Measurement of Neutral-Beam Deposition Profiles at W7-AS and LHD Stellarator

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Abstract:

Experiments to determine the neutral-beam deposition profiles in a stellarator have now been carried out at W7-AS and recently also at LHD using the same method for data evaluation. While modulating the neutral beam, spatially resolved measurements of the resulting T_e modulation amplitudes are carried out. Their evaluation yields the neutral-beam deposition profiles.

On W7-AS as compared to the previous modulation experiments [2,3] the diagnostic was improved during its last experimental campaign. At LHD these modulation experiments have been performed not only on a significantly larger machine, but the neutral beam system at LHD is quite different from that of W7-AS. The LHD system uses a negative-ion beam at a significantly higher acceleration voltage.

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}. For W7-AS with it´s positive ion beam, 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 LHD system uses a negative-ion beam at a significantly higher acceleration voltage of 150kV in hydrogen.. This implies that the fast hydrogen neutrals of the neutral beam have a single energy component. The calculation of A_{damp} is therefore easier. Its calculated for this single energy component.

Results:

On W7-AS as compared to the previous modulation experiments the diagnostic was improved during it´s last experimental campaign. This was done by measuring the signal of the neutral beam acceleration current with the same ADC used for the ECE diagnostics measuring the T_e modulation amplitudes. Thus it is possible to evaluate not only the T_e modulation amplitude, but also the phase information between the neutral beam and the measured T_e signal. One modulated W7-AS positive ion co source at an acceleration voltage of 55kV in deuterium was used.

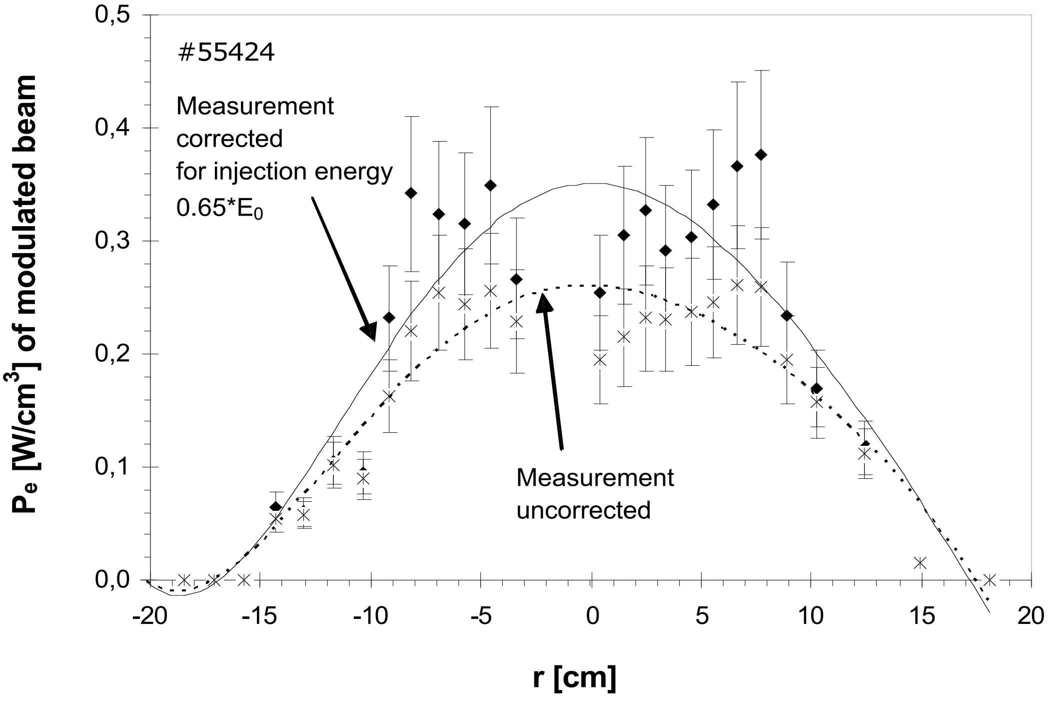

Fig 1: W7-AS: Measured power density profile for one modulated deuterium beam with a modulation frequency of 120Hz.

Fig 1 and Fig 2 show the measured power density profiles for two different shots with more ore less the same density profile ($n_e(0)=8\cdot10^{19}$ m^{-3}, $T_e(0)=250$ eV). The only difference is the modulation frequency. In both shots the same modulated co source was used. In Fig 2 the modulation period ▯is larger than the slowing down time of the ions from injection energy down to thermal energy t_{max} and therefore the damping factor A_{damp}

is close to 1. In Fig 1 the correction with the damping factor is significantly larger. But nevertheless the corrected power density profile of both shots is the same.

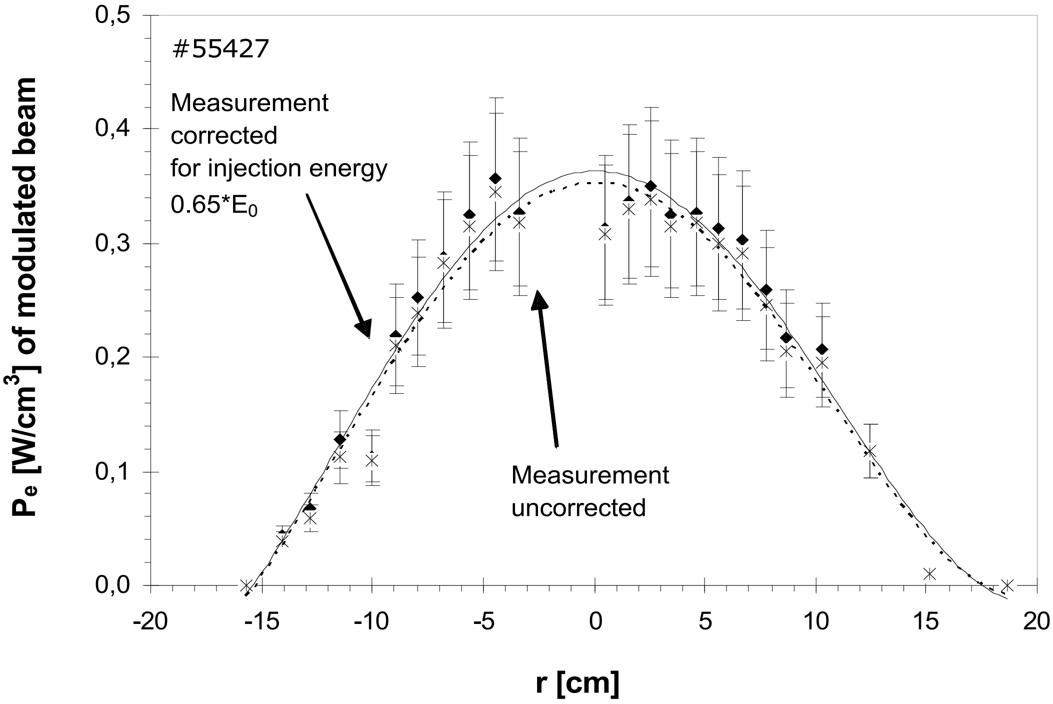

Fig 2: W7-AS: Measured power density profile for one modulated deuterium beam with a modulation frequency of 50Hz.

Fig 3 shows the phase shift between the modulated beam and the measured ECE temperature signal.

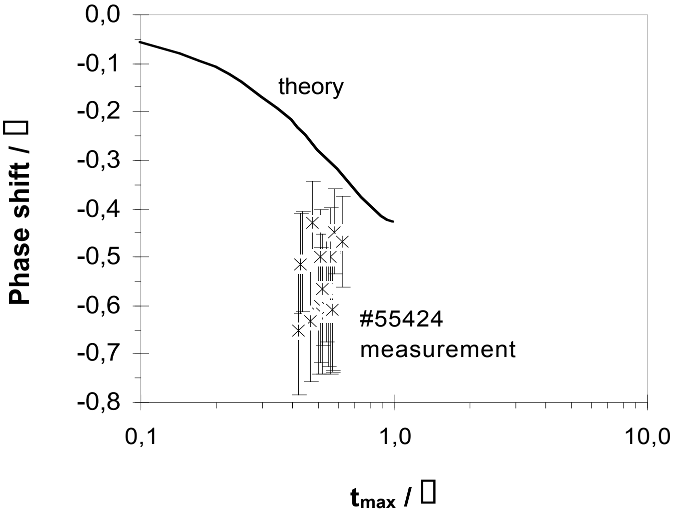

Fig 3: W7-AS: theoretical and measured phase shift.

This phase shift depends on the radio $t_{max}/□$. For the case that the modulation period is larger than the slowing down time the phase shift is very small, changing strongly in the range $t_{max}/□ < 1$. Now it was possible to measure this phase shift for the first time. Fig 3 shows the result for the same shot as used in Fig 1. The measured phase shift is very close to the theory.

The same method for the determination of the power density was used for LHD. Experiments were carried out using two counter beamlines: one modulated and one running continously for background heating. Three different magnetic field configurations were used to determine the effect of the magnetic field on the heating profile. The field configurations were: one more outward shifted configurations and inward shifted configurations in two steps. The T_e modulation amplitudes were measured with the ECE system at LHD.

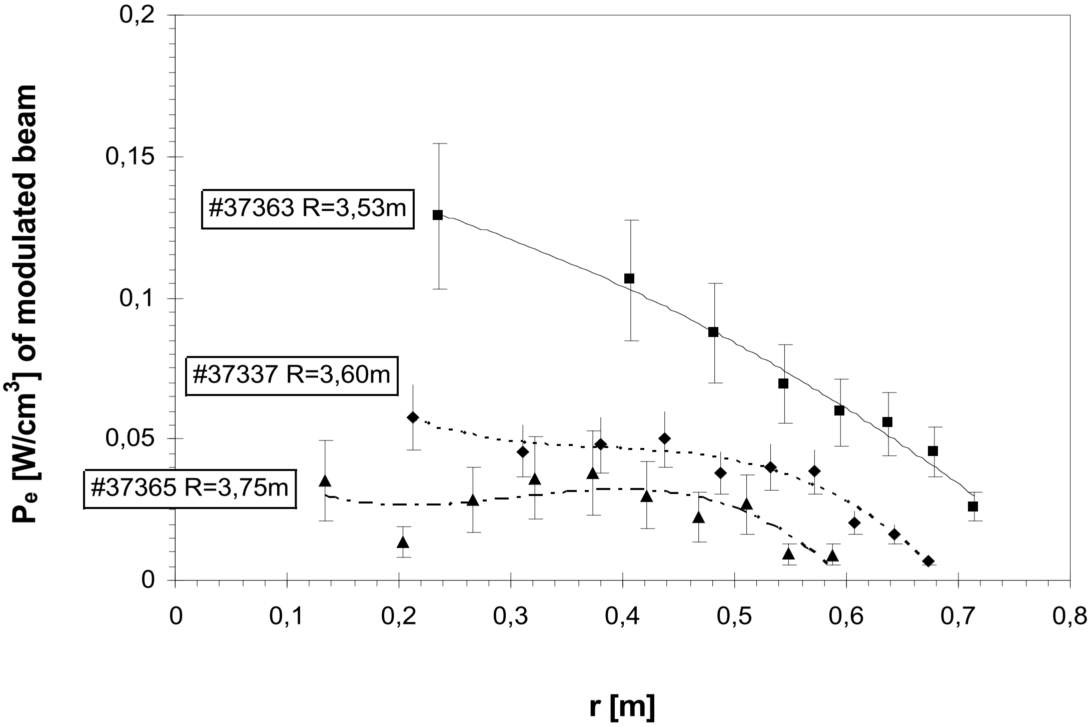

Fig 4: LHD: measured power density for tree different configurations. The central density was $0{,}8 \cdot 10^{19} m^{-3}$.

For LHD the heating power is strongly dependent on the plasma configuration. The more inward shifted configurations have a significantly higher heating power. The explanation for this strong effect could be that the magnetic field ripple is not so strong for the inward shifted configurations and therefore the fast particle loss is getting smaller. But it remains to compare it to the LHD neutral beam deposition code. At LHD the absolute value of the power density is smaller compared to W7-AS because of the different ratio of neutral beam bower to the plasma volume.

For a higher plasma density the power density becomes more peaked in the plasma centre. Fig 5 shows the power density for two different plasma densities and for the middle configuration of above.

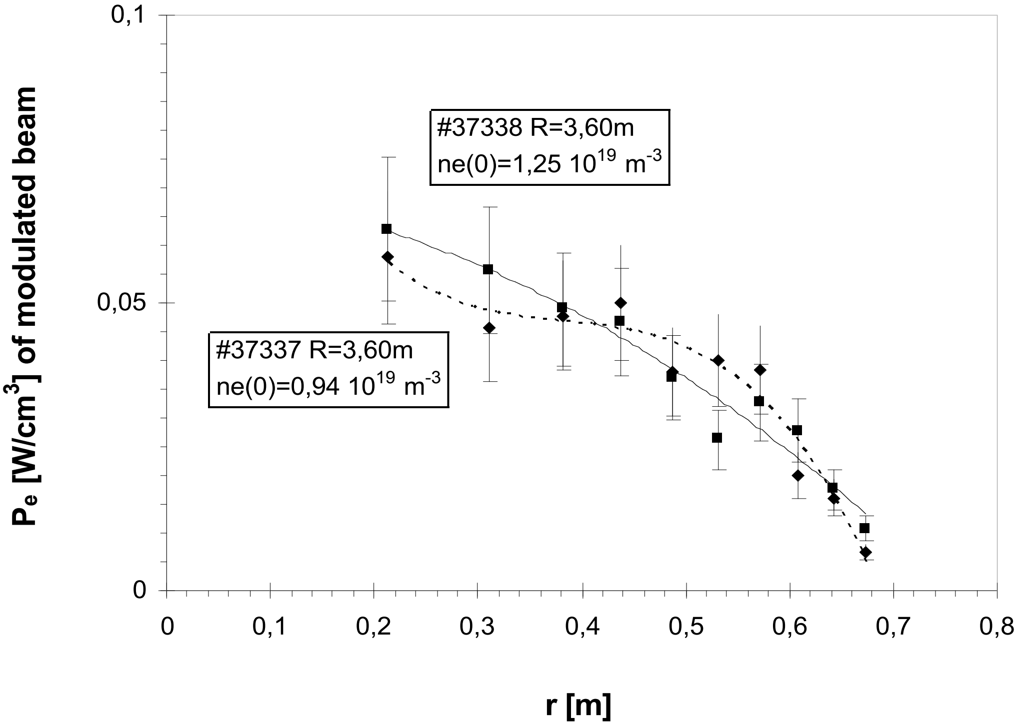

Fig 5: LHD: measured neutral beam power density for two different plasma densities and the same plasma configuration.

Conclusion:

Neutral beam modulation experiments were successfully used for the determination of the power density for the two machines W7-AS and LHD. At W7-AS it was for the first time possible to measure the phase shift between the beam modulation and the ECE temperature measurement. At LHD these measurements were made also for the first time and only for counter injection. A strong dependence on the power density of the plasma configuration was found. The more inwards shifted configurations have a significantly higher heating power.

References:

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[3] N. Rust, e.a., 28th EPS conf. on Contr. Fusion and Plasma Phys., (2001)