

MHD PHENOMENA IN LOW AND REVERSED SHEAR PLASMAS

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1. Interchange mode at ASDEX Upgrade

The discharges we are referring to are characterised by strong impurity accumulation of high-Z elements which leads to significant radiation in the plasma centre. The resulting time development of the electron temperature is given in Fig. 1. Since the density profiles are rather flat in these shots, for times later than 3 s a positive pressure gradient can develop. A more detailed analysis shows that the pressure gradient changes its sign from time to time. After 3.1 s a ($m = 4, n = 3$) mode has been observed by soft X-ray (SXR) as well as by Mirnov diagnostics. The growth time of this mode has been found to be less than $500 \mu\text{s}$. In Fig. 2 the SXR amplitude of the ($4, 3$) mode is given together with the pressure gradient at $\rho = 0.60 \dots 0.65$. It is obvious that the mode's amplitude is large for positive pressure gradients and weakens strongly when the pressure gradient becomes negative. A wavelet analysis for the mode considered together with its frequency as expected from the electron diamagnetic drift and the measured plasma rotation is given in Fig. 3. As is seen, the measured mode frequency is in quantitative agreement with the expected variations in the electron diamagnetic drift frequency with the pressure gradient.

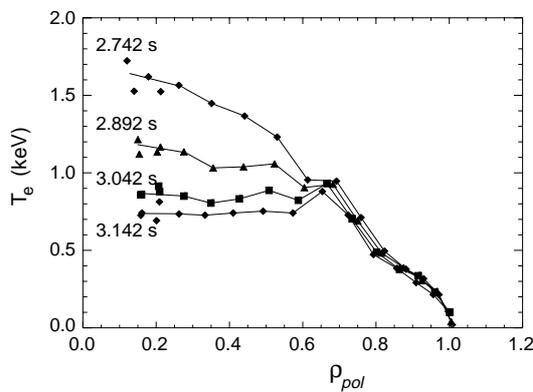


Fig. 1: Electron temperature profiles versus the square root of the normalized poloidal flux for different times of ASDEX Upgrade shot #8533.

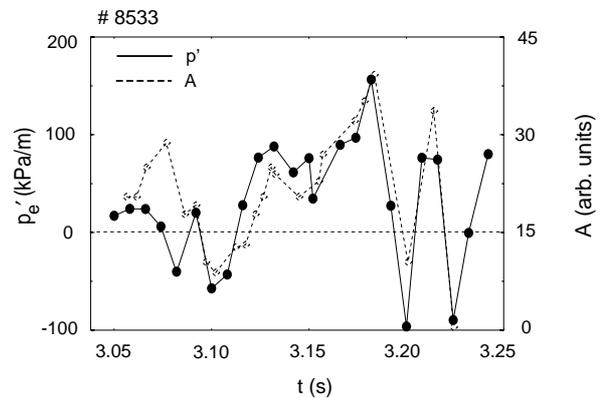


Fig. 2: Pressure gradient at $\rho_{pol} = 0.60 \dots 0.65$ together with the amplitude A of the observed ($4, 3$) mode.

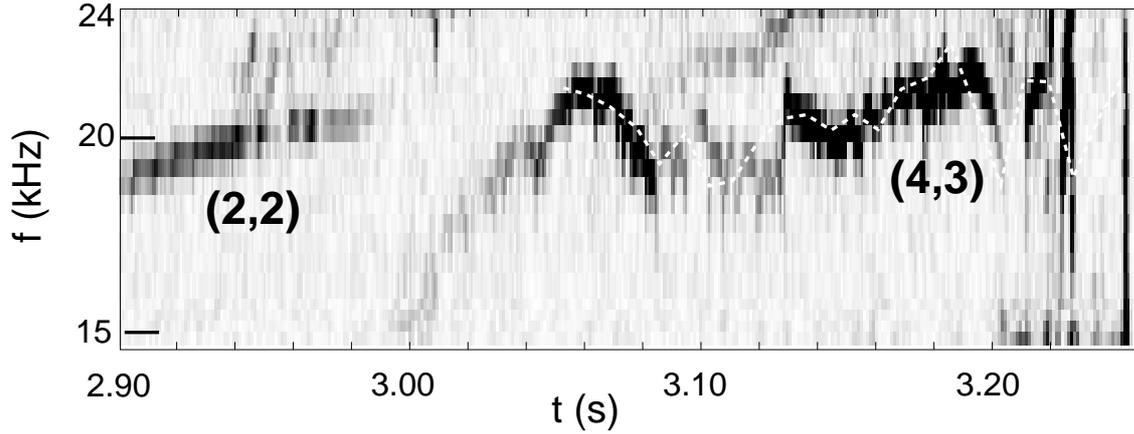


Fig. 3: Wavelet amplitude plot of the $(4, 3)$ mode. Dark areas represent mode activity. The dashed line gives the frequency variation of the electron diamagnetic drift together with slow changes of the toroidal plasma rotation.

In order to identify the observed mode, a stability analysis using the resistive MHD code CASTOR has been performed. Since at ASDEX Upgrade no direct measurement of the current profile is possible, one has to rely on indirect information. 200 ms before the onset of the $(4, 3)$ mode the q -profile can be found from cascades of high- n tearing modes [1,2]. The time development of the q -profile afterwards has been found carrying out a transport analysis with the ASTRA code [3]. Using the resulting q -profile for CASTOR calculations, the observed mode has been identified to be an interchange mode driven by the positive pressure gradient. The growth rate of the mode has been found to be proportional to $p^{2/3}$ as expected for interchange modes. [4]

2. Double tearing modes

One of the most important resistive MHD instabilities in advanced scenarios is the double tearing mode. Reversed shear plasmas have been investigated at TEXTOR, where the q -profile is measured via polarimetry [5]. The reversed shear again has been reached by impurity accumulation in the plasma centre [6]. We have investigated discharges with similar q -profiles but different heating scenarios. Whereas in ohmic discharges one finds strong mode activity leading to internal disruptions, no significant MHD activity has been observed in NI heated plasmas. A stability analysis for the ohmic discharges using the CASTOR code shows both the $(2, 1)$ and the $(3, 2)$ double tearing mode (DTM) to be unstable with linear growth rates $\gamma_{(2,1)} = 3.3 \cdot 10^{-3}/\tau_A$ and $\gamma_{(3,2)} = 2.7 \cdot 10^{-3}/\tau_A$ with τ_A being the Alfvén time. Due to the larger pressure in NI heated discharges, the DTMs are less unstable. The growth rate of the $(2, 1)$ DTM, e.g., is reduced by a factor of 10. Since differential rotation, not included in the CASTOR code, would further stabilise the DTM, one would not expect DTMs to be unstable in NI heated discharges, where tangential injection leads to sheared toroidal plasma rotation. This is in good agreement with the experimental observations. The internal disruptions in ohmic discharges could be explained by overlapping $(2, 1)$ and $(3, 2)$ islands, which has to be proved

by a non-linear stability analysis.

Whereas in discharges with strong impurity accumulation in the plasma centre the equilibrium bootstrap current is negligible, for investigating usual advanced scenarios one should include the influence of the perturbed bootstrap current due to the pressure flattening across magnetic islands. Therefore, the non-linear evolution of the neoclassical double tearing mode has been investigated by numerical modelling [7]. As predicted by analytical theories [8], the perturbed bootstrap current is found to have a stabilising effect on the inner island but a destabilising effect on the outer island as seen in Fig. 4.

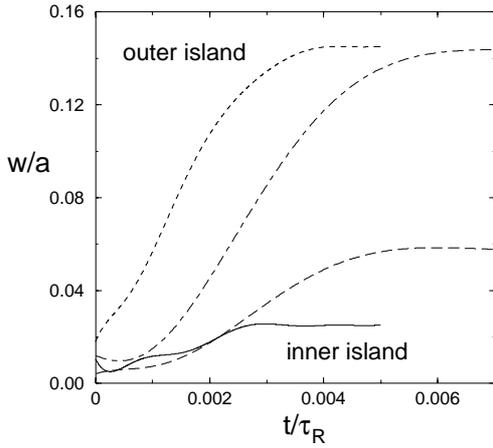


Fig. 4: ($m = 3, n = 1$) saturated island width normalized to the minor plasma radius versus time (normalized to the resistive time). The solid and dotted curves represent the inner and outer island width, respectively, taking into account the bootstrap current. To obtain the dashed and dashed-dotted curves, the bootstrap current has been neglected.

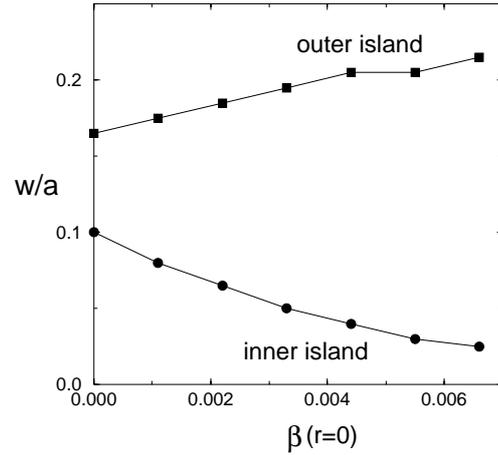


Fig. 5: The normalized saturated island width as a function of $\beta(r = 0)$, which is proportional to the equilibrium bootstrap current.

The influence of pressure, and hence, of the fraction of the equilibrium bootstrap current, on the growth of DTMs is demonstrated in Fig. 5. Here the width of both islands is given as a function of $\beta(r = 0) = p(r = 0)/(2\mu_0 B_{0z}^2)$, which, after normalisation, is proportional to the equilibrium bootstrap current. In contrast to analytical theories, our simulations are not restricted to a large distance between the two rational surfaces and include plasma rotation. Since the growth of DTMs is strongly affected by the coupling of the two rational surfaces, the influence of the distance between the rational surfaces, dr , is investigated in Fig. 6. It is seen that both the inner and the outer island width increase as dr decreases due to the stronger coupling between the two islands. The perturbed bootstrap current reduces the inner island width and decreases the outer island width. Since for the largest distance ($dr = 0.55$) the effect of the bootstrap current on the outer island is negligible, the outer island is somewhat smaller compared to the purely resistive case due to the weaker coupling to the inner island. As seen

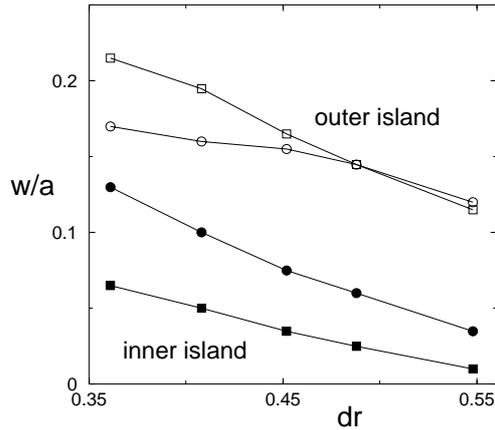


Fig. 6: The normalized saturated island width as a function of the distance between the two rational surfaces, dr . The curves with solid and empty squares represent the inner and outer island width taking into account the effect of the perturbed bootstrap current. The curves with solid and empty circles represent the inner and outer island width obtained neglecting the bootstrap current.

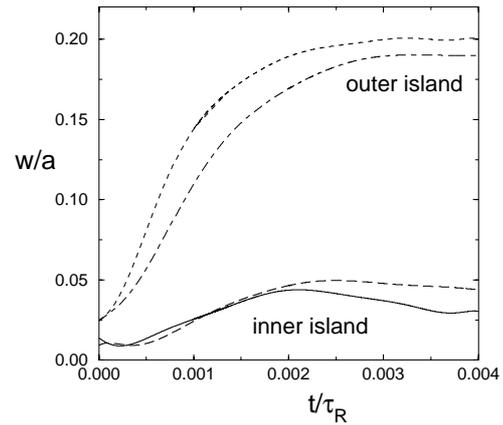


Fig. 7: The normalized island width as a function of time, where the solid and dotted curves represent the inner and outer island width, respectively, obtained neglecting differential rotation. For a differential rotation of $\Delta\omega = 6.3 \cdot 10^4 / \tau_R$ the dashed and dashed-dotted curves result.

in Fig. 7, sheared plasma rotation plays a stabilising role in the island's growth. However, this effect is important only for small islands. Once the outer island is sufficiently large driven by the perturbed bootstrap current, the phase between the two islands will be locked and both islands rotate with the same frequency. Since the DTM is mainly driven by the outer mode, which is destabilised by the perturbed bootstrap current, its stabilisation or the decoupling of the modes by differential rotation is necessary for stabilising the DTM.

References

- [1] A. Gude, K. Hallatschek et al.: Plasma Phys. Control. Fusion **40** 1 (1998)
- [2] S. Günter et al.: Nucl. Fusion **38**, 325 (1998)
- [3] G.V. Pereverzev: "ASTRA: An automatic system for transport analysis", IPP-Report 5/42 (1991)
- [4] S. Günter et al.: "Interchange modes in low shear regions with locally inverted pressure profiles", *submitted to Nucl. Fusion* (1998)
- [5] H.R. Koslowski, H. Soltwisch: Fusion Engineering and Design **34-35**, 143 (1997)
- [6] H.R. Koslowski et al.: Plasma Phys. Control. Fusion **39**, B325 (1997)
- [7] Q. Yu, S. Günter: "Numerical modelling of neoclassical double tearing modes", *submitted to Nucl. Fusion* (1998)
- [8] Q. Yu: Phys. Plasmas **4**, 1047 (1997)