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On the Stabilisation of Neoclassical Tearing Modes with ECRH at High β_N in ASDEX Upgrade

G. Gantenbein, A. Keller[1], F. Leuterer[1], M. Maraschek[1], W. Suttrop[1], H. Zohm[1], ASDEX Upgrade-Team[1]

Institut für Plasmaforschung, Universität Stuttgart, Pfaffenwaldring 31, D-70569 Stuttgart
[1] Max-Planck-Institut für Plasmaforschung, EURATOM Association, Boltzmannstrasse 2, D-85748 Garching

Introduction

A very important parameter, characterising the performance of a fusion plasma device is the ratio of the plasma pressure p to the magnetic pressure, $\beta = p/(B^2/2\mu_0)$, or, in normalised form $\beta_N = \beta[\%] /(I_p[MA]/a[m]B[T])$. In tokamak discharges macroscopic instabilities like neoclassical tearing modes (NTMs) can be excited at high β_N values well before the ideal MHD limit has been reached, which is usually calculated to be $\beta_N \approx 4$ for the discharges considered in this contribution. These modes are driven by the gradients of the current and density profiles and reduce the local bootstrap current which further enhances the destabilisation of the instability. The presence of these modes leads to an enhanced heat transfer in radial direction and thus to a loss of confinement. In some cases these modes can lead to a slow down of the plasma rotation and a major disruption.

Since it is planned to operate next step machines, such as ITER, at highest possible β_N values, where the excitation of NTMs is highly probable it is important to study the behaviour of these instabilities and to develop appropriate techniques to avoid or suppress the NTMs. Recent experiments and calculations show that it is possible to replace the missing bootstrap current locally by injection of RF power at the electron cyclotron resonance frequency and thus to stabilize the NTMs [1, 2, 3].

Experimental conditions

In ASDEX Upgrade the plasma configuration for these experiments has been a lower single null high confinement mode (H-Mode) with edge localised modes (ELMs).The inductively driven plasma current has been kept constant to 0.8 MA, with the feedback control system the particle density has been fixed to $\langle n_e \rangle \approx 5 \times 10^{19}$ m^{-3}. We used a strongly NBI heated target plasma ($P_{NBI} \approx 10 - 15$ MW) with $B_t \approx 2$ T in the plasma center. In such a configuration a rotating NTM with poloidal mode number m= 3 and toroidal mode number n= 2 may develop at the q= 3/2 surface, if β_N is sufficiently high and a seed island of sufficient size is generated.

The magnetic island is detected by a set of Mirnov coils surrounding the plasma in poloidal and toroidal direction. With the ECE diagnostic the profiles of the electron temperature $T_e(R,t)$ are measured and correlated to the data of the Mirnov coils. Thus we determine the localisation of the ECRH absorption and the position and width of the island with a spatial resolution of 1-2 cm. A typical value of the saturated island width w is 8–10 cm and a deposition width of d= 4-5 cm.

Although stabilisation of NTMs works with electron cyclotron resonance heating (ECRH) and electron cyclotron current drive (ECCD), we report here only ECCD results, because this method is more efficient [4]. The RF power is injected from the low field side (LFS) and delivered by 3-4 gyrotrons (up to 1.6 MW in the plasma), operating at 140 GHz. The absorption takes place on the high field side (HFS) in 2nd harmonic X-mode [5].

It has been shown that the effect of the ECCD on the development of the magnetic island depends sensitively on the matching of deposition and resonant q-surface [6]. The region in which stabilisation is efficient has been estimated to be ≈4 cm, which is approximately half of the saturated island width. Since there is a small jitter in the position of the island from discharge to discharge and the plasma parameters itself may change during the discharge due to e.g. additional P_{NBI}, some of the experiments have been performed with a variation of the toroidal magnetic field (B_t) during the discharges. Thus a movement of the RF deposition relative to the island position is obtained and the deposition is slowly swept across the island in every discharge.

Experimental Results of Stabilisation with ECCD

Fig. 1 illustrates a typical discharge where the 3/2 NTM is completely stabilised. In this discharge B_t is kept constant and the island vanishes immediately after ECCD is switched on. The reduction of β_N due to the appearance of the NTM is partially recovered. At t= 2.8 s the NBI power is increased up to 12.5 MW and β_N increases also up to 2.7 until the NTM is triggered again at t≈ 3.1 s and grows to its saturated width. Since this happens in the presence of ECCD injection it is assumed that the deposition and island position does not match any more. This assumption is supported by the analysis of the ECE signals which show a radial shift of the island by about 5 cm.

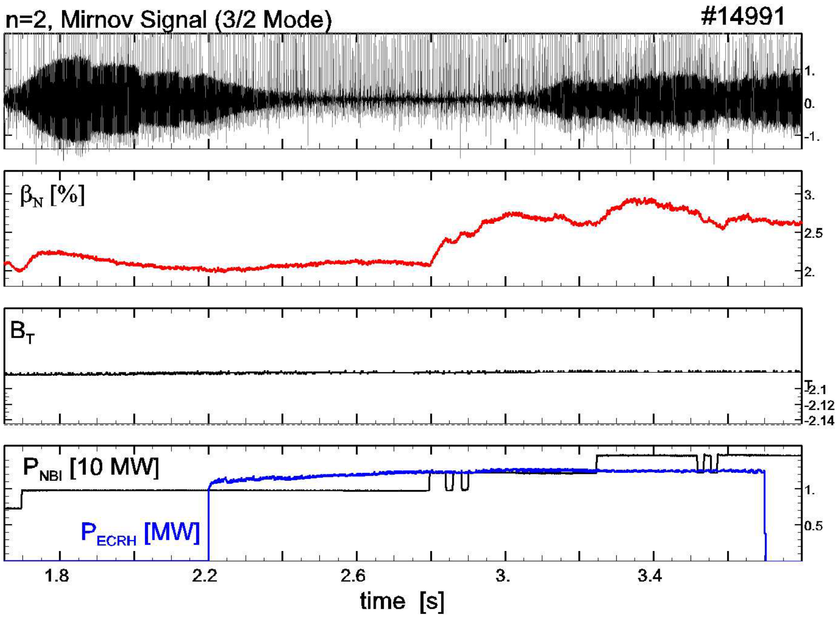

Fig. 1: Stabilisation of 3/2 NTM with fixed magnetic field B_t

A discharge with a very similar timing is given in Fig. 2. However, in that case B_t is changed during the shot, thus providing that the ECCD deposition meets the resonant q-surface and consequently keeps the discharge free from 3/2 NTM in a steady state for about 300 ms at $\beta_N \approx 2.6$. This situation is constant until we increase the NBI power from 12.5 to 15 MW at t= 3.25 s. In that case β_N increases temporarily up to 3.0 and 3/2 NTM is triggered again at the end of the B_t scan.

Conclusions

In this paper we report on NTM stabilisation at ASDEX Upgrade. Up to now highly reproducible discharges have been used to demonstrate the influence of ECCD on the island evolution. The in-situ tracking of the island position during the discharge and the corresponding control of the ECRH system is considered as very important. This control includes a trigger signal for the gyrotrons as well as the correct adjustment (poloidal) of the launching mirrors. The built-up of such a system at ASDEX Upgrade is presently carried out.

Many discharges at ASDEX Upgrade are limited by the 2/1 mode at the q= 2 surface. Since this island is located at a larger radius r, where T_e is smaller and thus the current drive efficiency is reduced, it is assumed that in general the stabilisation of this NTM will require more ECRH power then the 3/2 mode. Efforts will be made to stabilise this mode in the next experimental campaign.

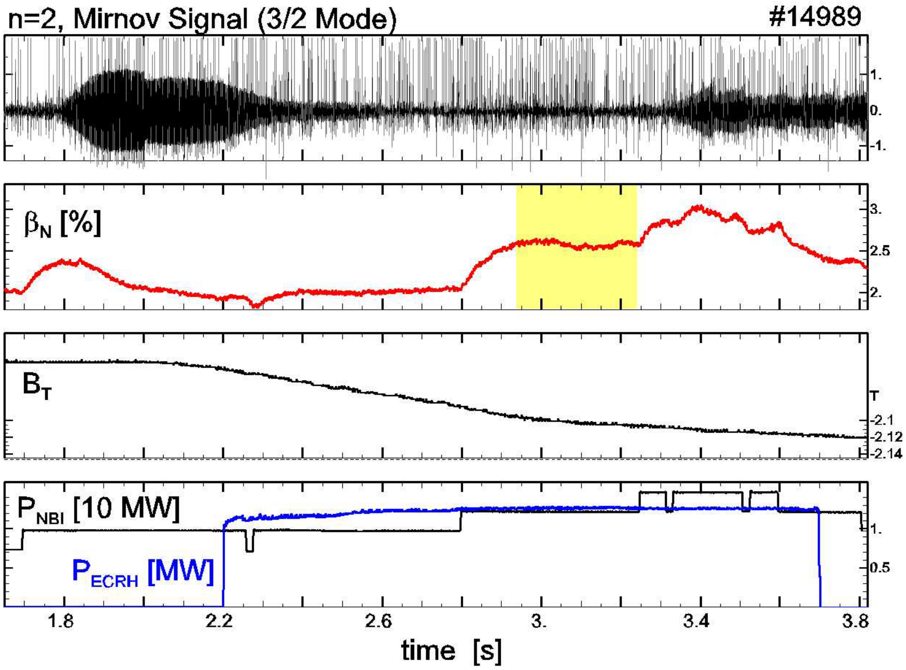

Fig. 2: Stabilisation with varying magnetic field and steady state interval at high β_N.

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