ION TEMPERATURE IN SOC AND IOC DISCHARGES IN ASDEX

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Abstract. Active and passive charge exchange measurements were made to investigate the behaviour of the central ion temperature and the temperature profile for SOC and IOC discharges in ASDEX. Both methods show an increase in the central ion temperature during transition from SOC to IOC. Both methods also show a wider temperature profile for ions than for electrons. Peaking of the ion temperature profile during IOC cannot be definitely concluded from the measurements.

The applied Ti-diagnostics. Passive and active beam charge exchange diagnostics were used simultaneously. The main advantage of the passive analysis is its continuous applicability during the discharge. The active system in principle allows space-resolved measurements but normally in the pulsed beam mode only.

The earlier difficulties in interpreting the passive signal at higher densities have been widely overcome. As long as the line density $\bar{n}_e$ is below about $3 \cdot 10^{19}\ m^{-3}$ the central ion temperature T_{io} can be derived direct from the passive signal. At higher densities the outer parts of the plasma deform the neutral flux spectrum and T_{io} is generally underestimated. The amount underestimated was calculated by simulations with the AURORA Monte Carlo code[1], taking into account the neutral density due to recombination[2], which is important at elevated densities. A set of correction factors was obtained for line densities of up to $8 \cdot 10^{19}\ m^{-3}$. These allow the "central" ion temperature in the line of sight of the analyzer to be determined with an estimated error of probably less than 10 %. Owing to the continuous availability of the electron density and temperature profiles from the YAG laser scattering a good basis for this correction procedure is given at ASDEX. For the ion temperature profile an estimate from the raw data and other information is made.

In Fig. 1 the underestimate obtained with the AURORA code for a large variety of ohmic discharges is shown as a function of the mean neutral energy $\langle E_{cx} \rangle$, normalized to T_{io}. Because the n_e and T_e profiles are well known the uncertainty of the correction for a distinct discharge is much smaller than the band in the figure indicates. At neutral energies higher than $7 \times T_{io}$ the resulting correction $(T_{io,cx}/T_{io})^{-1}$ is lower than 20 % even for high density and low temperature. Towards lower energies the correction and its dependence on the profiles increases. Figure 2 shows that for a given type of profile the underestimate can be uniquely determined over a wide range of temperatures T_{io}. In all our measurements the neutral fluxes were sufficiently high to permit evaluation at energies higher than about $5 \times T_{io}$ and to keep the correction to less than 35 %.

The active diagnostic takes into account beam penetration, charge exchange and absorption of the neutrals on the way to the analyzer. The accuracy of these calculations depends mainly on the accuracy of the density measurement (YAG laser). The temperature evaluation procedure is improved in several respects, the most important being that the statistical weight of the measuring points is taken into account. Not included hitherto, however, are effects resulting from the beam halo. For the high densities concerned in this paper the active system is at the limit of its applicability and the error for the central temperature might be as large as ± 15 %.

SOC-IOC discharges. Since ASDEX was remodelled for long-pulse heating and the slits between the main chamber and divertor were reduced, at mean densities higher than $3 \cdot 10^{19}\ m^{-3}$ a new ohmic confinement regime, the IOC regime, has been detected[3,4]. It has peaked density profiles and improved confinement and can be induced and sustained by reduced gas puffing. The hitherto usual regime has flat density profiles and a saturated confinement time at large densities and is called the SOC regime.

Figure 3 shows the temporal behaviour of various physical quantities in a series of discharges with two SOC-IOC transitions. The line density $\bar{n}_e$ was used for controlling the plasma density. During the first density flat-top the plasma stays in the linear confinement regime. Then the first strong gas puffing increases the density and the saturated regime is reached. During the second density flat-top there is a transition from SOC to IOC. With the density increase towards the third plateau the plasma switches back to the SOC discharge but recovers to IOC during the plateau. The central electron and ion temperatures are strongly modulated during these transitions. The values are clearly higher during IOC and lower during the SOC phase. From the figure the amplitude might appear to be lower in the active T_i measurements than in the passive ones. The complete set of data, including discharge series, which are not shown here, proves that this difference has to be contributed to statistics, and that there is no systematic difference in the central ion temperatures gained with the active and passive methods (see Fig. 4). The time dependences of the central electron and ion temperatures are very similar. The gap between the two is smaller during IOC than during SOC. This would be consistent with the assumption of reduced anomalous ion transport during IOC[5].

Figure 3 also gives information on the profiles in the form of peaking factors (central value divided by the volume-averaged value). Strong anomalous transport as would be caused by η_i-modes could lead to a less peaked profile during SOC. The ion temperature profiles were measured in a series of shots with different analyzer sightlines in the plasma. As Fig. 3 shows, the changes in the peaking factor of T_i are within the error bars and a possible peaking of the T_i profile during transition to IOC is less than 10 %. The gradual peaking of the T_i profile during the IOC, which is indicated in the passive data and approximately follows the density peaking is at the detection limit and is not confirmed by the other experimental series.

The T_i profiles are consistently broader than T_e profiles and show higher ion than electron temperature at the edge. This behaviour is reproduced in many other profile measurements on ASDEX. Figure 4 shows the ranges of active and passive ion temperature profiles found during SOC and IOC. In the central plasma region the ranges overlap well, but in the outer plasma regions the passive ion temperatures are systematically higher than the active ones. The difference may be due to the fact that ripple-banana trapped fast ions influence the passive measurement[6], which especially measures the fast ion tail in contrast to the active system, which can use each part of the spectrum.

Future improvements. In the passive diagnostic the trapped particles can be avoided during the next measuring period by toroidal inclination of the analyzer. The necessary correction factors can be determined more accurately by iteratively using the obtained profile in the simulation runs. For the active system the application of He beams[7] may reduce possible halo effects and the disturbance, especially of the central measurement, produced by the three energy components of the hydrogen beam.

Summary. The accuracy of passive charge exchange ion temperature measurements at high plasma densities has been improved by plasma simulation calculations with the AURORA Monte Carlo code. The central ion temperatures from active and passive measurements agree within the error bars. The profiles from the passive method are wider than those from the active method. The difference may be due to ripple-banana-trapped fast ions. During transition from SOC to IOC the central ion temperature increases by around 40 % and the ratio T_i/T_e from 75 % to 90 %. This is consistent with lower anomalous transport during IOC than during SOC. Generally, the ion temperature profiles are distinctly wider than the electron temperature profiles obtained with the YAG laser.

References.

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Figure Captions.

Fig. 1: Results of the AURORA code simulations for a large variety of plasma parameters, which covers well the ohmic operational range of ASDEX. $T_{io,cx}/T_{io}$ is the underestimate of ion temperature when determined direct from the slope of the passive CX spectrum. $\langle E_{cx}\rangle/T_{io}$ is the mean energy of CX flux used for evaluation and normalized to T_{io}. (A, B, ... = 1, 2 ... points).

Fig. 2: Similar to Fig. 1, but all plasma parameters fixed to the values during the IOC phase, except T_{eo} and T_{io}, which are varied.

Fig. 3: Time evolution of temperatures and density in discharges with SOC-IOC transitions.

Fig. 4: CX ion temperature profiles during the SOC and IOC phases.

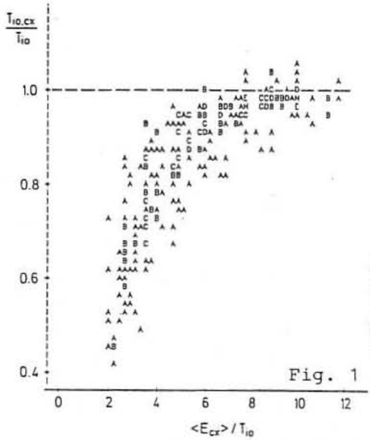

Fig. 1

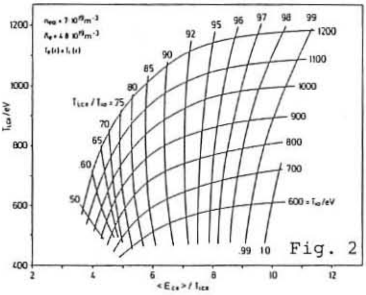

Fig. 2

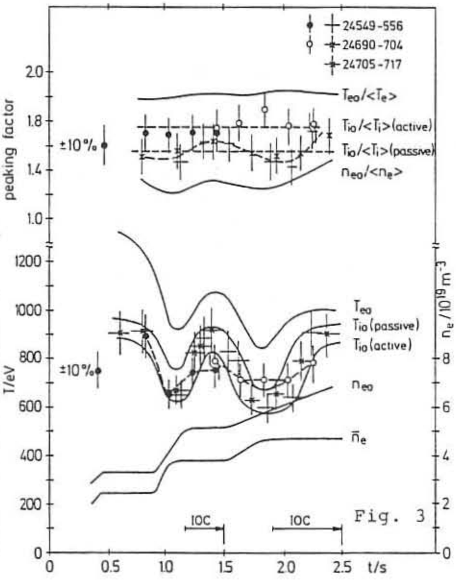

Fig. 3

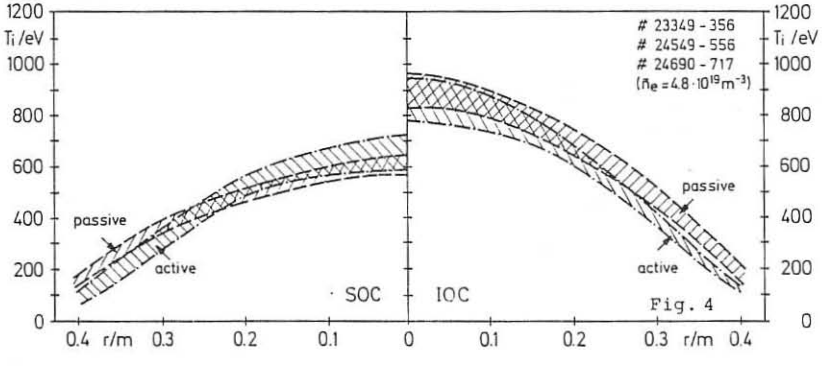

Fig. 4