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Neutral-Beam Deposition Profiles in the W7-AS Stellarator

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Abstract:

Measurements aimed at determining the NBI deposition profile in the W7-AS plasma with beam modulation methods have been continued. Two distinctively different types of results have been found. The first type is obtained when the plasma is maintained by the modulated beam only (one half beam in the average). In this case the measured profiles of the power density delivered to the electrons $p_e(r)$ are centrally peaked and agree surprisingly well with the profiles calculated with the FAFNER Monte Carlo code.

The second type was seen when one beam was running continuously in addition to the modulated beam (one and a half beams in the average). In these cases the calculated profiles of $p_e(r)$ were also centrally peaked but the measured ones were hollow. Whether this discrepancy is caused by the modulation method itself is an open question.

Introduction:

The method of measuring the deposition profiles of neutral beams in a plasma by modulating the beam has been presented [1]. Additional measurements have been done to extend these previous results. For analyzing the measurements, an attempt has been made to avoid all the uncertainties of heat conduction and other effects influencing T_e by modulating the beam so fast that the energy is conserved locally. In this case the deposited power density $p_e(r)$ can be determined from $p_e(t) = (3/2)\,\mathrm{d}(n_e\, T_e)/\mathrm{d}t$. Usually the relative variation of n_e is negligible compared with the relative variation of T_e. A Fourier analysis for a periodically modulated beam then delivers the power density

$$p_e(r)\left[\frac{\mathrm{W}}{\mathrm{cm}^3}\right] = 1.6\times10^{-6}\times\frac{3\pi^2}{2\sin\pi d_c}\times\frac{f[\mathrm{Hz}]\,n_e(r)\left[\frac{10^{13}}{\mathrm{cm}^3}\right]\,\tilde{T}_e(r)[\mathrm{eV}]}{A_{\mathrm{damp}}}\,.$$

f is the modulation frequency, d_c the duty cycle, $n_e(r)$ the local electron density and $\tilde{T}_e(r)$ the measured modulation amplitude of the electron temperature. The damping factor $A_{\rm damp} < 1$ takes into account that the power modulation depth is reduced by the finite ion slowing-down time of the fast ions. $A_{\rm damp}$ has to be calculated locally from n_e, T_e, E_b (beam energy), E_c (critical energy) and f [2]. $n_e(r)$ is measured by microwave interferometry, $T_e(r)$ and $\tilde{T}_e(r)$ by ECE measurements. E_b, f and d_c are quantities defining the neutral beam. So $p_e(r)$ can be calculated from measured quantities. The only arbitrary assumptions are that the beam has only one energy species and that ion slowing-down is classical, i.e. purely collisional.

Results:

Fig. 1 shows an example for the cases where the shape as well as the magnitude of the measured power density agree with the calculated power density. The correction factor $A_{\rm damp}$ as derived in [2] is calculated for the power-averaged neutral-particle energy $E_b = 0.65\,E_0$. In all these cases the plasma was maintained by the modulated beam only which means that during the beam off periods the plasma was an afterglow plasma. The average values for $n_e(0)$ and $T_e(0)$ were $\approx 9 \times 10^{13}\,\mathrm{cm}^{-3}$ and $\approx 450\,\mathrm{eV}$, respectively. The modulation periods were varied from 64 ms to 4 ms. Agreement with theory was obtained for 8 ms and 4 ms.

Fig. 2 shows a case where shape and magnitude of $p_e(r)|_{\rm exp}$ were significantly different from $p_e(r)|_{\rm theor}$. Theory delivers a centrally peaked profile whereas the experimental profile is hollow with a maximum at $r \approx 10\,\mathrm{cm}$. In all these cases one beam was running continuously, the modulated beam was superimposed with a duty cycle of $d_c = 0.5$. Central plasma parameters were $n_e(0) \approx 8 \times 10^{13}\,\mathrm{cm}^{-3}$ and $T_e(0) \approx 800\,\mathrm{eV}$. For this situation the modulation period has not yet been varied as widely as for the case of Fig. 1. The measurement with 18 ms instead of 9 ms of Fig. 2 also shows a slightly hollow profile.

Discussion:

It is concluded from Fig. 1 that the modulation method can be applied to neutral beams if the ion slowing-down is classical. The discrepancy, as shown in Fig. 2, could be explained by nonclassical slowing-down. It must be mentioned, however, that we have no experimental evidence so far. One possibility is that oscillations are excited by the modulation method itself, e.g. by beam-plasma interactions occurring after switching on the beam during the first slowing-down time (compare Ref. [3]). It may, however, also be possible that some Alfvén instability may be driven at the higher T_e and beam β of the second case. Further experiments with a larger variation of the modulation period are planned.

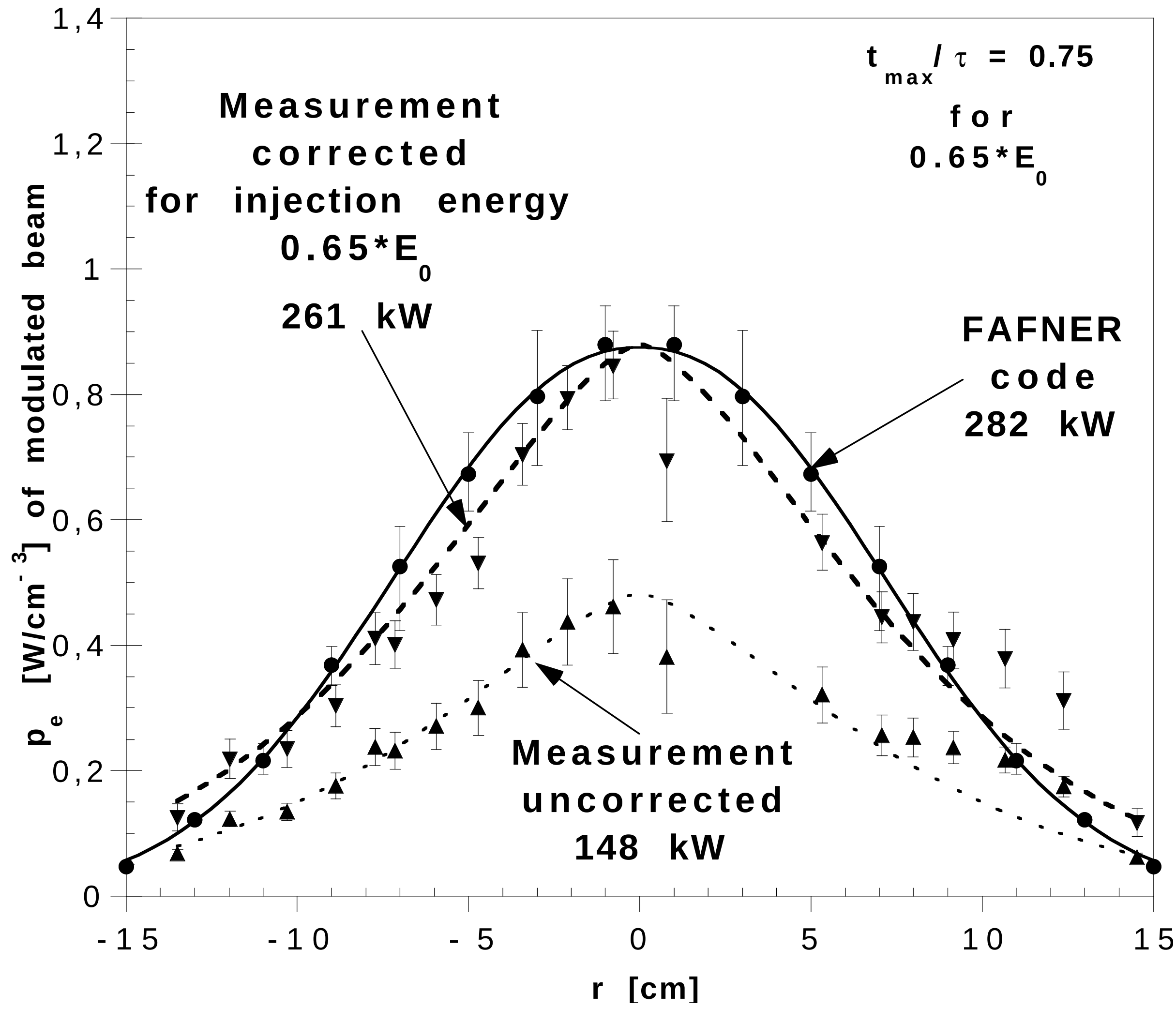

Fig. 1: Comparison of calculated and measured power density profiles. The measured data points are corrected for slowing-down damping of the power modulation depth. Pulse #45980, deuterium beam in deuterium plasma, source Ost4 (inner, co), plasma maintained by modulated beam only, $n_e(0) \approx 9\times10^{13}\,\mathrm{cm}^{-3}$, $T_e(0) \approx 450\,\mathrm{eV}$. *Modulation period* $\tau = 8$ *ms.* $t_{\max}$ *is the total ion slowing-down time from injection energy to thermal energy at* $r = 0$. *The quoted power levels are those resulting from numerically integrating the deposition profiles.*

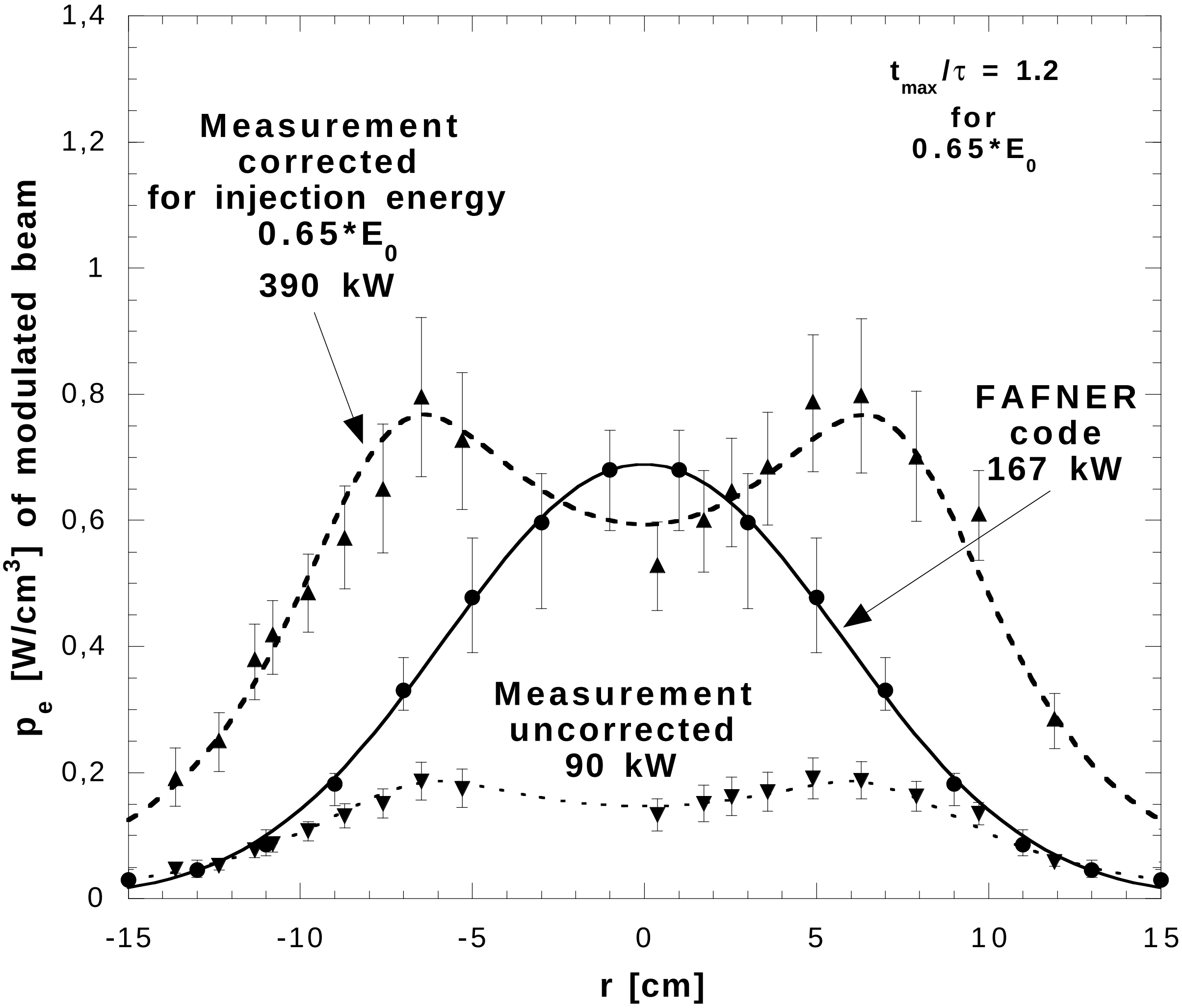

Fig. 2: Comparison of calculated and measured power density profiles. Pulse #42915. Same beam as in Fig. 1, however plasma maintained by an unmodulated beam (Ost1) together with the modulated beam (Ost4) (both inner, co), $n_e(0) \approx 8 \times 10^{13}\,\mathrm{cm}^{-3}$, $T_e(0) \approx 800\,\mathrm{eV}$. *Modulation period* $\tau = 9$ *ms. The quoted power levels refer to the modulated beam only.*

References:

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