TRANSITIONS BETWEEN REGIMES OF IMPROVED AND DEGRADED CONFINEMENT WITH OH AND NI HEATING

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Introduction

A new class of improved confinement regimes characterized by peaked density profiles has been identified in recent studies on ASDEX /1/. Gas fuelled ohmic discharges pass into the **IOC** (improved ohmic confinement) regime upon reduction of the external gas flux at high density. Improved particle and energy confinement are then obtained with an unsaturated rise of the energy confinement time with density, $\tau_E \sim \overline{n}_e$, up to the density limit /2/. A similar improvement is achieved when the density is raised with fuelling from **pellet injection** /3/. In both cases the improvement in energy confinement correlates with a peaking of the density profile. The same correlation is found in **counter-NI** heated discharges /4/. There, a reduction of the gas puff rate triggers a continuous rise in β_p together with a gradual peaking of the radial density profile $n_e(r)$.

Transitions between IOC and SOC Regimes

The transitions between the different ohmic confinement regimes have been studied with discharges as shown in Fig.1. It contains three density plateaus, at $\overline{n}_e = 2.5\times 10^{13}$ cm^{-3} in the linear ohmic confinement (LOC) regime, at $\overline{n}_e = 3.9\times 10^{13}$ cm^{-3} and at $\overline{n}_e = 4.8 \times 10^{13}$ cm^{-3} , both in the IOC. The density is ramped up between the plateaus by increasing the gas flux Φ_{gas} for short durations of about 0.2 s. During the first phase of enhanced gas puffing, β_p remains constant while $\overline{n}_e$ increases. The discharge passes there from LOC to SOC. Immediately after reduction of Φ_{gas}, β_p starts to rise and steady state IOC conditions are attained after a slow transition of about 0.3 s. At 1.5 s, the gas flux is increased again. This triggers now a transition from IOC back to SOC as seen from the degradation in β_p with increasing $\overline{n}_e$. At the start of the transition, Φ_{gas} is much smaller than at the begin of the preceding transition from SOC to IOC. This indicates that the rate of change of Φ_{gas} seems to provide the trigger for the transition between the confinement regimes. Upon a second reduction of the gas feed rate at 1.7 s, another IOC transition is triggered. The form of the density profile during these multiple transitions between confinement regimes is monitored by the ratio of central to peripheral line integrated density, $Q_N=N_e(0)/N_e(0.75a)$. During the SOC phases Q_N drops and the $n_e(r)$-profile is broadening. With begin of the IOC transitions, Q_N starts rising and $n_e(r)$ therefore is peaking. The peakedness increases with increasing density /5/.

The changes in β_p occur on the same long time scale as the changes in the form of the electron density profile. The duration of the transition to a new steady state increases with increasing density. The improvement in confinement in the IOC regime can be consistently described by a reduction of anomalous heat conduction due to η_i-modes /6/. Both, SOC and IOC regimes are treated with the same ansatz for χ_i , summing up neoclassical and anomalous transport. The η_i-modes are destabilized in the gradient region if the ratio $\eta_i = (d\ln T_i/dr)/(d\ln n/dr) = L_n/L_{T_i}$ exceeds a threshold value η_i^*. According to drift wave theories the critical value should be of order η_i^*=1-2. In the experiment, radial profiles of η_i and η_e are determined from the radial profiles of $n_e(r)$, $n_e(r)$,$T_e(r)$ and $T_i(r)$. The temporal evolution of the radial positions with η_e=1.5 and η_i=1.5 is plotted in the lower part of Fig.1. In the regions with smaller radii, $\eta_{e,i}>1.5$ holds and η_i-modes should be unstable. During the SOC phases the unstable regions are expanding. With begin of the IOC transitions, the unstable region begins to shrink and at the highest density it disappears completely. The gradual improvement of confinement in IOC might therefore be explained by the expansion of the plasma region not affected by η_i-modes. As the excitation of these modes depends on the local form of the plasma profiles, the time scale of profile redistributions (and not of the growth time of the modes) should determine the time scale of changes in confinement. This could then explain the long time scales characteristic for the IOC transition.

Transitions from SOC/IOC to Pellet Injection

Pellet injection at high density and the IOC regime present many similarities. The improvement in confinement in both regimes is clearly correlated to the peaking of the density profile. In transport code calculations the improved confinement could be explained by the same mechanism, the suppression of η_i-modes. Transitions between the two regimes are investigated in order to understand better the role of the plasma profiles. The variation of τ_E with $\overline{n}_e$ is shown for two discharges in Fig.2. In #25645 (solid line) the IOC regime was established with τ_E=105 ms after passage through the SOC phase. Pellet injection into the fully developed IOC regime drives the energy confinement time up with density. No improvement is achieved beyond the scaling $\tau_E \sim \overline{n}_e$, already recovered in the IOC regime. Pellet injection rather extends this scaling to higher densities. As in the IOC regime the whole plasma region was already stable against η_i-modes, no additional improvement was expected from further peaking of $n_e(r)$ with pellet injection.The experimental result seems to confirm the assumed transport model. With pellet injection into an SOC target plasma (#25648,dotted curve in Fig.2) with flat density profile, $n_e(r)$ starts peaking and the region with $\eta_i>\eta_i^*$ is shrinking. The larger gain in τ_E during the initial phase of pellet injection in this case could therefore be explained by the suppression of η_i-modes.

Neutral Beam Injection into SOC /IOC Target Plasmas

With neutral beam injection (NI), transitions between confinement regimes can be studied in both directions: Co-NI into IOC was investigated up to P_{NI}=2 MW. At high NI power, normal L-mode confinement is regained. Ctr-NI into SOC plasmas leads to improved confinement /4/. With ctr-NI into IOC, improved confinement is maintained. In Fig.3 the three cases are compared for P_{NI}=0.6 MW. Co-NI into IOC leads to a further transient peaking of $n_e(r)$. During this phase, β_p rises and the region with $\eta_e>1.5$ shrinks rapidly. About 50 ms after begin of NI, $\eta_e<1$ in the whole plasma region. Then large sawteeth trigger a flattening of $n_e(r)$, leading to a decrease of β_p and an expansion of the region with $\eta_e>1.5$, starting from the center. A new steady state with degraded confinement is attained 0.2 s after begin of NI. With ctr-NI into SOC, Q_N rises strongly in the begin and then continuously throughout the NI pulse. The increase in β_p correlates with this peaking of $n_e(r)$. The large region with $\eta_e>1.5$ starts shrinking while $n_e(r)$ is peaking resulting in $\eta_e\approx1$ over the whole radius after 0.3 s. Then the region with $\eta_e>1.5$ begins to expand again, now starting close to the periphery. This degradation is caused by strong radiation cooling due to impurity accumulation /1/. Ctr-NI into IOC leaves the already peaked $n_e(r)$ profile nearly unchanged in the beginning and leads to a continuous peaking in the later phase similar to ctr-NI into SOC. The initial β_p increase is small due to larger orbit losses with ctr-NI. The radial profile of η_e does not change from IOC to ctr-NI until impurity radiation becomes dominant again in the late phase.

Summary

The investigation of transitions between improved confinement regimes with peaked density profiles and degraded regimes in ohmic and NI-heated plasmas clearly demonstrates the close link between the energy confinement time and the form of the electron density profile. Pellet injection into IOC plasmas and ctr-NI into IOC target plasmas show that no additional improvement results from further peaking of the $n_e(r)$ profile once it is peaked such that $\eta_{e,i}\approx1$ over a large plasma region. The correlation of confinement improvements with a shrinking of the plasma region unstable against η_i-modes suggests strongly that the stabilization of these modes by the peaking of $n_e(r)$ is the common mechanism in the whole class of improved confinement regimes characterized by peaked density profiles.

References

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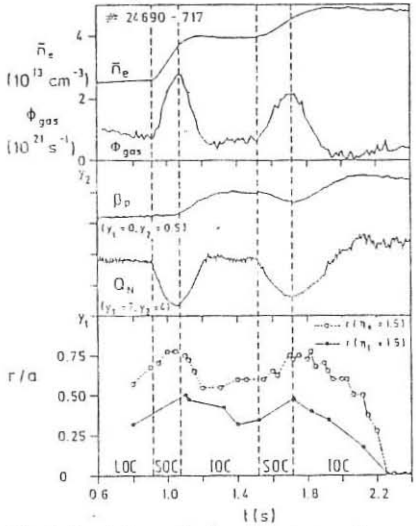

Fig.1: Evolution of plasma parameters during transitions between ohmic confinement regimes in a deuterium discharge with 3 density plateaus. I_p=380 kA, B_t=2.17 T, q_a=2.75.

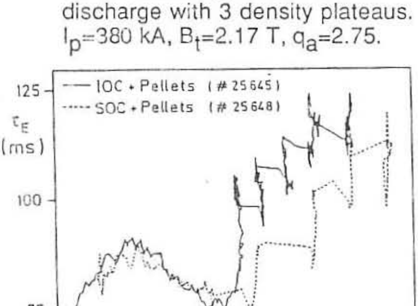

Fig.2: Variation of the energy confinement time with density in SOC and IOC phases and with subsequent pellet injection. I_p=380 kA, B_t=2.17 T.

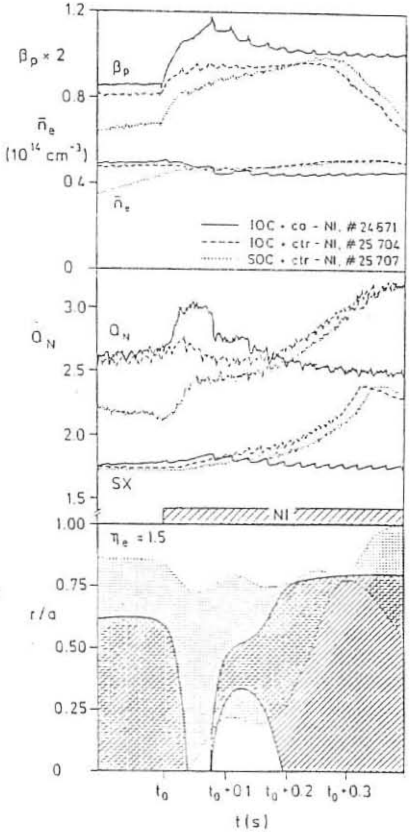

Fig.3: Temporal evolution of plasma parameters with NBI in co and ctr direction, resp., into IOC and SOC target plasmas. The lower part shows the radial extent of the region with η_e >1.5 for co-NI into IOC (solid boundary lines) and for ctr-NI into SOC (dotted boundary lines). I_p=380 kA, B_t=2.17 T, q_a=2.75. P_{NI}=.6 MW.