Modified high-n/high-m tearing modes in low shear regions with high pressure gradients and high resistivity

S. Günter, S.D. Pinches, A. Gude, K. Hallatschek, K. Lackner,
and the ASDEX Upgrade-Team
MPI für Plasmaphysik, EURATOM-Association, D-85748 Garching, Germany

1 Introduction

Recently at ASDEX Upgrade modes with high toroidal mode numbers n and probably $m = n + 1$ have been observed in discharges with high impurity accumulation [1]. In Fig. 1 of [1], a wavelet analysis of the soft X-ray data for the modes of a typical shot is given. Whereas the lower (m, n) modes can be observed continuously, one finds a cascading behaviour for the higher mode numbers ($n \geq 5$). Within one cascade the modes follow each other in such a way that each subsequent mode has its own mode number raised by 1. Comparing different cascades within one shot, one finds that the highest reachable n-number decreases with time. The aim of this paper is to investigate the nature of these modes and to find out for which conditions these modes appear. These theoretical investigations have been performed using the resistive MHD code CASTOR [2].

2 Theoretical investigations of the observed modes

Once the mode numbers and the location of the modes are known from SXR measurements, one may infer the q-profile. A typical q-profile just before the first cascade is given in Fig.1 together with the corresponding current and shear profiles. The locations of the (3,2) and the (11,10) modes are shown. The q-profiles of the shots considered have a characteristic flat region near the $q = 1$ surface where the high (m, n) modes are located.

Due to the large current gradient and the small shear all modes $(m, n) = (n + 1, n)$ with $2 \leq n \leq 10$ are tearing mode unstable in a circular cylinder. However, in a toroidal plasma, even for vanishing pressure, only those modes up to medium mode numbers are tearing mode unstable if one neglects mode coupling. Adding only a very small pressure, these modes also become stabilized.

Including the coupling between modes with different poloidal mode numbers m, however, the pressure dependence of all considered modes changes dramatically. The growth rates for various mode numbers (m, n) versus pressure are given in Fig. 2. As can be seen, modes with low mode numbers are not influenced by pressure at all, except for very low pressures. For medium mode numbers one finds a stabilizing effect due to pressure only for extremely low pressures. With increasing pressure mode coupling becomes more important and leads to rising growth rates.

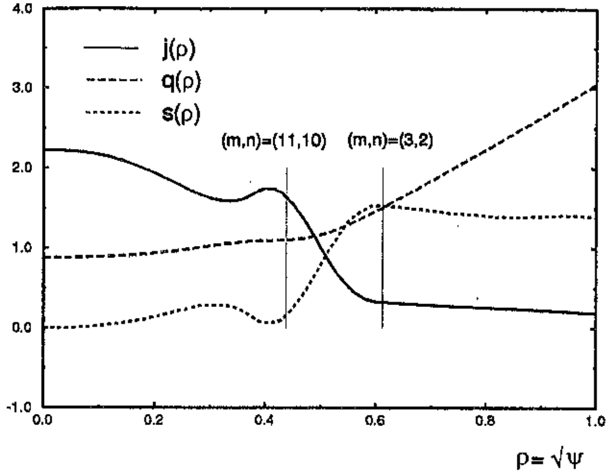

Fig. 1. Typical profiles for current (j), safety factor (q), and shear (s) for ASDEX Upgrade discharge 8529.

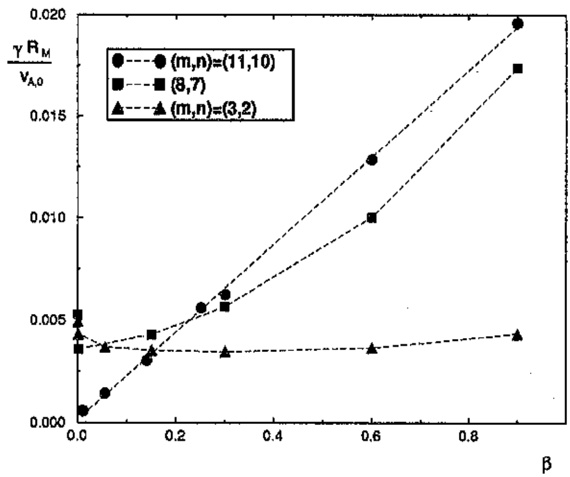

Fig.2. The pressure dependence of the growth rate for the modes $(m,n) = (3,2), (8,7), (11,10)$. The growth rate is normalized to $1/\tau_{A,0}$, where $\tau_A, 0$ is the Alfvén time.

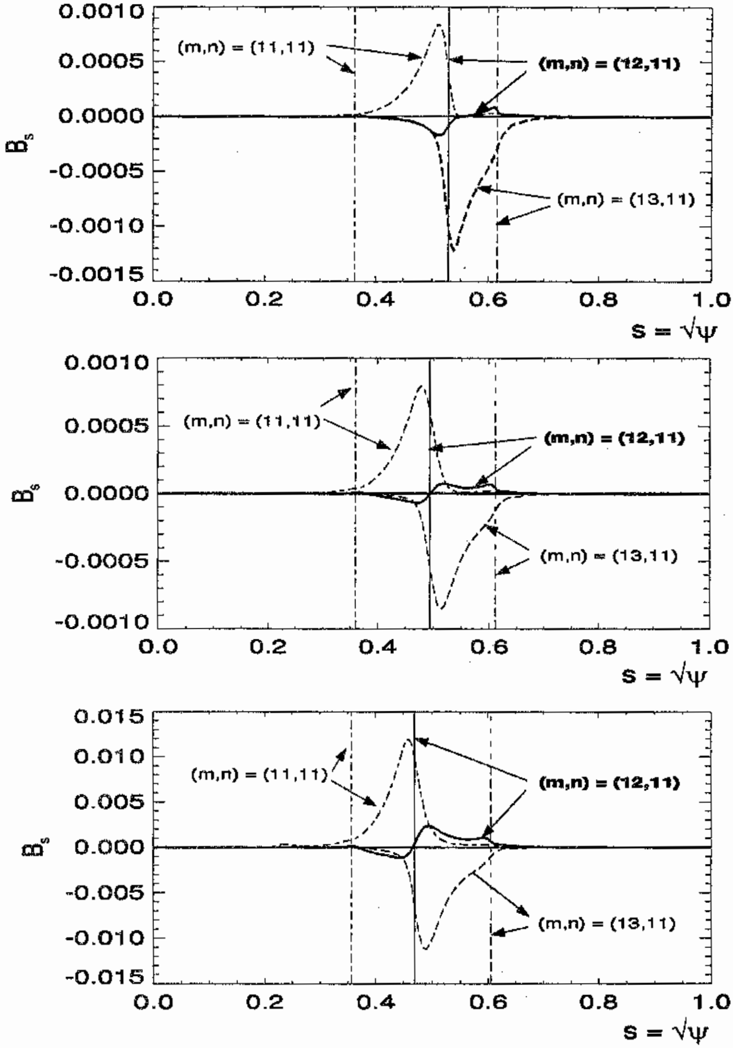

Fig. 3. The radial magnetic field B_s for the $(12,11)$ mode. The Fourier components $(11,11)$ and $(13,11)$ together with their corresponding rational surfaces are included. The pressure rises from top to buttom: $\beta_{pol} = 0.05, 0.3, 0.6$.

Modes with very high mode numbers would be stable in a torus without mode coupling even for vanishing pressure. Due to mode coupling, however, their growth rates rise proportional to β_{pol}. Varying the pressure gradient at the rational surface, keeping β_{pol} constant, one again finds a linear dependence between growth rate and pressure gradient. One may conclude, therefore, that the pressure dependence of the growth rate is mainly caused by the pressure gradient at the corresponding rational surface.

In order to study the properties of the observed modes one has to consider their eigenfunctions. The most dramatic change due to mode coupling can be seen in the radial magnetic field B_r. The influence of the mode coupling rises with increasing mode number and with higher pressure. The influence of the pessure is shown in Fig. 3 for the $(12, 11)$ mode. It becomes obvious that the radial fields of the neighbouring Fourier components $(m = n, n+2)$ become very important at the $q = (n+1)/n$ surface. For very high mode numbers such as that shown in Fig. 3, the radial field at this rational surface predominantely is given by the harmonics $m \neq n+1$. The radial field of the component with $m = n+1$ may become zero or even change the direction at its rational surface if the pressure becomes high enough. In this case there would be no radial magnetic field with the right helicity at the considered rational surface that could cause a tearing of the magnetic field lines. Thus, through mode coupling the classical tearing modes change their properties completely. Nevertheless, the variation of the growth rates with respect to resistivity of the modes considered is proportional to $\eta^{3/5}$ corresponding to the well known tearing mode scaling.

The investigation of tearing modes with high mode numbers requires the inclusion of many poloidal harmonics as well as a high radial resolution. To ensure that the results are reliable, convergence studies have been carried out. Taking the experimental pressure it has been shown that the inclusion of 12 poloidal harmonics and 100 radial grid points is sufficient even for the highest mode numbers.

3 Conclusions

The observed high-n/high-m modes in ASDEX Upgrade discharges with high impurity accumulation have been shown to be modified tearing modes. These modes are unstable in low shear regions due to mode coupling. High resistivities, high pressure and current gradients at the corresponding rational surfaces as well as low shear support the mode growth.

[1] A. Gude, K. Hallatschek et al., this conference

[2] W. Kerner et al., JET report JET-P(97)04, submitted to J. Comp. Phys. (1997)