

NEUTRAL-BEAM MODULATION FOR PROFILE MEASUREMENTS OF POWER AND PARTICLE DEPOSITION

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Abstract

This paper contains a first attempt to measure the NBI deposition profile directly by beam modulation techniques. The experiments have been conducted in W7-AS. Spatially resolved measurements of the modulation amplitudes and phase shifts of T_e and n_e have been carried out. The results were analyzed by using the FAFNER code and applying standard Fourier techniques to derive damping factors and phase shifts. The latter arose from the slowing-down time of the fast ions. Although the inherent assumptions in the analysis are not fulfilled over the major part of the plasma, there is agreement to some extent between measurements and theory. The remaining discrepancies are being discussed. Improvements both in the experiments and the analysis are projected.

1. Introduction

The direct measurement of the deposition profile of ECRH in the plasma has become a common technique: the ECRH power is modulated and the subsequent response of T_e is measured by ECE [1]. For NBI neither the total heating efficiency nor the power deposition profile has been measured directly so far. In case of NBI the problem is more complicated, because the beam ion slowing-down time (t_{\max}) is much longer than the electron-plasma energy exchange time in case of ECRH. When the beam is switched on and off, the heating power does not respond instantaneously because of the finite slowing-down time of the fast ions. Therefore the power modulation resulting from beam modulation is damped if the modulation period is comparable to t_{\max} or shorter. In order to achieve deposition profiles with negligible damping effects, the modulation period τ should be long compared to the ion slowing-down time t_{\max} . On the other hand, the modulation period should be short compared to the energy confinement time τ_E of the plasma. Hence the overall requirement for the modulation period τ is

$$t_{\max} \ll \tau \ll \tau_E. \quad (1)$$

It is evident that this requirement for the modulation period τ is not fulfilled automatically for all plasma/beam parameters. It is best fulfilled in large plasmas at high densities and low electron temperatures. This experiment is a first trial, violating both constraints.

2. Fourier analysis of modulated beam heating

An analysis of damping and phase shifts of the modulated power due to the finite slowing-down time has been done in ref. [2]. Damping factor and phase shift depend on the ratio t_{\max}/τ , where t_{\max} is the time for slowing-down of the ions from injection energy down to thermal energy and τ is the modulation period. For $t_{\max} = \tau$, the damping factor A_{damp} decreases to 0.4. For longer slowing-down times, A_{damp} decreases approximately proportionally to $(t_{\max}/\tau)^{-1}$. The phase shift between the power modulation and the beam changes strongly in the range $t_{\max}/\tau < 1$ and stays near $\pi/2$ for $t_{\max}/\tau > 1$. Fig. 1 shows the dependencies of the damping factor and the phase shift on the ratio t_{\max}/τ as calculated in ref. [2].

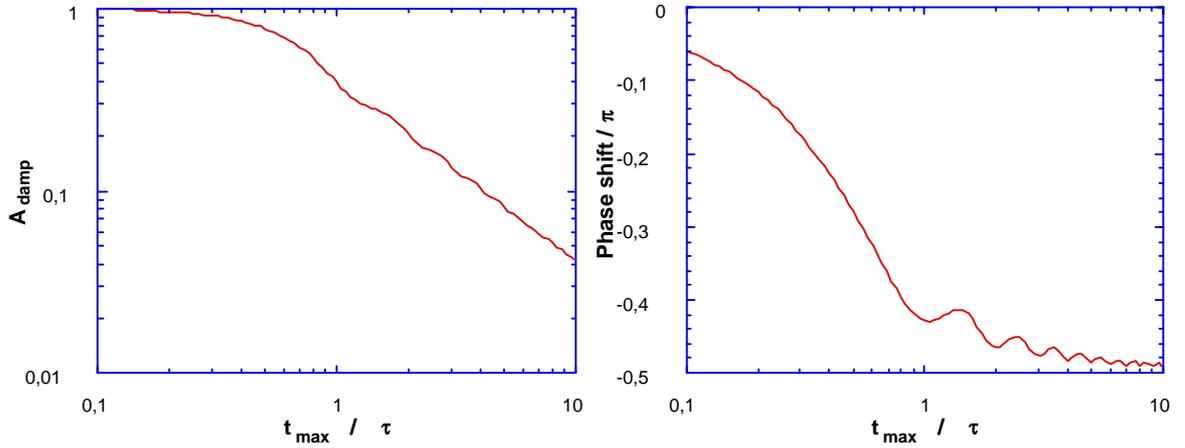


Fig. 1: Damping and phase shift of modulated power
 t_{\max} = complete ion slowing-down time, τ = modulation period

3. Measurements with modulated beams

First measurements with modulated beams have been done. The modulation frequency was mainly 55 Hz, the duty cycle 1/2. An example is given in Fig.2. The profile $T_e(r)$ was measured using ECE [3], $n_e(r)$ was delivered by multichannel interferometry [4]. The graph $t_{\max}(r)$ shows the local complete slowing-down time of full-energy beam particles in comparison with the modulation period. In the central part of the plasma the slowing-down time exceeds the modulation period. Strong damping of the power amplitude is to be expected there. The third plot in Fig. 2 shows the power density per electron as calculated with the FAFNER code [5] for the plasma profiles and the beam as given here. The fourth plot shows the calculation \tilde{T}_e amplitude derived from $T_e = \text{const.} * (p_e \tau / n_e) * A_{\text{damp}}$ under the

assumption of no heat conduction. The second curve in this graph shows the expected phase shift between heating power and beam.

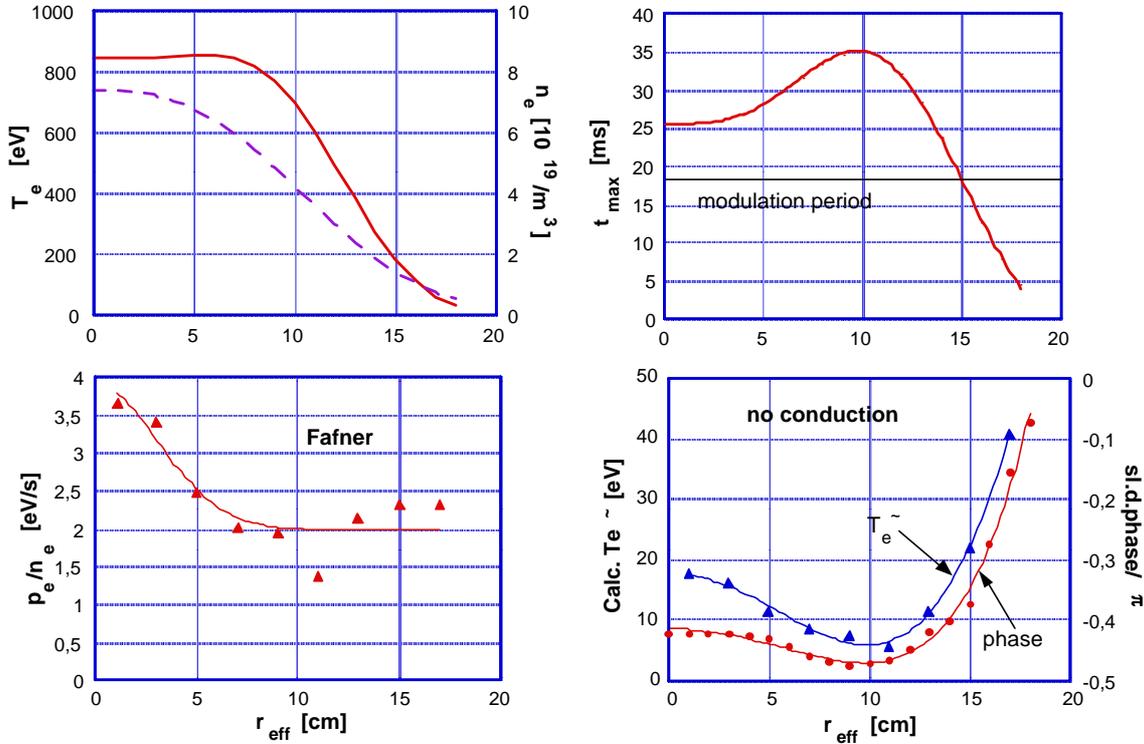


Fig. 2. Plasma profiles, calculated power density and expected modulation effects, see text - #42564, source O2

The measurements of the modulation amplitudes \tilde{T}_e and \tilde{n}_e of T_e and n_e at the fundamental frequency are shown in Fig. 3 for the same discharge. At radii $r > 8$ cm there is relatively good agreement of measured and expected amplitudes of \tilde{T}_e especially if it is kept in mind that heat conduction is not included in the calculation. There is a substantial disagreement, however, at radii $r < 8$ cm, where the first part of condition (1) is strongly violated.

The density amplitude \tilde{n}_e on the other hand shows reasonable agreement with the expectation in the inner part of the plasma. At the outer part the measured density amplitude is much higher than the FAFNER expectation. It is to be concluded that these ions are created not from the beam but by a certain gas influx caused by the modulated beam, probably by gas released from the wall by impinging beam neutrals or by lost ions. This interpretation is backed by the H_α signal emitted from the beam-plasma interaction region which is strongly modulated. If measured at an opposite place, the H_α modulation depth is much smaller.

Phase shift measurements of \tilde{T}_e and \tilde{n}_e have been done. They are, however, not yet understood and are not shown here. The significance of heat conduction is probably too high in these measurements.

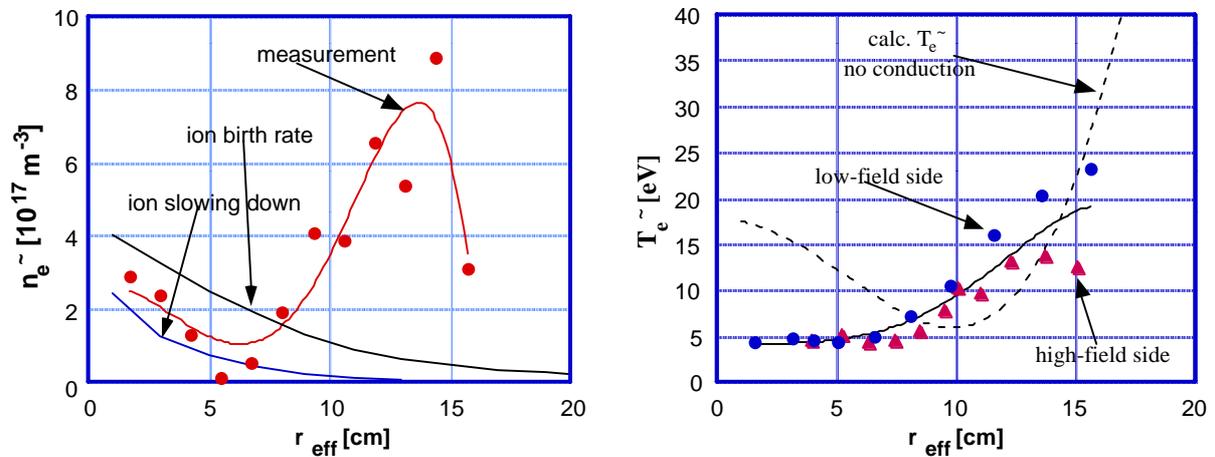


Fig. 3. Measured profiles of the amplitudes of \tilde{T}_e and \tilde{n}_e and comparison with the theory

4. Conclusions

First measurements directed towards determining the deposition profile of the neutral beam power in a plasma by beam modulation have been done. The conditions have not yet been suitable for this determination because the modulation period is comparable to the slowing-down time of the beam particles as well as to the energy confinement time of the plasma, violating condition (1). It is planned therefore to extend these measurements to higher plasma densities to reduce effects of the finite slowing-down time and of heat conduction.

Furthermore, ref. [2] assumes that all beam particles slow down in a homogenous plasma and without lost orbits. The FAFNER code, which includes plasma inhomogeneity as well as particle losses but no time dependence, has to be extended therefore to deliver the temporal development of the heating power profile.

References:

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