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Stochastization as a possible explanation for some fast MHD phenomena in ASDEX Upgrade

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The role of stochastization of magnetic field lines is analyzed in fast reconnection phenomena occurring in magnetized fusion plasma during various conditions in the ASDEX Upgrade tokamak. The mapping technique [1,2] is applied to trace the field lines of toroidally confined plasma where perturbation parameters are expressed in terms of experimental perturbation amplitudes determined from the ASDEX Upgrade tokamak. In this formalism the equations for magnetic field lines take the Hamiltonian form

$$\frac{d\psi}{d\varphi} = -\frac{\partial H}{\partial \vartheta}, \qquad \frac{d\vartheta}{d\varphi} = \frac{\partial H}{\partial \psi}, \qquad (1)$$

where $\psi = \dfrac{r^2}{2a^2}$ is a toroidal magnetic flux canonically conjugated to the poloidal angle ϑ, φ is a toroidal angle, and a is a minor radius of the plasma (50 cm at ASDEX Upgrade). The Hamiltonian H

$$H = H_0(\psi) + H_1(\psi,\vartheta,\varphi) \qquad (2)$$

can be represented as a sum of the unperturbed flux

$$H_0(\psi) = \int \frac{d\psi}{q(\psi)} \qquad (3)$$

and the perturbed part of the flux

$$H_1(\psi,\vartheta,\varphi) = \sum_{m,n} H_{mn}(\psi)\cos(m\vartheta - n\varphi + \chi_{mn}) \qquad (4)$$

Here $q(\psi)$ is the safety factor characterizing the winding of the magnetic field lines, $H_{mn}(\psi)$ is the perturbation Hamiltonian which corresponds to the perturbations of the modes (m,n) with the phases χ_{mn}. It is obvious that practical implementation of the mapping method requires knowledge of the safety factor and of the perturbation Hamiltonian. Determination of these quantities from the experiment is a challenging task, because of the large uncertainties in the measurements. We have used all main MHD diagnostics (magnetic measurements, ECE, Soft X-ray cameras) to deduce these perturbations from the experimental measurements and convert them into the form suitable for the Hamiltonian formalism (see Fig.1, described in details in Ref [3,4]).

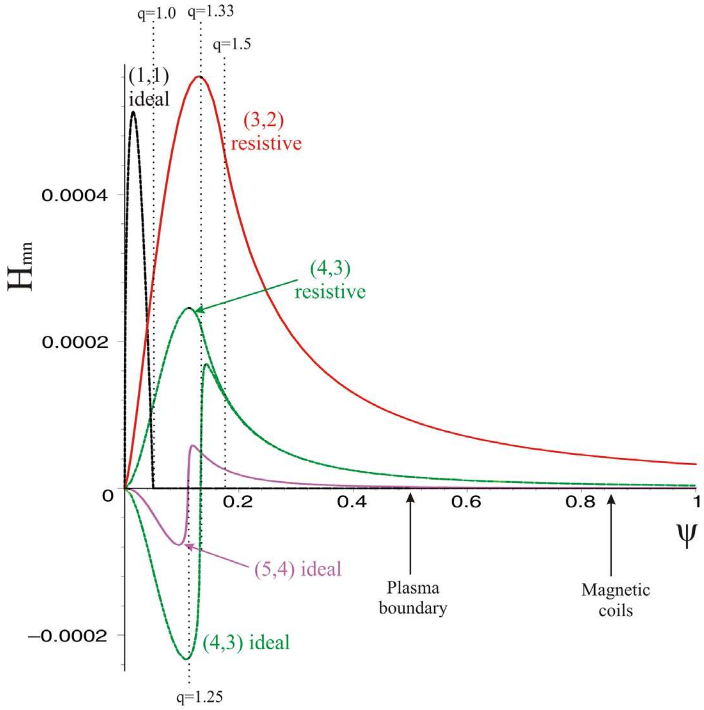

Figure 1. Experimental perturbations for the (1,1), (3,2), (4,3) and (5,4) modes as a function of magnetic flux for the ASDEX Upgrade discharge #11681, t=2.98s. The parametrization for the (4,3) mode is shown for both the ideal and the resistive variants of the instability. The parametrization for (5,4) mode is shown only for the ideal instability. The plasma boundary and the position of the magnetic coils are indicated by the arrows. The dotted vertical lines mark the positions of resonant surfaces.

In order to create stochastic region in tokamak one has to fulfill two conditions:

(1) amplitude of the perturbations must be sufficiently large

(2) all the modes have to be locked simultaneously.

Without first condition, the perturbations only slightly deform the field lines. Without second condition, perturbations from one of the resonances are screened by the neighboring resonant surfaces which have different rotation frequencies. In this paper we discuss in details two examples: frequently interrupted regime of neoclassical tearing mode (FIR-NTM) and minor disruption due to interaction of the (2,1) and (3,1) mode.

Frequently interrupted regime of neoclassical tearing modes (FIR-NTM)

During the FIR-NTM the amplitude of the NTM after reaching a certain size suddenly drops to a much smaller value [5,6]. After this the mode growth starts again. In this way the NTM amplitude never reaches its saturated value. The time in which these amplitude drops occur is very short (about 500 ms), much shorter than the resistive MHD reconnection rate (few 10 s of milliseconds in the ASDEX Upgrade). It has been suggested that this experimental observation can be explained by stochastization of magnetic field lines when the island separatrix is destroyed. We have found that experimental amplitudes of the perturbations are always sufficient to stochastise the magnetic field (first condition), but stochastization appears only during the coupling of the modes (second condition). Poincare plots are shown in Fig.2.

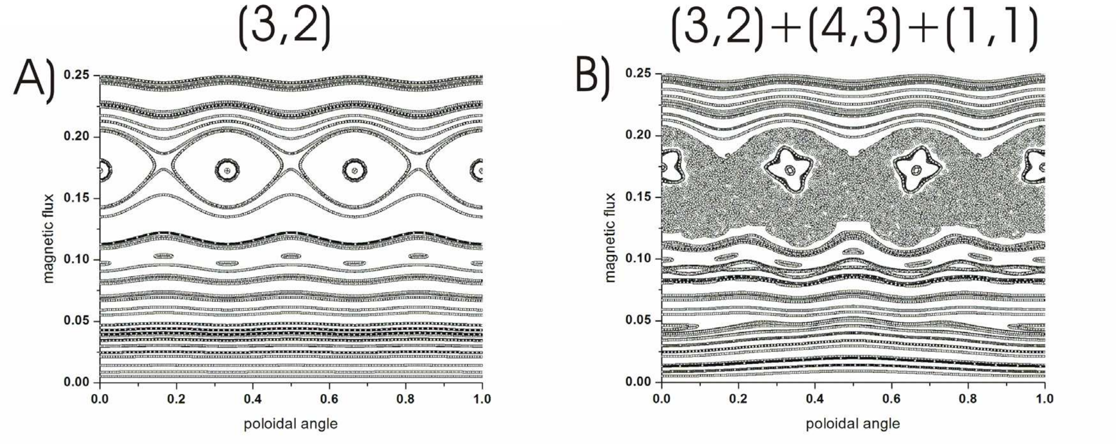

Fig.1. Poincare plots for single (3,2) tearing mode (A) and for interaction of (3,2) tearing mode, (4,3) ideal mode and (1,1) ideal modes (B). Stochastic region is clearly seen in figure (B).

The (1,1) mode, which is needed for a nonlinear coupling between the modes, has a negligible influence on stochastization itself. In this example, stochastization plays a positive role and reduces influence of the NTM on the plasma confinement.

Minor disruption due to the interaction of the (3,1) and (2,1) tearing modes

It was observed in ASDEX Upgrade discharge that series of minor disruptions are accompanied by the interaction of the (3,1) and (2,1) modes [7]. Such a minor disruption leads to temporary deterioration of confinement and flattening of the temperature profile. We have modeled this disruption by using the perturbation amplitude obtained by means of ECE measurements. This case is completely different as compared to the FIR-NTM case. These modes are always coupled (second condition) and one can observe stochastization around the islands (see Fig.3). But the full stochastization between the resonant surfaces appears only if the amplitude of the (2,1) is slightly increased (0.00008→0.00010) as shown in Fig.3. (Only in this case the first condition is also fulfilled.) One would expect that such a stochastization destroys the confinement between the corresponding resonant surfaces and flattens the temperature profile which is observed in the ECE measurements [7]. This would lead for strong reduction of the plasma confinement and minor disruption. In this example stochastization plays a negative role.

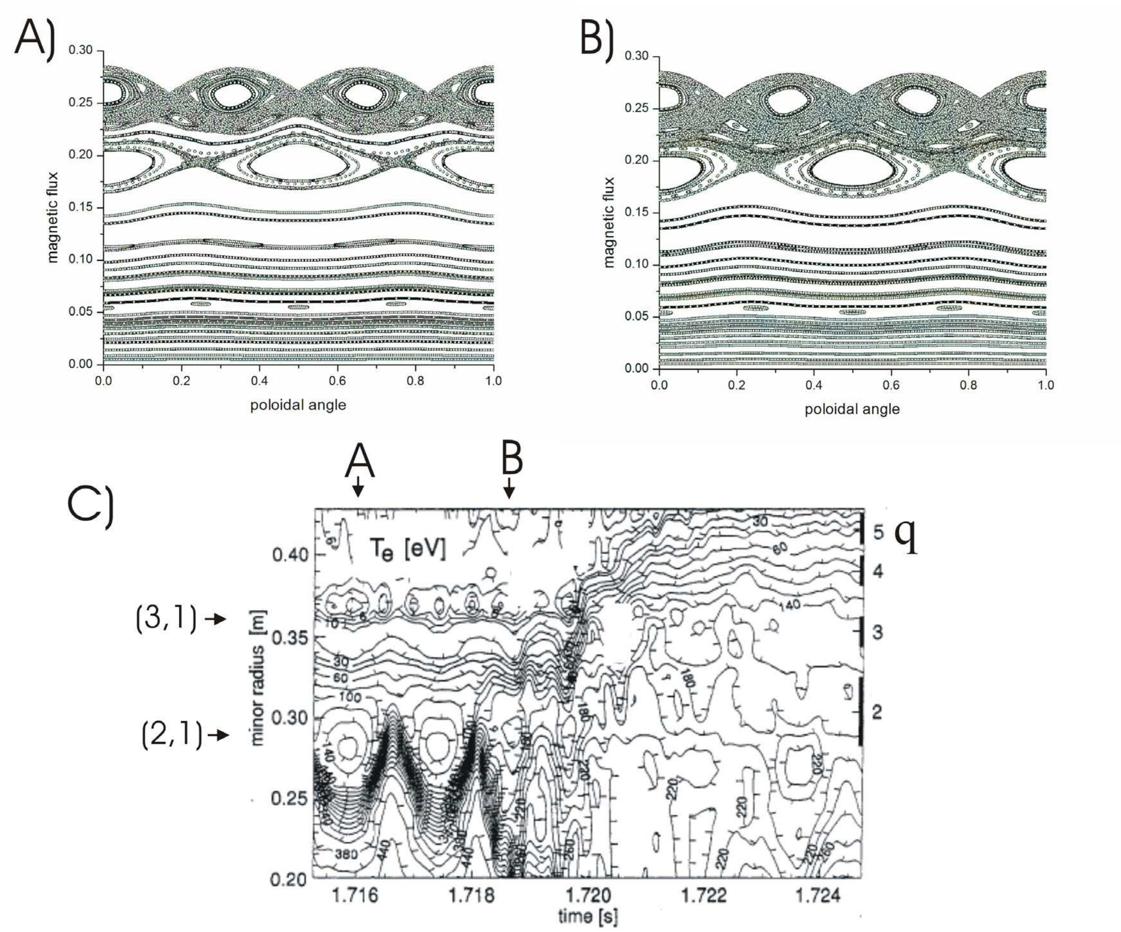

Fig.3. The (2,1) tearing mode and (3,1) tearing mode are used as perturbations. (A) Amplitude of (2,1) is 0.00008. (B) Amplitude of (2,1) is increased (0.00010) and stochastic zone is developed between the resonant surfaces. (C) ECE measurements from Ref.7. Time points for cases A and B are shown.

Our investigations demonstrate that stochastization can be regarded as a possible cause for the loss of the confinement in ASDEX Upgrade and can play an important role for completely different MHD phenomena.

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