PARTICLE TRANSPORT IN SAWTEETH

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Summary

The particle transport in ASDEX discharges with sawtooth oscillations is investigated on time scales comparable to and smaller than the sawtooth period. The net particle flux is calculated using time dependent electron density measurements both from 16-point Thomson scattering [1,2] and 4-chord FIR interferometer [3] diagnostics. The inward flux during the sawtooth build-up phase at $\bar{n}_e \approx 5 \cdot 10^{19} m^{-3}$ is found to be of the order $10^{19} m^{-2} s^{-1}$ around the radius of the q=1 surface and extends considerably to the outside. This relatively large inward flux is balanced by disruptive outward particle transport during the sawtooth collapse phases, resulting in a quasi-stationary flat denstiy profile.

Method

At ASDEX there is no direct measurement of the particle flux in the bulk plasma. The electron density, however, is measured. It is related to the radial electron flux by the continuity equation

$$\dot{n}(r,t) + \frac{1}{r}\frac{\partial}{\partial_r}(r \cdot \Gamma(r,t)) = S(r,t)$$

(Γ: radial electron flux, $\dot{n}$: electron density change, S: electron sources, r: minor radius)

The radial particle flux ($n_i \approx n_e$) is then

$$\Gamma(r,t) = \frac{1}{r}\int_o^r r'[S(r',t) - \dot{n}(r',t)]dr'$$

With the density n(r,t) known, the flux is then

$$\Gamma(r,t) = -\frac{1}{r}\int_o^r r'\dot{n}(r',t)dr'$$

Density profiles are derived from YAG (laser Thomson scattering) measurements and HCN (laser interferometric) measurements. The YAG data are available for 16 points with minor radius from 0.055 ... 0.39 m every 0.017 s, with a resolution $\Delta_{YAG} \approx 5\cdot10^{18}m^{-3}$. HCN data (line integrated densities) are available for 4 horizontal chords with minor radius 0, +0.21, -0.21, -0.30 m every 0.001 s, with a resolution $\Delta n_{HCN} \approx 2\cdot10^{17}m^{-3}$. Although the density profiles from the 16 direct YAG measurements are more detailed, and hence better suited for flux calculations than profiles from the 4 inverted line integrals, the higher sensitivity and sampling rate of the HCN density profiles make them better suited for investigations of small and fast density changes characteristic for sawtooth oscillations. To find out whether the inverted HCN line integrals result in the same flux profiles as the direct YAG measurements do, both kinds of evaluation were done for a neutral beam-heated discharge, where the sawteeth are large enough to show up on the YAG density data. Since the sawtooth period in ASDEX discharges is of the order of a few times $10^{-2}s$, there are generally not enough YAG measurements between two consecutive sawtooth collapses to allow a direct flux calculation. Therefore, during the stationary phase of the discharge, i.e. when the density profile does not change significantly over many sawteeth, the YAG profiles are reordered in time according to their phase within a sawtooth. In this way an average sawtooth is reconstructed with enough sample profiles for calculation of the sawtooth build-up flux. The resulting flux profile is shown in Fig. 1a. The maximum inward flux is about $1\cdot10^{19}m^{-2}s^{-1}$.

For a cross-check the flux profile was calculated from the HCN measurements that were reordered in the same manner as the YAG profiles, and then straightforwardly from consecutive HCN profiles during one sawtooth (Fig. 1b and c). The YAG flux agrees well with the HCN fluxes, although the HCN profiles themselves do not match exactly the YAG profiles. The flux values found should be higher than the real flux, because the assumption of zero particle sources is not true for neutral beam heated discharges (10^{20} ions/s injected for $P_{NBI} \approx 10^6W$), but the error introduced is systematic and the same in both YAG and HCN measurements.

The good agreement lends confidence to the calculation of sawtooth build-up fluxes from HCN data alone in an ohmic discharge with sawteeth too small to be detected in the YAG data. In this case, the plasma is source-free. The inward flux is found to be on the order of $\approx 10^{19}m^{-2}s$ around the radius of the q=1 surface and extends considerably to the outside (see fig. 2).

Conclusions

Since the density profile is generally quasi-stationary in the presence of sawteeth, we must conclude that the inward flux is compensated for by the violent, disruptive particle transport in the opposite direction which takes place in the sawtooth collapses. This ensures that the net particle flux, averaged over times long compared to the sawtooth period, is zero, and the density profile remains unchanged as long as the sawteeth continue.

The inward flux seen during the sawtooth build-up phases is not marginal. A simple estimate shows that the observed inward flux could double the central density within 0.1 ... 0.2 s, if there were no opposing mechanism. There are indeed some cases, when the balancing effect of the sawtooth collapses is obviously absent. This is found, for example, in the early stages of a discharge, before sawteeth have started [5], or during successful pellet refuelling [6]. The observed peaking of the density profile in these cases is of a magnitude that is compatible with the profile peaking during the sawtooth build-up.

References

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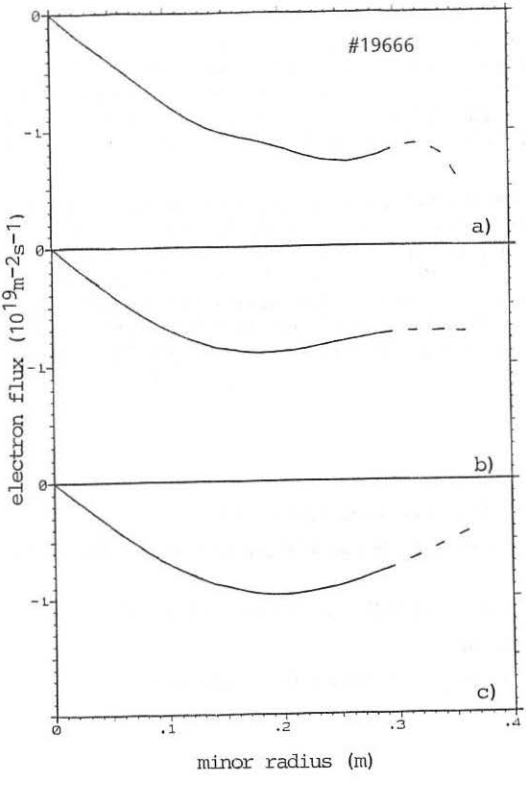

Fig.1: Inward flux during sawtooth build-up in neutral beam heated discharge

a) calculated from YAG data, re-ordered, average over 7 sawteeth

b) from HCN data, re-ordered, average over 7 sawteeth

c) from HCN data, consecutive samples, single sawtooth

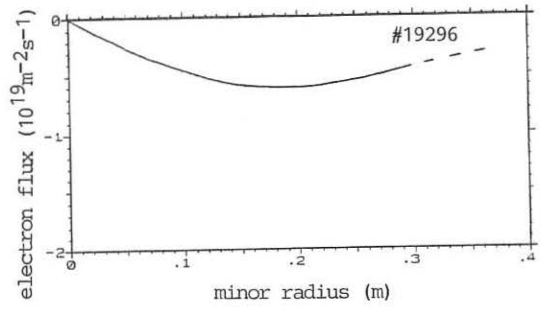

Fig.2: Inward flux during sawtooth build-up in ohmic discharge

HCN data, average over 5 sawteeth