Fast Determination of T_i-Profiles from Analysis of Neutral Flux Measurements

H.-U. Fahrbach, O. Kardaun, J. Stober, Yu.N.Dnestrovskij †,
W. Herrmann, A. Khutoretsky †, and the ASDEX-Upgrade team
Max-Planck-Institut für Plasma-Physik, EURATOM-Association,
D-85748 Garching, Germany
† RRC "Kurchatov-Institute", 123182, Moscow, Russia

1 Introduction

Up to now the determination of the radial ion temperature profile [1] in ASDEX-Upgrade from the energy spectrum of neutral particles uses the EIRENE Monte-Carlo code [2] for the calculation of the neutral density profile. This method is restricted to investigations of special interest, because of the necessary long computing time. For online evaluation during experiments a fast automatic procedure is needed. The classical logarithmic slope evaluation [3] is limited to low density and/or high temperature plasmas and does not provide profile information. Therefore a new computer code CENS [4] has been developed. It avoids specific Monte Carlo runs, but uses information about the neutral density obtained by such calculations in the past.

2 Measurements and method of evaluation

The energy spectra of hydrogen and deuterium neutrals are measured with two Neutral Particle Analyzers [5]. The neutrals are ionized in a hydrogen gas cell, separated in energy and mass by a magnetic and an electric field, and detected by 2 sets of 10 channeltrons. Figure 1 shows the geometry of the CX diagnostic at ASDEX-Upgrade.

The neutral flux emitted from the plasma is described by an integral over the line of sight [1]. The integral contains the profiles of the ion and electron temperature, T_i and T_e, the ion, electron and neutral density, n_i, n_e and n_n. The determination of the T_i profile is a difficult ill-posed non-linear problem, for which no simple method is available, and as much information about the other profiles as possible has to be taken into account. The n_e and T_e profiles and the magnetic flux surface geometry are taken from other diagnostics, but the neutral density cannot be measured until now and is the main obstacle for a straightforward determination of T_i.

Two groups of neutrals have to be distinguished: The 'wall' neutrals, which penetrate from the plasma boundary into the plasma and the neutrals due to volume recombination, which are calculated according to standard formulas [6] and added to the wall neutrals. In the central plasma region they can be the dominating part, when the density is high and/or the temperature low. In that case, the neutral problem is less severe. CENS uses a parametric representation of the wall neutral density, obtained from fits to Monte-Carlo calculated wall neutral profiles of discharges with very different properties. The following function was found to describe the profiles sufficiently well for our purposes [7,8]:

$$\ln n_{n,w}(\rho) = \ln n_{n,w}(1)(1 + k_n(1-\rho))^{-1/3} \tag{1}$$

The parameters are $n_{n,w}(1)$, the wall neutral density at the edge, and k_n, a monotonic function of the dimensionless inverse fall-off length, which determines the shape of the profile. In Fig.2 the wall neutral density profile as obtained by EIRENE simulations and the approximation with the function above are shown for some ASDEX-Upgrade discharges.

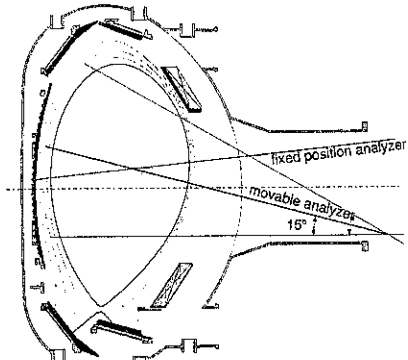

Figure 1: Viewing lines of the two Neutral Particle Analyzers in the poloidal plane. The movable analyzer can be turned also in toroidal direction.

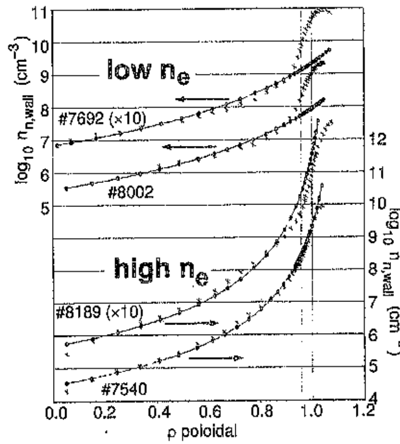

Figure 2: Density profiles of wall neutrals, calculated from simulation by the EIRENE code (stars) and fitted by the analytical function class (circles+line) in Eq.(1).

The CENS code fits the neutral profile simultaneously with a spline function model for the T_i profile by minimizing the deviation between the simulated and the measured fluxes. The parameters to be fitted are the T_i values at the knots, $\ln(n_{n,w}(1))$ and k_n. To get an estimate for the reliability and the accuracy of the results, pseudo-random noise according to the experimental errors is added to the neutral flux input data and the profiles are repeatedly calculated. In a first step the behaviour of CENS was studied in the so-called quasi-experiment mode [8], where the solution is known. Here we concentrate on processing of experimental data from plasmas in ASDEX-Upgrade.

3 Processing of experimental data

The program CENS provides a number of parameter options and modes, which make it a versatile tool and suitable for rather different conditions. The optimal operational range, where it recovers well the basic features of the T_i profile, but avoids the creation of oscillations and other artefacts, had to be found. For this purpose the following quantities were varied and the results compared with complete EIRENE simulations: 1. the number of spline knots, 2. the strength of Tikhonov regularisation, which favours solutions with low curvature. 3. the starting profiles, 4. the range of the flux spectrum 5. the amplitude of pseudo-random noise added to the experimental fluxes.

Satisfying results were obtained in a sufficient wide range of parameters. In particular the choice of the initial conditions is not critical. The optimal number of spline knots is 4 to 6. With 6 knots a moderate amount of Tikhonov regularisation is necessary; with a lower number of knots it can be reduced considerably.

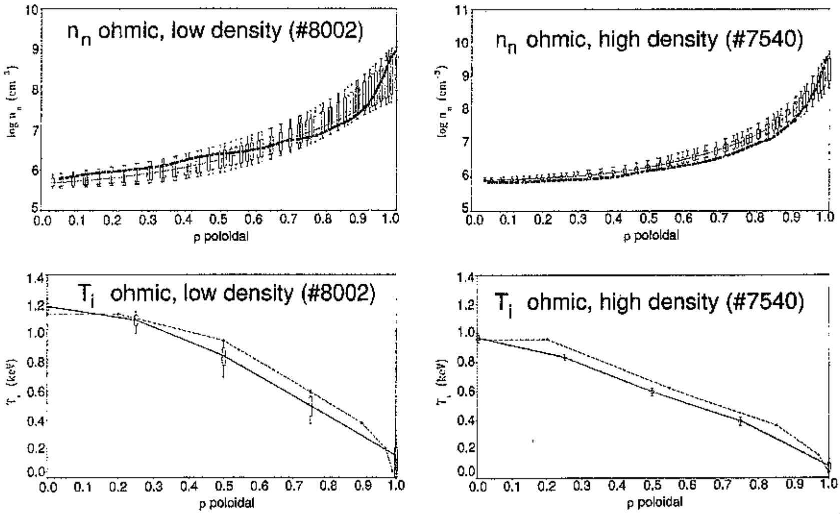

Figure 3: Ion temperature and neutral density profiles as a function of the normalised flux-surface radius ρ, for two ohmic discharges. The solid lines connect the median values. The boxes denote the interquartile ranges $Q_{75} - Q_{25}$, and the whiskers 90% interval estimates $Q_{95} - Q_5$. The dashed lines are a reconstruction based on EIRENE Monte Carlo simulations of the neutral density, in which additional measurements from the CX LENA diagnostic have been used. The accuracy (interquartile range) of latter reconstruction is in the order of 10% for the ion temperature and of 30% for the neutral density profile.

In Fig. 3 the results for two ohmic deuterium discharges are shown: #8002 has low density and current ($3 * 10^{19} m^{-3}$, 0.6MA), #7540 higher density and current ($6 * 10^{19} m^{-3}$, 1MA). The asymmetric position of the neutral density median at ρ *poloidal* > 0.7 for #8002 indicates, that there are two groups of solutions. The small interquartile distances in the central plasma region are due to the large contribution of neutrals from volume recombination.

Fig. 4 shows the recovered T_i profiles for a hydrogen discharge with increasing plasma density and Neutral Hydrogen Injection power, as given in the table within the figure. The evaluation uses the deuterium fluxes, which are not disturbed by the Hydrogen Injection. The steep rise between curves 3 and 4 and following slow decrease (curves 4 to 6) of the ion temperature reflects the switching on of the heating power and the continuously growing plasma density. At the end of the ohmic phase and at the highest densities essentially no particles from the plasma center contribute to the flux. The flux birth profiles provide limits for the radius, below which the T_i profile has to be regarded merely as an extrapolation of the outer parts with no local information. In fig. 4 this is indicated by the change from solid to dashed lines.

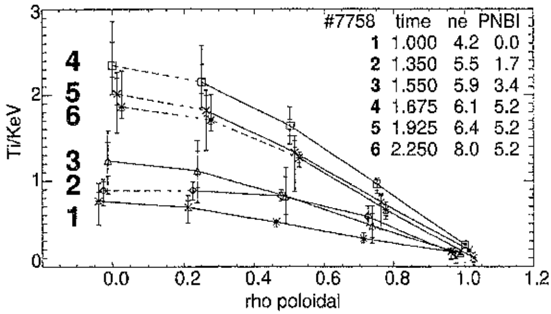

Figure 4: Ion temperature profiles of a discharge with increasing density and Neutral Beam heating power. The double error bars indicate the interquartile ranges $Q_{75} - Q_{25}$ and $Q_{90} - Q_{10}$, obtained from 80 realisations. Units: Time/s, $n_e/10^{19}m^{-3}$, PNBI/MW.

4 Conclusion

The CENS code allows fast determination of T_i profiles with an accuracy of 5 to 20 % over a reasonable range of plasma parameters. Simultaneously the wall neutral density can be determined with an accuracy of a factor of about 10. Regarding the huge dynamic range ($> 10^6$, see Fig.2,3) and the absence of measurements, such a determination of the neutral density profile may nevertheless be of interest. The computing time needed for one profile evaluation is about 1 minute on a standard workstation, depending on the desired accuracy of the interval estimates. Therefore, with CENS working in an automatic mode, it seems possible to provide temperature profiles for several selected intervals between two discharges. An overview about the T_i behaviour (about 10 profiles per discharge) for all discharges of a typical experimental day can be provided over night.

Part of this work was carried out under grant I/70032 of Volkswagen-Stiftung in 1995 – 1996.

References

[1] Stober J. et al., *Proc. of the 23nd EPS Conference on Controlled Fusion and Plasma Physics, Kiev, 1996,* **20C,III**, 1023 (1996), EPS

[2] Reiter D., *KFA Jülich reports*, **Jül-1947**, (1984), **Jül-2599**, (1992)

[3] Wagner F., *J. Vac. Sci. Technol.*, **20**, 1211 (1982)

[4] Yu.N. Dnestrovskij et al., IAE-5780/6, Russian Research Centre "Kurchatov Institute", Moscow, (1994)

[5] Bartiromo et al., *Rev. Sci. Instrum.*,**58**, 788 (1987)

[6] Yu.S. Gordeev et al., JETP. Letters, **25**, 204 (1977)

[7] O.J.W.F. Kardaun and A. Kus, IPP 5/68, (1996)

[8] A.V. Khutoretsky et al., Status Report of grant I/70032, Volkswagen Stiftung, 1997