Stabilization, with ECRH, of an *m/n = 2/1* tearing mode preceding a radiative density limit disruption

F. Salzedas, A.A.M. Oomens, F.C. Schüller and the RTP team

FOM-Instituut voor Plasmafysica `Rijnhuizen', Association Euratom-FOM,

Trilateral Euregio Cluster, P.O.Box 1207, 3430 BE, Nieuwegein, The Netherlands

The presence of low *m* MHD modes in a plasma discharge, can lead to a degradation of the confinement of energy and particles. In particular it is generally accepted that the *m/n = 2/1* mode plays a major role in the onset of density limit disruptions [1], where the energy confinement is totally lost. Motivated to seek a solution for these problems, the stabilization of the non-saturated *m/n = 2/1* tearing mode during the radiative contraction of the current channel that precedes major density limit disruptions, was studied at RTP (a = .164 m, R_0 = 0.72 m), with both modulated and continuous (cw) Electron Cyclotron Resonance Heating (ECRH). Tearing modes have already been stabilized elsewhere both with cw [2] and modulated [3] ECRH, however, in those cases radiation losses were not significant. Delay of density limit disruptions with ECRH was achieved in T-10 [4], but problems in reproducing the operation conditions made the analysis difficult.

In the experiments here described, good reproducibility of the disruption events was achieved by puffing *Neon* gas in a *Helium* Ohmic plasma. The evolution of the MHD instabilities in these plasmas is equivalent to the ones observed in pure *Hydrogen* Ohmic plasmas. However, due to the high effective ion charge (Z_{eff}) of Ne, the Ohmic density limit is kept low ($<n_{emax}> \approx$ 3.4 x 10^{19} m^{-3} or 3.9 x 10^{19} m^{-3}, with I_p = 80 or 100 kA respectively, and 1.98 T $\leq B_\phi \leq$ 2.39 T, 4 $\leq q_a \leq$ 6) and below the cut-off density of the 20 channel ECE radiometer and of the gyrotron. The gyrotron used in these experiments can deliver up to 320 kW of microwave power (P_{ECRH}) either modulated or cw, at the frequency of 110 GHz, in 2nd harmonic X mode. A signal proportional to the m=2 component of the poloidal magnetic field (B_θ), derived from 12 Mirnov coils, was used to trigger the gyrotron. When in cw operation, only the amplitude information was used to trigger at a predefined threshold, while for modulated ECRH both the amplitude and the phase of the signal where used to control the microwave beam.

Sawteeth always preceded density limit disruptions in the discharges studied here. As n_e approaches $<n_{emax}>$, radiation in the edge of the plasma enhances the energy loss, inducing a contraction of the current profile. This destabilizes the m/n = 2/1 mode whose amplitude increases continuously during $\approx$ 1.5 ms, after which a major density limit disruption occurs. In these conditions the growth rate of the mode has to be reduced in less than 1.5 ms in order to prevent the disruption. In this paper, two types of experiments done in RTP to control the

growth rate of the tearing mode, will be described. In the first type, cw ECRH could stabilize the mode. In the second type, modulated ECRH in phase with the O-point could not stabilize the mode.

Due to limitations on the toroidal magnetic field, B_ϕ, it was difficult to increase ρ_{dep} (the 110 GHz cold resonance) beyond $r_{q=2}$, for $I_p = 100$ kA, so some experiments with cw ECRH were carried out at 80 kA. The position of the q = 2 rational surface ($r_{q=2} = 0.55a$ for 80 kA and $r_{q=2} = 0.61a$ for 100 kA) was inferred from the measured ECE $T_e(r)$, and it was in agreement with q(r) calculated from high resolution Thomson scattering $T_e(r)$ assuming Spitzer resistivity. It was observed that whenever $0 \leq \rho_{dep} \leq 0.73\,a$ and $P_{ECRH} > 0.2\,P_{Ohm}$ the m = 2 growth rate could be decreased. In particular for $\rho_{dep} \approx r_{q=2}$ and $P_{ECRH} > 0.3\,P_{Ohm}$ the amplitude of the m = 2 mode could be decreased to noise level in ≈ 4 ms.
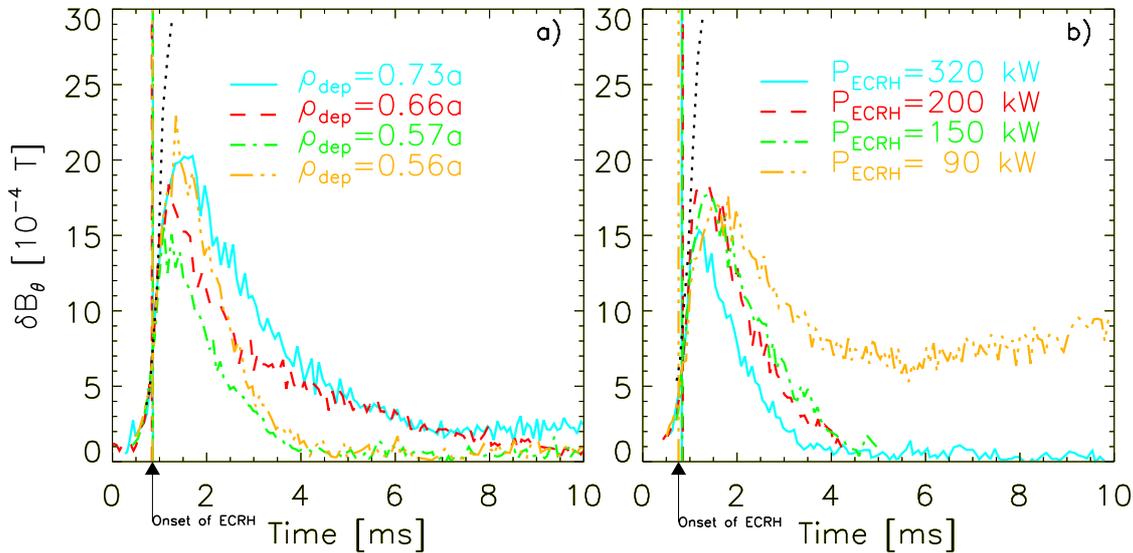

Figure 1 - Evolution of $\delta B_\theta^{m=2}$ amplitude a), for a ρ_{dep} scan around $r_{q=2}$ with $P_{ECRH} = 320$ kW, and b), a P_{ECRH} scan for $\rho_{dep} \approx 0.62a$. The dotted line refers to a discharge without ECRH that disrupted. $I_p = 80$ kA and $P_{ohm} = 280$ kW at the onset of the ECRH.

The further ρ_{dep} is moved outside $r_{q=2}$ (towards the edge of the plasma) the longer it takes to stabilize the mode, due to a slower amplitude decrease of the mode and not to the fact that the maximum of dB_θ is higher. Fig. 1a) shows that for $\rho_{dep} = 0.73a$, the mode amplitude could not be reduced to noise level. On the other hand, for $\rho_{dep} < r_{q=2}$ the time to reach full stabilization does not increase. So it is clear that it is not necessary that $\rho_{dep} = r_{q=2}$ to stabilize or even to reach the fastest decrease rate. The fact that stabilization is less effective for larger ρ_{dep}, where $T_e(r)$ is lower is probably due to the lower P_{ECRH} absorption that occurs in the colder plasma edge.

In Fig. 1b) it is seen that the decrease rate of the mode is practically insensitive to P_{ECRH}. Only for $P_{ECRH} \approx 0.3\,P_{Ohm}$ the initial decrease rate is smaller becoming negative 4 ms after the onset of the ECRH, allowing the mode to saturate and slowly increase in amplitude. It

should be stressed that when the mode reaches saturation, particle confinement is affected and the density stays at the Ohmic limit and does not increase until the disruption, although gas is still being puffed into the chamber. This is in contrast to the cases where the mode is suppressed, where n_e continues to increase until, depending on the total input power, a new density limit is reached.

The effect of ECRH on the T_e profile when $\rho_{dep} \approx r_{q=2}$ is to decrease the first and second derivatives of the T_e profile around $r_{q=2}$, as can be seen on Fig. 2, where high resolution Thomson scattering profiles of the electron density, $n_e(r)$, $T_e(r)$ and electron pressure $p_e(r)$ are shown, before and during the ECRH. Fig. 2 also shows that after the m=2 mode is suppressed n_e (and also p_e) increases in the edge and even more in the core of the plasma, but not in the region in between.
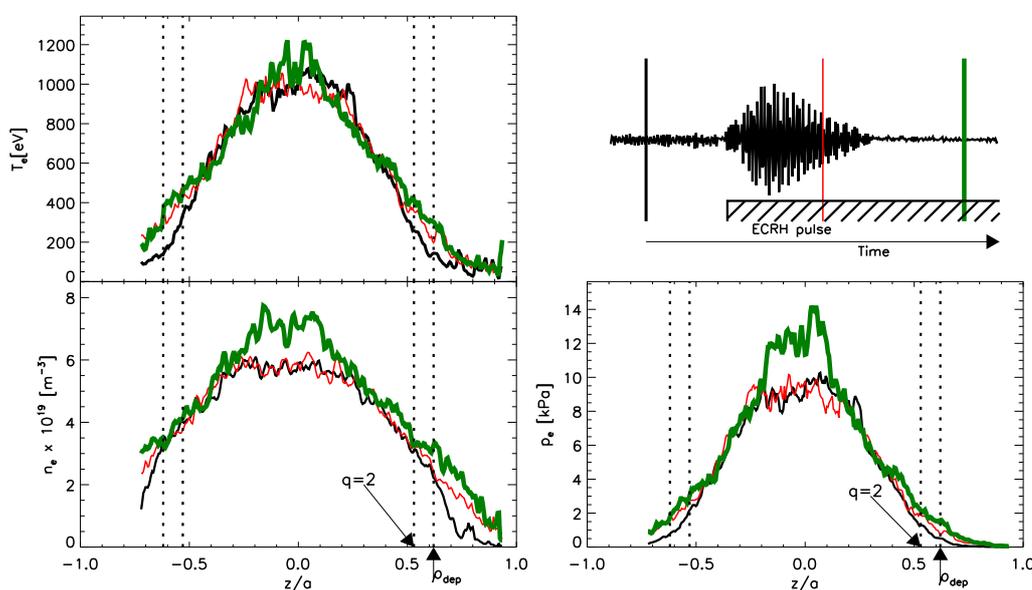

Figure 2 - High resolution Thomson scattering profiles of n_e, T_e and p_e, from three different discharges and at three different times relatively to the m = 2 mode (black line 6 ms before the mode, red line during the mode suppression, green line 7 ms after the mode was suppressed). The time sequence is indicated in the top right corner. The half-width of the absorbed EC power profile is $\approx 0.06a$. $I_p = 80$ kA, $q_a = 5.5$, $P_{ECRH} = 320$ kW, $P_{Ohm} = 280$ kW.

Using the knowledge about the stabilization efficiency for different ρ_{dep}, acquired in the cw experiments [5] modulated ECRH was applied on the m = 2 mode during approximately half a toroidal rotation period of the mode. By adding a delay to the trigger signal the power deposition could be made to coincide with different parts of the mode, in particular around the O or X points.

The geometry of the experimental setup was such that the P_{ECRH} pulses are in phase with the m = 2 T_e perturbations measured by the ECE radiometer. This is illustrated in Fig. 3 that shows a discharge where P_{ECRH} was deposited around the O point. The maximum of the

P_{ECRH} pulse (that correspond to 200 kW) coincides with the minimum of the T_e perturbations, which are due to the colder O point.

As it can be seen in Fig. 3 the mode could not be stabilized. Depositing the power at the X point produced the same result, i.e. neither X or O point heating could stabilize the mode.
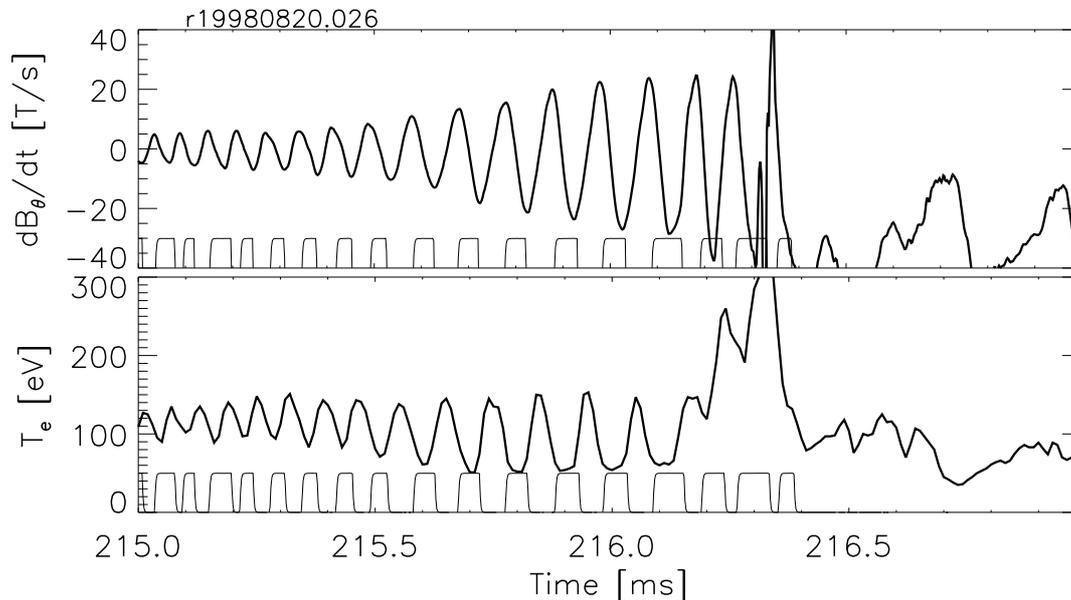

Figure 3 - Modulated ECRH around the O point of the mode. The electron temperature was measured at $r = 0.58a$. $I_p = 100$ kA, $q_a = 4$, $\rho_{dep} = 0.67a$, $P_{ECRH}^{max} = 200$ kW and $P_{Ohm} = 360$ kW.

In conclusion it was observed in RTP that for $0 \leq \rho_{dep} \leq 0.73a$ and $0.2\ P_{Ohm} < P_{ECRH} < 1.45\ P_{Ohm}$, the m/n = 2/1 tearing mode that precedes a radiative density limit disruption, could be stabilized with continuous ECRH.

Depositing modulated ECRH, at $\rho_{dep} \approx r_{q=2}$, in phase with the O point no stabilization was observed. This result is in apparent contradiction with numerical simulations [6] that predicted that modulated ECRH should be more efficient than cw, however in these simulations energy losses by impurity radiation were not taken into account which may explain the discrepancy in results. The experiments in RTP indicate that radiation losses play a dominant role in the mode destabilization and that they cannot be neglected in numerical simulations.

References
[1] F.C. Schüller Plasma Phys. Control. Fusion **37** (1995) A135.
[2] K. Hoshino *et al.*, Phys. Rev. Lett. **69** (1992) 2208.
[3] K. Hoshino *et al.*, in *Proc. of the 15th Int. Conf. on Plasma Phys. and Contr. Nucl. Fusion, Seville, Spain, 1994* (IAEA, Vienna, Austria, 1995), **Vol. 1**, p. 697.
[4] D. A. Kislov *et al.*, Nucl. Fusion **37** (1997) 339.
[5] F. Salzedas *et al.*, submitted to publication.
[6] G. Kurita *et al.*, Nucl. Fusion **34** (1994) 1497.