetic axis, the off-axis rotation of the hot spot affects a plasma roughly within the $q = 1$ zone.

Assuming growing values of Δ (at fixed D) we can distinguish three possibilities concerned to a chord with distance Z to the magnetic axis. These three cases and their characteristic different features are exhibited schematically in Fig. 3a,b,c (the dashed curves belong to parallel but opposite to the axis positioned chords with the same distance Z).

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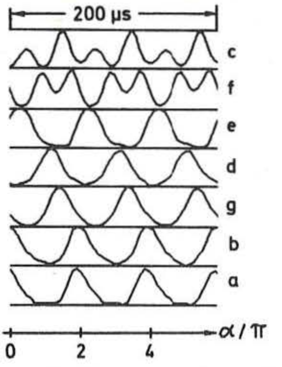

Fig. 1: SX traces of a m=1 mode with positions shown in Fig.2.

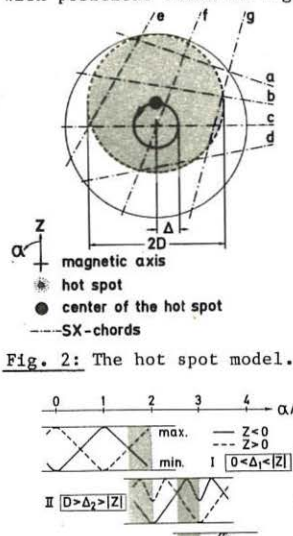

Fig. 2: The hot spot model.

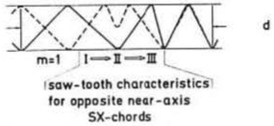

Fig. 3: Characteristics of the hot spot model for different cases with transitions (sectors hatched).

The sawtooth collapse

Near-axis SX chords show even during the conventionally defined period of the sawtooth collapse an oscillatory structure which seems to evolve from the m=1 mode with typical deviations from it. Such traces were interpreted as relaxation into an m=0 mode or a sudden change of direction of rotation.

With the assumption of a growing Δ, however, the observed behaviour as seen in the near-centre chords can well be described by the hot spot model.

Figure 3d exhibits the characteristic behaviour of two opposite chords during such a growth phase. The picture is "constructed" with the assumption of a transition from case I to case II and finally to case III each in a half period. Measured signals from two opposite SX channels with a radial distance $R = 2.5$ cm ($\approx Z$) agree very well with this model - Fig. 4b demonstrates an example.

Another example is presented in Fig. 5 (an expended section of Fig. 6). While the central chord points toward a precursor-free sawtooth the near-axis chords show clearly the development of a weak m=1 mode which is followed after two periods by the sawtooth transition with the typical evolution described above (Fig. 5a). Opposite chords with a larger distance R from the axis exhibit this transition one half period later.

Heat wave propagation

The developed picture based on the hot spot model explains the spikes in the SX traces and their irregular nature as often seen when SX signals are plotted on a large time scale (Fig. 6). The traces of this example document that the hot spot does not reach the plasma edge and the mode is damped. The hot spot decays and a heat pulse propagates to the plasma edge on a time scale roughly two orders of magnitude larger than the collapse time and with a velocity of about 10^4 cm/sec.

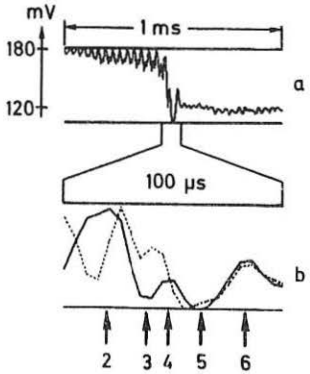

Fig. 4: a) The central signal from a sawtooth event with preceding m=1 mode. b) Vertically opposite near-axis signals during this sawtooth transition. The expended interval corresponds to the marked segment (by arrows) in Fig. 3d.

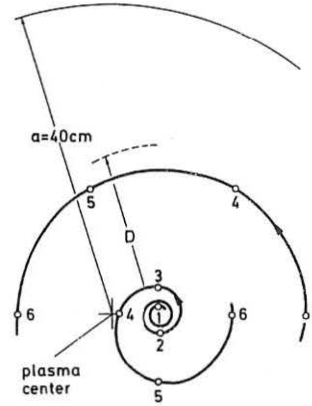

Fig. 7 The inner spiral represents the path of the hot spot centre during a sawtooth transition, the outer curve describes the movement of a second hot spot centre which is assumed to originate from the first one. The marked time points correspond to the arrows of Fig. 4b and 8.

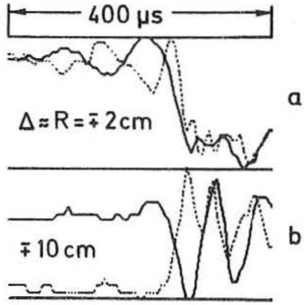

Fig. 5: A sawtooth transition after a weak but rapidly developing m=1 mode, shown for opposite channels at different distances from the magnetic axis.

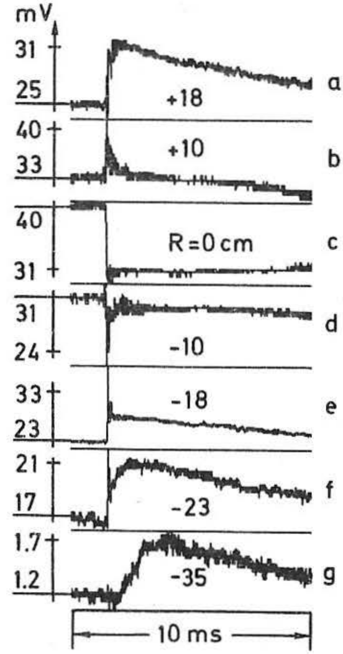

Fig. 6: A sawtooth collapse with typical spikes and the propagating heat pulse.

MHD activity

Together with the signals of a second camera the movement of the hot spot from the example described in Fig. 4 was reconstructed. Fig. 7 shows the path of the centre of the hot spot, which starts from an m=1 mode (marked time point 1) and roughly describes a spiral. After the time point 4 the determination of Δ becomes uncertain. From time point 3 on a second hot spot is clearly seen which rotates at a larger radius. The phase relation between both hot spots is well described by the assumption of a frequency ratio 3/2. Within the sawtooth transition the phase velocity of the inner hot spot decreases to about its half original value. During the m=1 mode Δ is smaller than 2 cm, the centre of the mode activity is clearly shifted outwards from the plasma centre and the mode structure is observed up to $r \approx 14$ cm.

Within the transition 2 to 3 the value of Δ increases to about 6 cm and the mode structure extends to $r \approx a/2$. The central channel shows at time point 3 a first distinct minimum and does not reach again its maximum value when the hot spot passes the horizontal channel at time point 4. It is assumed that the original hot spot is deformed and breaks up simultaneously when Δ starts to increase. Its absolute minimum shows the central channel at time point 5 and a last clear relative maximum is observed at time point 6.

In the following phase the MHD activity within a/2 becomes complicated but remains regular and ends finally in a stationary low frequency m=3 mode.

A thermal wave on a equilibrium transport time scale does not develop in this case. Beginning from time point 3 the outer plasma region ($r > a/2$) shows growing signals. Already at time point 5 these signals reach a first maximum at the top and bottom of the plasma. These maxima are followed by a somewhat larger signal at the top and a tremendous burst at the bottom region rising only 50 µsec after the beginning of the sawtooth transition with a duration of 200 µsec (Fig. 8). In this case the energy transport from the plasma core to the edge caused by a sawtooth event occurs on an ideal MHD time scale.

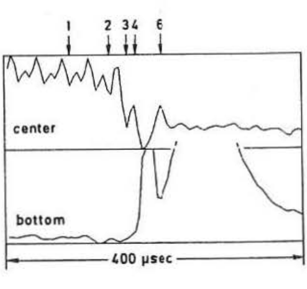

Fig. 8: SX signals from the central and edge chord during and after the sawtooth transition of Fig. 4b.

The sawtooth events discussed before were observed at the following experimental conditions. Fig. 4/7/8:
I_p = 380 kA, $q_{a,cyl}$ = 2.7;
$\bar{n}_e = 2.4 \cdot 10^{13}$ cm^{-3} increased from $1.5 \cdot 10^{13}$ cm^{-3} by means of a strong Ne puff;
NI power 3.4 MW; L-mode discharge with m=1 frequency of 26 kHz;
sample frequency 200 kHz.
Fig. 5/6:
I_p = 380 kA; $q_{a,cyl}$ = 2.9;
$\bar{n}_e = 3.5 \cdot 10^{13}$ cm^{-3}
NI power 1.7 MW + ICRH with 400 kW;
sample frequency 100 kHz.