LANGMUIR PROBE MEASUREMENTS IN THE ASDEX DIVERTOR PLASMA

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I. Introduction and apparatus: Langmuir probes have been used routinely in ASDEX divertor plasma diagnostics /1,2/. Recently, a fast movable probe carrier system was installed. Two fast sweeping movements with a speed of 1 m/s and 10 cm displacement were possible during a shot. The probe can also be kept, for an adjustable time interval, at the innermost position. The initial position of the probe can be adjusted by using the manipulator and a tilt mechanism. A large area of the divertor plasma can thus be scanned in the radial and vertical directions (see fig. 1).

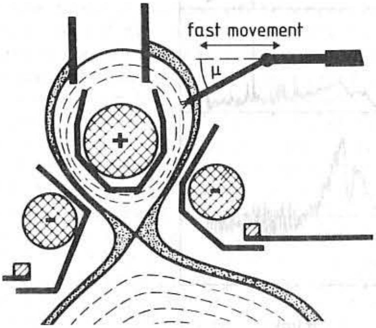

Fig.1: Probe arrangement and accessible area in the upper divertor.

The divertor probe system was used in all operation regimes of ASDEX. The triple-probe arrangement /3/ was mainly used but the probes were also operated as a double probe, especially for cross-check purposes. Up to four radial profiles of the ion saturation current, electron temperature and floating potential relative to the divertor plate were obtained during a shot.

II. Experimental results: Radial scans have revealed strong gradients of the plasma parameters across the flux surfaces, near the separatrix location. This fact is important since triple-probe operation is very sensitive to differences in plasma parameters seen by the three tips. In order to minimize the error introduced by these gradients in temperature and density evalu-

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ation, an optimum inclination of the probe arm was chosen so that the tips were as close as possible to the same flux surface. The data reported here were obtained with this optimum inclination ($\mu \approx 15^o$).

Ohmically heated discharges: Typical radial profiles of plasma parameters for two values of the main plasma densities are shown in fig. 2. The medium density profiles display the well-known characteristics of the ASDEX divertor plasma /1,2/: large maxima close to the separatrix, broad shoulders a few centimetres away in the ion saturation current and density profiles, and relatively flat temperature profile. The absolute values of the electron temperature and density are in good agreement with the double-probe cross-check measurements. The floating potential profiles are flat, with values slightly negative. At densities $\bar{n}_e \leq 5 \times 10^{13}$ cm^{-3}, a sharp negative "dip" develops close to the calculated position of the separatrix which cannot be attributed to a local temperature rise.

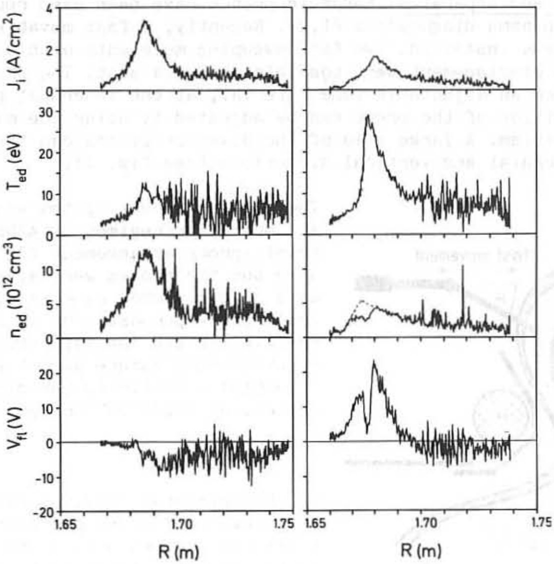

Fig.2: Profiles of ion saturation current, electron temperature, density and floating potential vs. major radius R for $\bar{n}_e = 4.3 \times 10^{13}$ cm^{-3} (left) and $\bar{n}_e = 1.4 \times 10^{13}$ cm^{-3} (right).

As the density is lowered, the floating potential becomes positive together with an increase of temperature around the separatrix, in a region which is more and more extended. Also the narrow "dip" is now well developed. Floating-potential gradients as high as ~100 V/cm can be observed in some low density shots. Even at the optimum inclination of the probe arm, floating potential differences of 5 to 8 V between tips were measured in a narrow zone around the separatrix. These high gradients together with a presumably non-Maxwellian electron velocity distribution clearly affect the derivation of the electron temperature and density profiles (see fig. 2).

Additionally heated discharge: During the additional-heating phases of the discharges (NI, LH, ICRH) the divertor plasma also displays specific features. Besides the enhanced power flow (increased ion saturation current and electron temperature), some changes were also observed in the floating-potential and density profiles. In fig. 3 a few examples of floating-potential profiles are presented. In the L phase of a NI-heated discharge, the floating-potential profiles show positive charging of the plasma around the separatrix, similar to that in OH discharges of lower densities. The negative "dip" is also more pronounced.

In the H phase, the burst activity makes the interpretation of floating-potential data very difficult. The ion saturation current and electron temperature between bursts are comparable with the values for ohmic phases. The peak values of bursts are much larger and extend over the whole profile, including the shoulder.

The RF heating produces different effects on the density and floating-potential profiles, mainly depending on the plasma density and the injected power. At medium densities ($\sim 4 \times 10^{13}$ cm^{-3}) and high powers (~2 MW), all the divertor plasma is positively charged, as can be seen in fig. 3.

III. Discussion: As seen above, all profiles show a pronounced structure depending on the density, heating power and heating method. The dependence of the maximum values of the electron temperature, density and floating-potential of the divertor plasma on the main plasma density for ohmic discharges is presented in fig. 4. A smooth evolution in all three measured parameters can be seen with rising density. No step-like change of V_{fl} with density as in D-III /4/ was observed. The floating-potential profiles suggest different transport to the divertor plates for different plasma densities. So, at high and medium densities, the floating potential stays slightly negative, being compatible with locally ambipolar transport on each flux tube /5/, and with some (few eV) drop in the electron temperature between the probe position and the divertor plate. As the density is lowered or NI power is added, the floating potential around the separatrix starts to rise and extends radially, the whole cross-section of the divertor plasma being positively charged at densities below 1×10^{13} cm^{-3}. The positive values of V_{fl} suggest locally non-ambipolar transport to the divertor plates. The mechanism by which the divertor plasma is charged is not yet clear. Non-Maxwellian electrons close to the separatrix (see below) together with vertically asymmetric plasma position and divertor recycling etc. could be candidates for explanation. Further experiments are needed to clarify these aspects.

The negative "dip" displayed very close to the calculated position of the separatrix, although expected, was surprising in some respects. Firstly, it implies strong gradients in floating potential which perturbs any multiple-tip probe measurements. Then, it is very narrow so that we believe that it can be used for separatrix position determination (as done in Fig. 3) with a better accuracy than magnetic measurements.

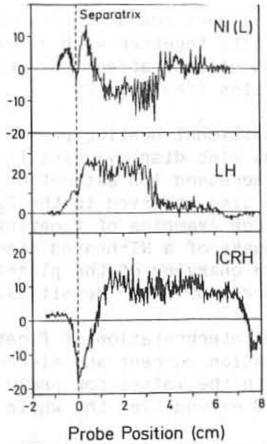

Fig.3: Floating potential profiles for different heating methods.

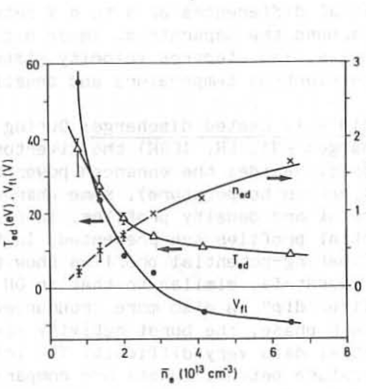

Fig.4: Peak values of electron temperature, density and floating potential vs. main plasma density $\bar{n}_e$.

Some estimation of the current density and energy of electrons responsible for the "dip" can be made by combining the available data. Values of 0.2 - 0.5 A/cm^2 and $E_e \geq 100$ eV were obtained in low-density discharges. At higher densities, these numbers are significantly lower and only upper limits can be estimated. The values obtained at low densities are in good agreement with those expected from a diffusive loss of fast electrons across the separatrix which can reach the divertor /6/. It is therefore concluded that the negative "dip" in floating-potential profiles as well as some distortion in ion saturation current profiles at very low densities are due to fast electrons which flow almost collisionless from the main chamber to the divertor very close to the separatrix.

The amounts of energy carried by these electrons can be locally important. Some comparisons with thermographic data have shown that the correction implied by these fast electrons has the right direction.

References

/1/ Y. Shimomura, M. Keilhacker, K. Lackner and H. Murmann, Nucl. Fus. 23, 869 (1983).
/2/ G. Fussmann et al., J. Nucl. Mater. 128/129, 350, (1984).
/3/ S.L. Chen, T. Sekiguchi, J. Appl. Phys. 36, 2363, (1965).
/4/ M. Shimada et al., in Plasma Phys. and Contr. Nucl. Fus. Res. 1984 (Proc. 10th Int. Conf. London, 1984), Vol. 1, IAEA, Vienna (1985) 281.
/5/ P.C. Stangeby, G.M. McCracken, S.K. Erents, J.E. Vince and R. Wilden, J. Vac. Sci. Technol. A1, (2), 1302 (1983).
/6/ U. Ditte, T. Grave, Probe and Thermographic Measurements in ASDEX Divertor, IPP Report, III/102 (1985).