Determination of Neutral-Beam Deposition Profiles with Modulation Experiments in Combination with ECRH-Heating in W7-AS

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Abstract:

Experiments for the determination of the neutral-beam deposition profiles in the W7-AS stellarator have now been extended to plasma discharges in combination with ECRH heating.

Plasma discharges, heated by one modulated beam only, showed good agreement between simulated and measured deposition profiles. The new measurements have continuous ECRH heating and one modulated neutral beam. In the plasma centre the measured neutral beam power deposition profile is larger than expected from simulations. During the beam-on phase there was a strong MHD activity that may have an influence on the power deposition.

Introduction:

The modulation method is an excellent way to measure the neutral-beam deposition profile. It was presented in detail earlier [1]. While modulating the neutral beam, spatially resolved ECE measurements of the resulting electron temperature T_e modulation amplitudes were carried out. If the variation of the electron density n_e is negligible compared to the modulation amplitude of T_e the power density $p_e(r)$ deposited by the modulated beam can be calculated by

$$p_{\mathrm{e}}(r)\left[\frac{\mathrm{W}}{\mathrm{cm}^3}\right]=1.6\cdot 10^{-6}\cdot\frac{3\pi^2}{2\sin(\pi\, d_{\mathrm{c}})}\cdot\frac{f[\mathrm{Hz}]\,n_{\mathrm{e}}(\mathrm{r})\left[\frac{10^{13}}{\mathrm{cm}^3}\right]\tilde{T}_{\mathrm{e}}(r)[\mathrm{eV}]}{A_{\mathrm{damp}}}. \qquad (1)$$

$\tilde{T}_{\mathrm{e}}(r)$ is the modulation amplitude of the electron temperature measured by a Fourier analysis, $n_{\mathrm{e}}(r)$ the local electron density, f the modulation frequency and d_{c} the duty cycle of the modulated neutral beam. The damping factor A_{damp} [2] takes into account that the finite slowing-down-time of the injected ions reduces the modulation depth of T_e. In this paper A_{damp} is calculated for the power-averaged neutral beam energy E_b=0.65E_0, where E_0 is the full beam energy. Under the assumption that the beam has only a single energy species and that the slowing-down is classical the evaluation of (1) is the measured neutral-beam deposition profile.

The measured neutral-beam deposition profile is then compared with a profile calculated by the Monte Carlo power deposition code FAFNER.

Results:

With plasma discharges heated by only one modulated beam there is good agreement between the deposition profile measurement and the results of the calculations. If the plasma discharge had one beam modulated and a second beam running continuously there was found to be a systematic deviation between simulation and experiment [3].

We now present the detailed evaluation of the modulated neutral beam deposition profiles for plasma discharges with additional ECRH heating. In these experiments one hydrogen beam was modulated while the plasma was heated continously by one ECRH gyrotron (400kW). Thus the measured modulation amplitude of the electron temperature is caused by the beam only. The addition of ECRH leads to both higher electron temperatures and a somewhat longer slowing-down-time (τ_{SD}) of the injected ions. The requirement $\tau_{SD} << \tau_{modulation}$ is still met however.

Fig. 1 shows an example of the measured and calculated neutral-beam deposition profile. The central plasma density was $n_e(0)$ = 7.6 10^{13} cm^{-3}. The time averaged central electron temperature was $T_e(0)$ = 670 eV, but less than 350 eV for r > 5cm because of the central ECRH power deposition. The modulation frequency was f = 125Hz and the duty cycle d_c = 0.5. The measured power density $p_e(r)_{exp}$ in the centre of the plasma is significantly different from the calculated power density $p_e(r)_{theor}$. For the plasma radius larger than 5 cm the agreement between measurement and theory is very good

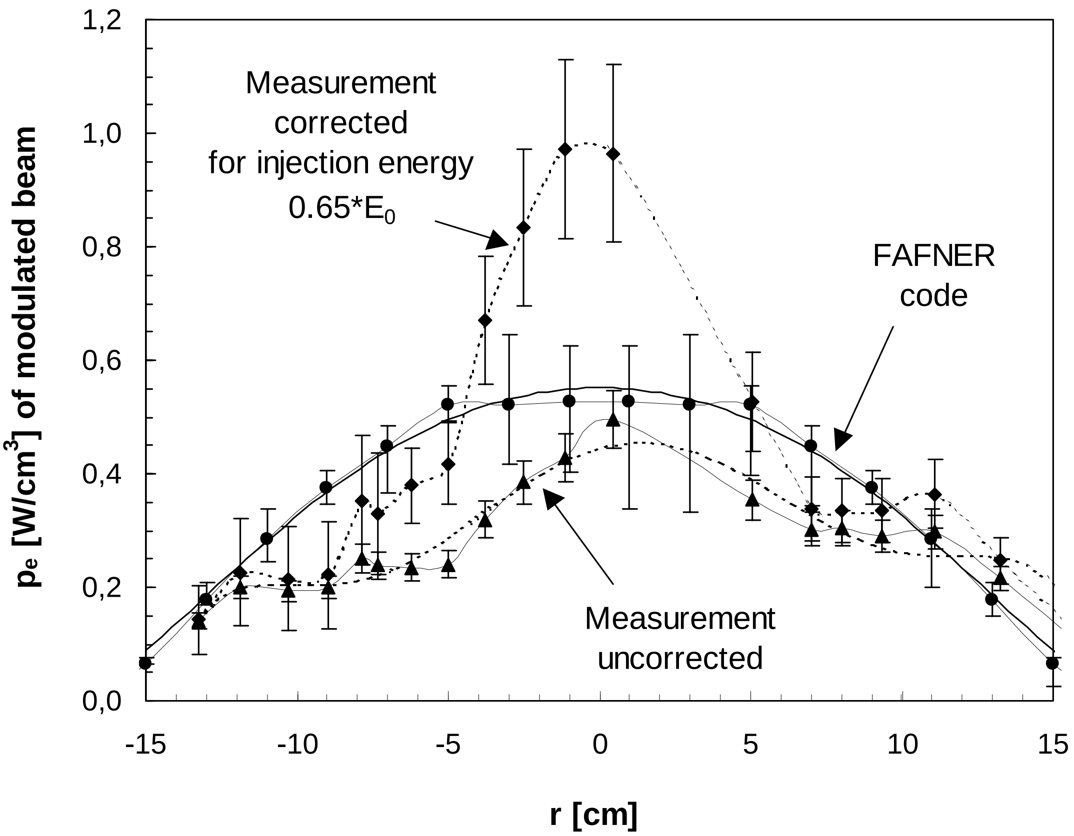

Fig. 1: Comparison of calculated and measured power density profiles. The measured data points are corrected with respect to the reduction of the power modulation depth because of the finite slowing down time of the injected ions. Pulse #46786: One hydrogen beam (Ost4) (inner, co) was modulated with a modulation frequency of 125 Hz while the plasma was heated continuously by one ECRH gyrotron (400kW). The quoted power density refers to the modulated beam only.

In addition a strong MHD activity was observed during the beam-on phase. Fig. 2 shows the Fourier transformation of a mirnov coil signal. The brightness is correlated to the magnitude of the signal. In this discharge the central plasma density was $n_e(0)=8{,}6\ 10^{13}\ \mathrm{cm}^{-3}$ and the average central electron temperature was $T_e(0) = 730$ eV and the beam was modulated with a frequency of 15 Hz. The strong MHD activity is only visible during the beam-on phase and and absent during the pure ECRH phase. The same behaviour was observed for plasma discharges when the beam modulation frequency was varied between 15 Hz and 250 Hz.

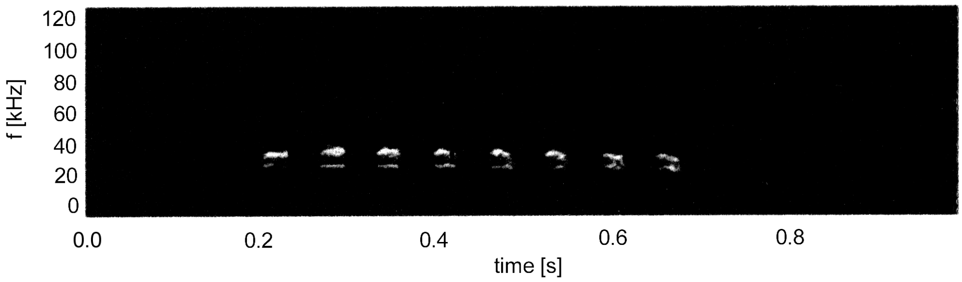

Fig. 2: Strong MHD activity was observed during the beam-on phase of the combined ECRH and NBI discharge. Pulse #46781: Same beam as in Fig. 1 but the modulation frequency was 15 Hz. (Slowing-down-time $\tau_{SD} << \tau_{modulation}$ *)*

Discussion:

The discrepancy between calculation and measurement as shown in Fig. 1 could be explained by beam-plasma interaction. An additional indication for that is the observed MHD activity during the beam-on phase (Fig. 2). The mechanism is not yet understood and needs further in depth examinations. The good agreement between calculation and measurements if the plasma is heated by one modulated beam only and the discrepancy in the presence of a second unmodulated beam is another indication that the observed discrepancies are related to a higher T_e.

Previously the fast ion density produced by continuos NBI was determined by the measurement of the neutron rate. From these measurements it was found that the slowing-down process of injected ions in W7-AS is a classical one, unless no strong MHD activity occurs [4].

References:

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