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First Results on the Radiative Improved Mode (RI Mode) with operation of the Dynamic Ergodic Divertor (DED) at TEXTOR

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Introduction

The Radiative Improved Mode (RI-mode) [1] in TEXTOR is a confinement regime, which combines power exhaust by a radiating plasma boundary owing to the injection of light impurities like neon with both high confinement (H93 ~ 1) and high density equal or larger to the Greenwald density.

Recently, the Dynamic Ergodic Divertor (DED) [2,3] has been put into operation in TEXTOR. Initial experiments are made for studying the impact of the DED on RI-mode discharges. These experiments are carried out with the (3,1) mode DED configuration in both static and dynamic regime at a frequency of the perturbation field of 1 kHz. For the dynamic operation two scenarios can be selected: Co rotation means that the toroidal projection of the DED field rotation would excite a rotation in the direction of the plasma current, Counter(Ctr) rotation has the opposite sense. One of the main difference between the two scenarios is that for static and Co rotating DED the activation of the tearing modes occurs usually beyond a rather reproducible threshold value, for Ctr rotation the tearing modes are usually not excited.

Experimental conditions

The discharges studied are carried out at I_p = 300 kA and B_t = 2.25 T corresponding to a safety factor at the edge of $q_{a,cyl} = 3.9$ (R_0 = 1.78 m, a = 0.43 m). The neutral beam injection and RF heating power are respectively 1.25MW and .7 MW. Neon injection starts at t=1.3s. The Neon injection is feedback controlled to keep the intensity of Ne-VIII line radiation constant. A radiated power fraction $\gamma = P_{rad}/P_{tot} \sim 75\%$ is obtained. Horizontal plasma position is chosen to optimise the RI-mode performance. This displacement does not optimise the impact of DED. DED current is ramping up starting at t=1.8s.

Experimental results

During the experiments, for the same experimental conditions, two types of discharges are observed before any injection of Neon or switching on of the DED probably due to different wall conditions and characterised by high or low recycling flux. The results obtained for the confinement depend on the recycling flux in a similar way as observed during previous RI-mode experiments. The values of the central density, peaking parameter and recycling flux during combined DED and Neon injection depend strongly on the low or high recycling situation.

Impact of DED on confinement

Figure 1 shows 2 discharges with high recycling flux with or without static DED.

For those two discharges the impact of DED is rather small. The usual peaking of the density when Neon is injected is not significantly affected by the DED and we observe with DED a small energy increase. Impact of DED on the radiated power for fixed intensity of NE-VIII line is within the error bars.

We show in figure 2 the evolution of τ_E / τ_{RIM} the ratio between the energy confinement time τ_E and the RI-mode law $\tau_{RIM} = KnP^{-2/3}$[4] in function of the recycling flux measured at the ALT limiter. The well known degradation of confinement with recycling flux is observed[5]. At a given recycling flux the DED slightly improves the confinement. In these discharges the H/D ratio is ~20%. This leads to an estimated reduction of $K \sim \sqrt{A_i}$ of 5%[6] that is taken into account in the calculation of τ_{RIM}. Energy confinement in these discharges are lower than the values predicted by the law characteristic of RIM discharges (with or without DED): τ_E / τ_{RIM} <1 (see figure 2). The level of recycling flux and the large Hydrogen concentration leading to a less efficient ICRH power deposition profile may explain these lower performances.

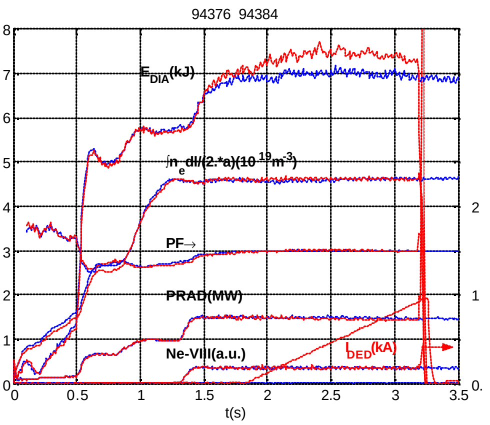

Figure 1 Comparison of: Diamagnetic energy, line integrated density, peaking factor of the density profile ($PF = n_{e0} / (\int n_e dl (R = 1.75m) / 2a)$), radiated power P_{RAD}, intensity of the Ne-VIII line, intensity of static DED current for two discharges with (red) and without DED (blue).

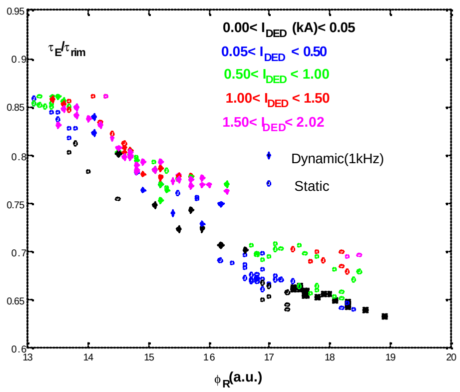

Figure 2 Evolution of the normalised energy confinement time as function of recycling flux for different values of the DED current static or dynamic (1kHz).

-Impact of DED on the maximum plasma density and density profile

Figure 3 compares the maximum density versus time for discharges with static (labelled DC) (high recycling and low recycling), Co(low recycling) and Ctr(low recycling) DED. At figure 5- 8 the evolution of the characteristic lengths of the density $L_n = |n_e / (dn_e / dr)|$ is compared for some of the discharges appearing in figure 3. We observe at t=1.3 s the usual peaking of the density induced by the Neon injection.

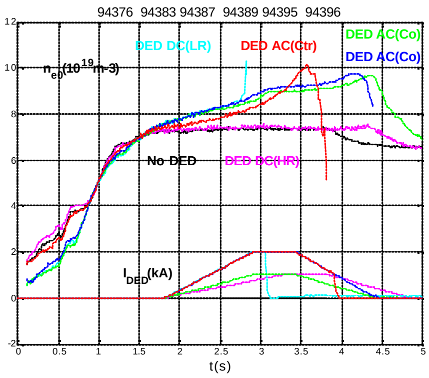

Figure 3: Evolution of maximum density during the DED operation. Shots with low recycling flux at the beginning of the discharge have the largest maximum density .

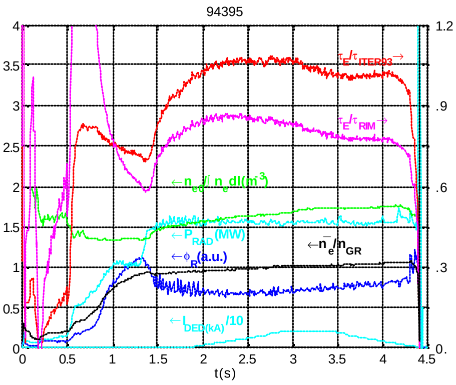

Figure 4: Evolution with time of $\tau_E/\tau_{Iter93}, \tau_E/\tau_{RIM}$, peaking factor of the density, ratio between density and Greenwald density limit, recycling flux at the ALT limiter, DED current.

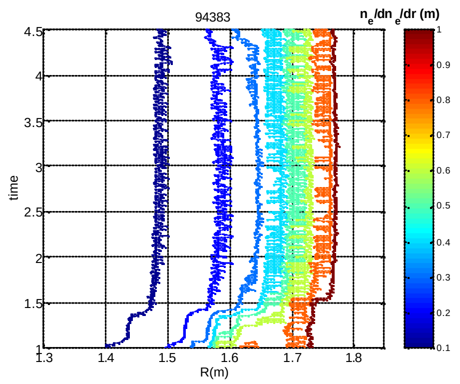

Figure 5: Contour plot of characteristic lengths of the density $L_n = |n_e/(dn_e/dr)|$ (HFS) during the DED pulse (DC) (High recycling flux) as function of R and t.

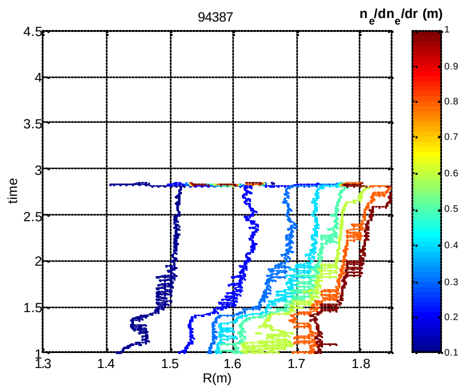

Figure 6: Idem shot with DED (DC) and low recycling flux

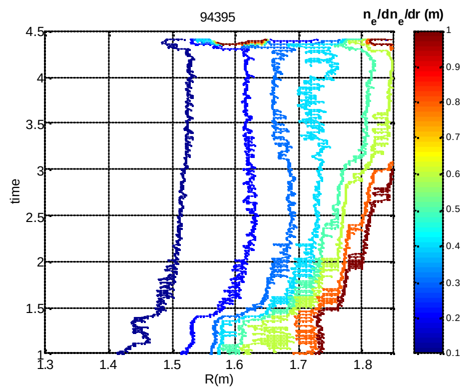

Figure 7: Idem shot with DED AC(Co) with low recycling flux. Same shot as figure 4.

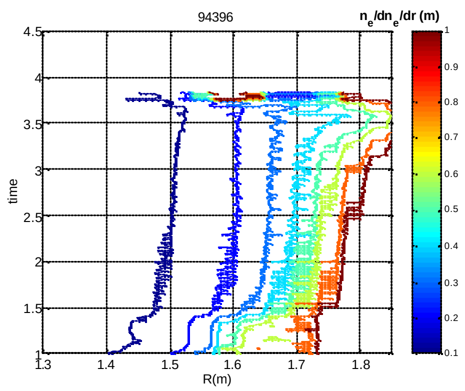

Figure 8: Idem shot with DED AC(Ctr) and low recycling flux.

This peaking is not affected by the DED for low recycling static operation (figure 5). In discharges with low recycling flux, the sawtooth instability is suppressed during DED operation and a further peaking of the density profile is induced (figure 6,7,8). This peaking leads to an increase of the line integrated density and to a very large central density. We observe that the peaking penetrates to smaller and smaller radius ending to a really triangular profile. In the case of static DED and Ctr DED operation, the density rise is followed by an increase of the radiated power and thereafter by a sudden increase of the recycling flux preceding plasma disruption (figure 6 and 8). In the case of Co DED, m=2 modes develops and the extreme peaking of the density does not take place. The disruption is postponed until the DED current has been reduced (figure 3). In the last case the energy confinement time reaches $1.05*\tau_{ITER93}$ at a density n/n_{GR} ~=1 (figure 4). It is also possible to avoid the extreme peaking of the density by increasing the injection of Deuterium gas. This injection induces a decrease of the particle confinement time and a flattening of the density profile. The combination of both techniques for optimising density profile and energy confinement will be studied.

-Impact of DED on the coupling resistance of the ICRH antenna

A decrease of 30% of coupling resistance is measured during Co DED operation. We attribute this decrease to the modification of the density in the scrape-off layer and/ or in the plasma in front of the antenna. This effect decreases the power delivered to the plasma only by ~5%. A reduction of the antenna resistance is seen also in all low recycling flux discharges with Ctr or static ergodic divertor .

Conclusion

The full characteristics of the RI mode have been reproduced in presence of DED working in both the static and the dynamic regimes. We have also observed in case of discharges with low recycling that, in presence of DED a very peaked profile is obtained together with sawtooth stabilisation. The m=2 mode induced by Co DED helps to control this peaking. In this case a confinement quality H93 = 1.05 has been obtained at $n/n_{GW} = 1.0$ (figure 4) with peaked density and temperature profiles. The ICRH antenna coupling resistance shows a rather small reduction during DED operation. The results presented in this paper are preliminary and based on a limited number of discharges. For this reason additional experiments are needed to fully confirm these conclusions.

References

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