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Evolution of electron density, temperature and pressure profiles in the RI-mode of TEXTOR-94.

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1. Introduction.

One of the most attractive features of the RI-mode of TEXTOR-94 (a limiter tokamak with R=175cm, a=46cm) is the linear dependence of its confinement time on the electron density what permits to operate with high energy confinement near the Greenwald density limit ($\mathbf{n_{Gr} = I_p/\pi a^2}$). [1]

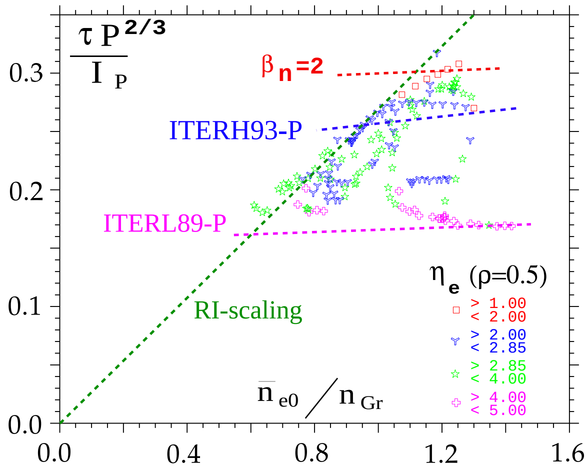

Fig. 1. Normalised confinement time versus Greenwald number.

The fact that the RI-mode scaling ($\tau_{RI} = \kappa\ \bar{\mathbf{n}}_{e0}\ (\mathbf{P}_{tot})^{-2/3}$) describes also the linear ohmic confinement (LOC-mode) suggests that the transport in LOC and RI-mode is governed by the same kind of turbulence, caused by an instability with linear growth rate inversely proportional to the electron density. The dissipative trapped electron instability (DTE) is considered as a possible candidate for such behaviour [2-4]. On the contrary, the transport in SOC and L-mode is considered to be dominated by the toroidal ion temperature gradient instability (ITG).

Figure 1 shows the diagram of the normalised confinement time ($\tau\ (\mathbf{P}_{tot})^{2/3}/\ \mathbf{I}_p$) versus Greenwald number ($\mathbf{n/n_{Gr}}$) for a data set taken at $B_t \cong 2.25$T and 380 < I_p (kA) < 400. The lines represent the RI-mode, L-mode and H-mode scalings and the operational beta limit ($\beta_n \approx 2$). The experimental data set shoun by means of the symbols covers an area delimited by the L-mode and RI-mode scalings and by the β_n limit. It is the aim of this paper to relate this wide scatter in performance to relevant parameters that are capable of characterising the profiles in density, temperature and pressure that might bring about the performance. The described experiments were performed under siliconized and boronized wall conditions and Ne injection. The plasma was auxiliary heated by NBI-co combined with ICRH.

1. Correlation of the density and pressure peaking factors and of the ηe value with confinement performance.

A peaking of the density profile which occurs as a result of impurity seeding is thought to be instrumental in the RI-mode behaviour. Such a peaking can be characterised by the ratio of the central to the volume averaged density ($\gamma_n = \mathbf{n_e(0)} / < \mathbf{n_e} >$). For the data set of Fig. 1, parameterised according to the density peaking factor, Fig. 2 shows the enhancement factor of the experimental confinement time with respect to the RI-mode scaling τ / τ_{RI} as a function of the Greenwald number. It appears that, at a given density, an increase of the energy confinement time is correlated with an increase of density peaking factor. On the other hand for a fixed ratio of τ/τ_{RI} an increase of electron density leads to an increase of its peaking factor. The points with $(\tau/\tau_{RI})>1$ at $n/n_{Gr}<0.8$ pertain to discharges that follow the L-mode scaling (ITERL-89P) when the latter predicts confinement in excess of the RI-mode scaling (see Fig. 1). Figure 3 shows a much weaker correlation of the same data with respect to the pressure peaking factor (γ_P = p_e (0) / < p_e >).

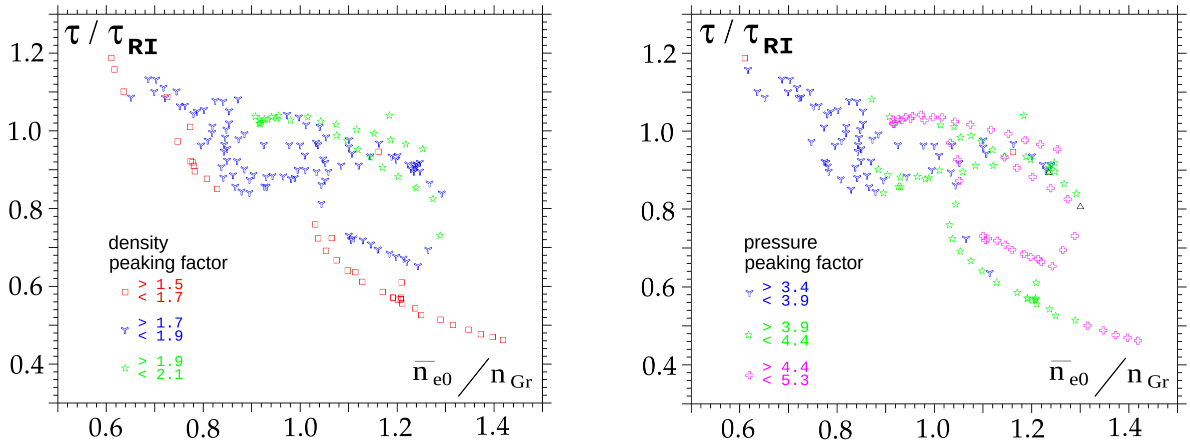

Fig. 2, 3. Confinement time respect to the RI-mode scaling versus Greenwald number with density and pressure peaking factors as parameters.

The variation of the parameter η_i which depends on the ion density and temperature profile shapes ($\eta_{i,e} = d\,(\ln T_{i,e}) / d\,(\ln n_{i,e})$) deserves special attention as it is an important parameter influencing the growth rates of ITG and DTE-modes [2-4]. The difficulty to obtain an experimental ion density for each discharge does not allow to make a systematic analysis of the evolution of η_i value. We will use the evolution of η_e as an approximation of that of η_i and show that this approximation is justified.

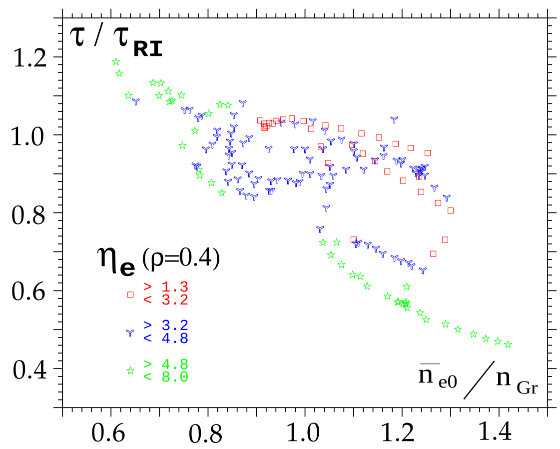

Fig. 4. Influence of η_e value on the obtained performance.

When the RI-mode confinement is established, a strong reduction of η_e value is observed in different radial zones of the plasma and under a variety of discharge conditions. From Figs. 4 and 2 it appears that τ / τ_{RI}, at fixed density, is correlated with a decrease of η_e and that η_e evolves roughly as $1/\gamma_n$. It is also seen from Fig. 1 that the values of η_e are the most strongly reduced for points following the RI-mode scaling

The time and space evolution of η_e for selected discharge conditions pertaining to the data set of Fig.1 is illustrated in more detail in the next figures. Figure 5 shows the time traces of the density and the diamagnetic energy for three selected discharges which differs by their gas puff rate. For the same discharges, Fig. 6 shows the evolution of the normalised confinement times versus the Greenwald number. At slow gas puff rate, the confinement follows the RI-mode scaling up to the β_n limit where MHD activity sets in [5], which then triggers a back transition to a confinement state intermediate between L and RI-mode. For the case of strong gas puff rate, a rollover to L-mode is observed. In the third case with an intermediate gas puff through the ALT limiter [6], a stationary confinement phase of H-mode quality is obtained up to $\mathbf{n/n_{Gr}}$ =1.3 (but lower than the RI-mode scaling) followed by a slow back transition to L-mode.

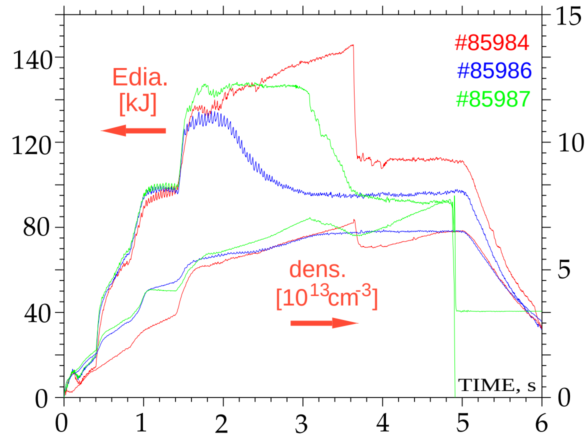

Fig.5. Variation of diamagnetic energy and density for three different gas puff scenarii.

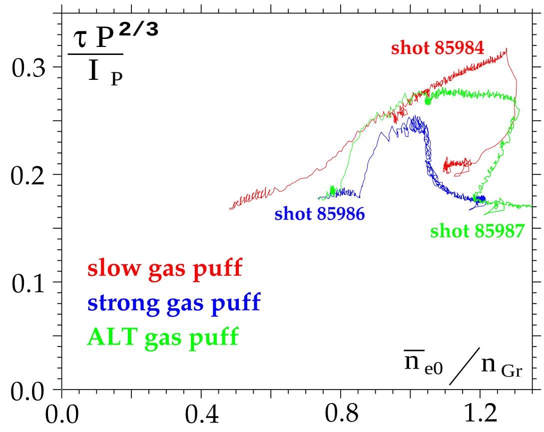

Fig.6. Evolution of normalised confinement with Greenwald number, different gas puff scenarii.

Figure 7 shows the time evolution of η_e in the gradient plasma zone for the discharges displayed in Figs. 5 and 6. When confinement follows the RI-mode scaling, one observes a reduction of η_e with increasing density, as witnessed by red (#85984 up to 3.6 s) and the green (#85987 up to 3.1 s) curves. When a back transition occurs, η_e increases as the confinement degrades: this could indicate the restart of micro-turbulence. Note however that after the back transition in # 85984 η_e only increases slightly (red curve on Fig.7): the reduced confinement after t = 3.6 s is now attributed to MHD activity.

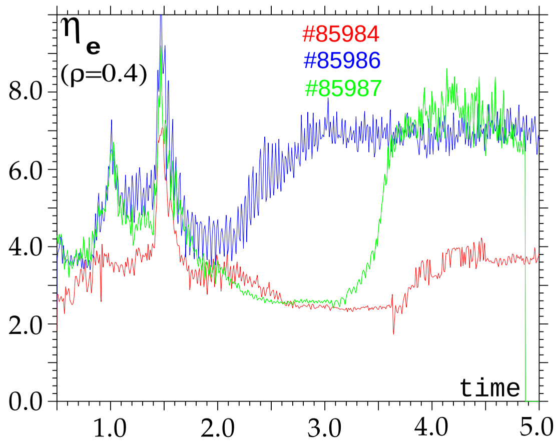

Fig. 7. η_e temporal evolution for different discharge conditions

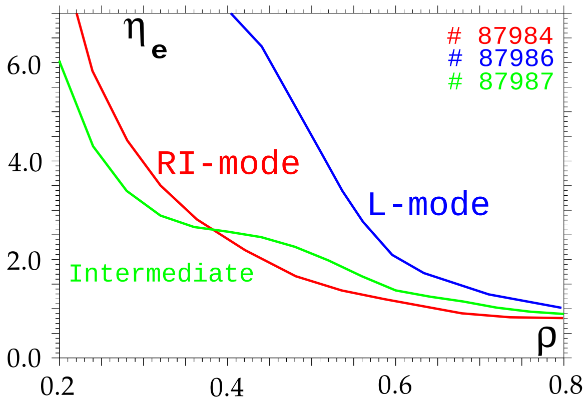

Fig. 8 Radial profiles of η_e for the three discharges of Fig.5 at the same value of n/n_{GR}=1.2.

Figure 8 shows the η_e profiles prevailing in the three discharges of Fig. 5 at the same density $\mathbf{n/n_{Gr}}$ **=1.2**. In #87984, the discharge is in the RI-mode and the η_e profile is peaked in the centre with low values in the outer plasma zone. In the L-mode (#87986), the η_e grows in the gradient region and gets substantially higher at ρ < **0.6**. Discharge #87987 suggests that, if η_e sets confinement, it does so around mid-radius.

2. Experimental comparison of η_i and η_e values and modelling.

Figure 9 shows a comparison of the temporal evolution of η_e and the quantity $\eta_i^* = \mathbf{Ln_e} / \mathbf{LT_i}$, demonstrating fair agreement. To obtain the true η_i, $\mathbf{Ln_i}$ should be used instead of $\mathbf{Ln_e}$. The knowledge of the impurities concentrations at each ionisation state is needed and first estimates could be obtained from simulation by means of the RITM-code [7]. Figure 10 shows the ratio of $\mathbf{Ln_i}$ and $\mathbf{Ln_e}$ for L-mode and RI-mode conditions selected from the three discharges of Fig. 5. It is found that these two quantities do not differ by more than 20% in the mid-radius zone with the highest gradients. We tend to conclude that η_e can be used as a reliable first approximation of η_i and that both of these parameters are reduced when the confinement, at a given density, is improving.

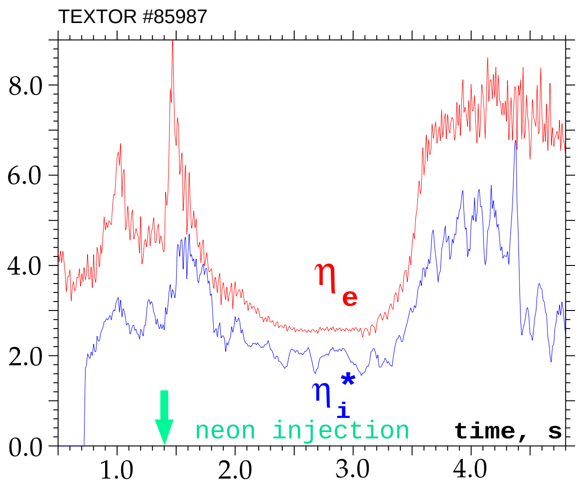

Fig. 9. Comparison of the η values of the electron and ion components.

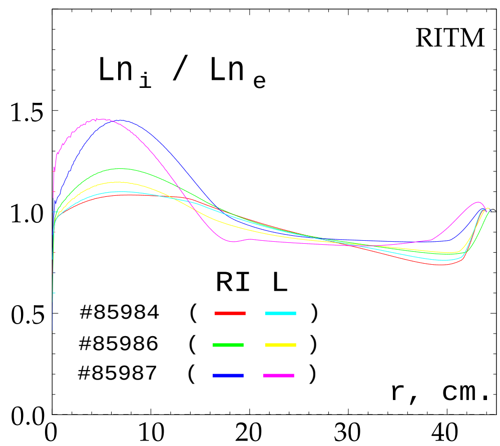

Fig.10. Comparison of $\mathbf{Ln_i}$ *and* $\mathbf{Ln_e}$ *for different discharge conditions.*

3. Summary.

1. The confinement improvement with respect to the L-mode is characterised, at a given density, by an increase of the density peaking factor and also by a decrease of η_e in the gradient plasma zone. The best confinement corresponds to that given by the RI-mode scaling.

2. For all experimental conditions in which η_i and η_e could be compared, the former matches the behaviour of the latter. As the lowering of η_i is thought to be a crucial ingredient to suppress ITG turbulence, the present findings tend to support the theoretical explanation that RI-mode confinement improvement is tributary to the quenching of that turbulence [2-4].

4. References.

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