Radial Energy Balance Analysis of ASDEX H-Mode Discharges

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Abstract
Radial transport and confinement properties of ELM dominated (H) and ELM free (H*) beam heated ASDEX-discharges are studied using the PPPL transport analysis code TRANSP. For similar plasma parameters the H* discharges have energy confinement times of about 1.5 as large as those in H discharges and correspondingly reduced electron heat diffusivities due to the absence of the ELM's. Electron conductive losses dominate the energy losses besides radiation cooling.

1. Introduction

In the beam-heated high confinement ASDEX discharges (H-mode) confinement times comparable to the ohmic values are found and usually edge localised modes (ELM's) are observed which are associated with burst-like releases of particles and energy from the outer half of the plasma /1/. Confinement depends on the frequency of the ELM's and the deduced transport coefficients should be upper limits for the values describing the underlying quasi-stationary transport. Moving the plasma column to the outer wall suppresses the ELM's (H*-mode), but high Z-impurities accumulate in the plasma center and produce together with the strongly rising plasma density a rapid increase of the total radiation losses and a peaking of the radiation power density at the magnetic axis /1/.
Radial transport of H-(# 8475) and H*-(#11447) discharges has been studied using the transport analysis code TRANSP (PPPL) /2/ and measured radial plasma profiles, namely the electron temperature, electron density and radiation losses. The measured shape of the plasma boundary vs. time can be specified as input data for TRANSP and the interior flux surface geometry is periodically updated. This is of importance for the analysis of the flux surface averaged transport of the plasmas investigated with β_p up to 2, where a

large toroidal shift of the magnetic axis (up to a/5) and of the plasma profiles exist. Compared with previous studies /3/ using a predictive transport code the present calculations differ through the mentioned geometrical effects, a more transparent propagation of the experimental errors and the applicability to discharges with strong radiation losses exceeding 50 % of the input power.

2. Radial transport in H and H* discharges

The two discharges described here differ only weakly in the time development of the line density and temperatures up to 100 ms after the neutral beam heating is turned on (t_{on} = 1.1 sec; t_{off} = 1.3 sec; 3.2 MW heating power, $H^\circ \rightarrow D^+$, co-direction), but then the density in the H* discharge rises further. The plasma current I is different, namely 380 kA in the H- and 320 in the H*-discharge(B_t = 2.16 T). Energy transport during beam heating is dominated by electron heat conduction in all cases studied. During the L-phase after the beams are turned on the energy confinement time $\tau_E = W/(P_{cond} + P_{conv})$ decreases by a factor of more than two compared with the ohmic one, being close to the energy replacement time $\tau_E^* = W/(P_{heat} - dW/dt)$ (see Fig. 1). This shows that nearly the whole input power is lost by energy transport; radiation and CX losses are small. The electron thermal diffusivity χ_e is enhanced over a large part of the plasma column compared with the ohmic values (see Fig. 2). Whereas the ohmic χ_e is well described by a parameter dependence $\chi_e = \frac{3.4 \cdot 10^{15}\, B_t\, a/R}{n_e^{0.8}\, T_e\, q}$ [m²/s, T, m^{-3}, keV] for the q >1 region /4/, the confinement times during the L-phase are roughly given by $\tau_E(L) \propto P_{heat}^{-1/3} \cdot I$ which can be written as $\tau_e(L) \propto I^{3/2} / \langle n^{2/3}\, T^{1/2} \rangle$ /4/.

The H-mode is associated with an increase of the energy confinement and with a reduction of the still dominating electron thermal conduction over the entire plasma cross-section. The same holds for the H*-mode, but now the energy replacement time is decreasing over the time due to the increasing radiation losses (see Fig. 1,2). Taking the scaling of the H-mode confinement $\tau_E(H) \propto I$ /4/ the energy confinement of the H-discharge # 8475 should exceed that of the H* discharge # 11447 by a factor of 1.2. But with approximately the same density and temperature profiles at 1.21 sec for both discharges $\tau_E(H)$ is only 75 ms at $r = 35$ cm whereas $\tau_E(H^*) > 120$ ms is obtained (see Fig. 1). On the contrary the electron thermal diffusivities are reduced over a large part of the plasma area compared with those of the H-mode (see Fig. 2). This improvement of confinement for the H* mode can obviously be attributed to the absence of the energy loss channel by the ELM's.

The time dependences of τ_E and χ_e at all radii show that transition from OH $\rightarrow$ L behaviour is abrupt (see Fig. 1). There is no delay between the turn-on of the beams and the switching from the OH to the L-mode behaviour of χ_e. The transition from L $\rightarrow$ H mode is much slower, whereas the L $\rightarrow$ H* change over is again sharp for the range $r > 30$ cm where the transition obviously starts. χ_e near the plasma axis is decreasing due to the increasing radiation losses in the center starting already in the L-phase.

The ion heat conduction is described by the neoclassical value in all discharge phases (OH,L,H,H*) yielding for the calculated T_i-profiles the measured neutron fluxes. In all cases the conductive ion losses are comparable to the convective ones (calculated by assuming a particle confinement time of 50 - 100 ms) and much smaller than the conductive electron losses.

3. Conclusions

Comparing the electron thermal conductivities of H and H* discharges, dominating the energy losses besides the strong radiation losses of the H* discharges, reduced $\chi_e(H^*)$ values and correspondingly higher $\tau_E(H^*)$ are found, which can be attributed to the lack of energy losses due to ELM's. Similar behaviour has been stated by /3/ for H-discharges with ELM free phases of less than 30 ms being much shorter than the energy confinement time of 120 ms. There seems to be no further increase of τ_E or decrease of χ_e up to the radiation collapse time at 1.27 sec (burst-free phase lasts from 1.16 s to 1.27 sec). A study of the properties of an insulating sheath near the separatrix /5/ needs more error handling. Indeed a blocking of the heat flux is found at the plasma edge and the T_e-profiles become flat there with high edge T_e- values. But high radiation losses in the later phases of the H*-discharges and the uncertainties in the T_e-measurements increase the error for the calculated plasma energy losses due to the electrons and ions in this boundary region.

References

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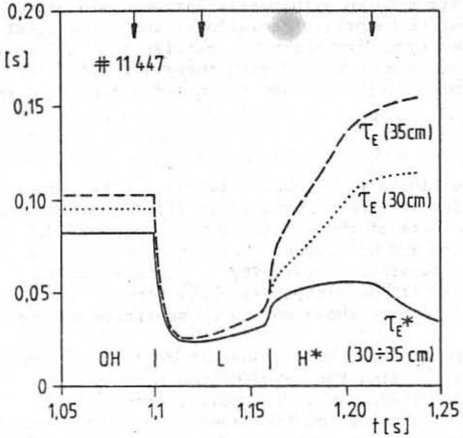

Fig. 1: Energy confinement (τ_E) and replacement (τ_E^*) time of a H* discharge. Arrows indicate the times where the radial χ_e profiles of Fig. 2 have been taken.

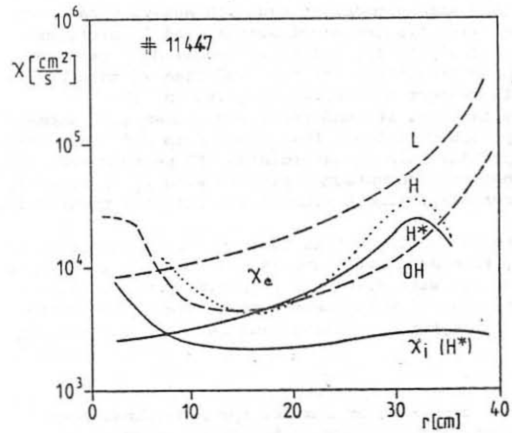

Fig. 2: Radial profiles of the electron thermal diffusivity χ_e for OH, L and H* mode in a H* discharge. For comparison the χ_e profile of a H-discharge (# 8475) with similar plasma parameters and the neoclassical ion heat diffusivity χ_i(H*) are also shown.