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RESULTS FROM LANGMUIR PROBE MEASUREMENTS IN PDX AND PLT

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Fits to Langmuir probe measurements made near the midplanes of the PDX and PLT tokamaks imply density and electron temperature profiles. In ohmically heated plasmas with either circular or diverted configurations, the edge densities decrease approximately exponentially with e-folding lengths of 1-4cm. Electron temperatures are low (5-50 eV) and decrease more gradually than the density profiles in the outer edge.

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1. Introduction

More is known about plasma properties in the center than in the edge of large tokamaks, primarily because the hotter center is more interesting since it will produce more fusion power. Also, most diagnostics measure properties along chords. It is not very practical to measure on chords which pass only through the edge, and it is hard to unravel the edge contribution from chords which pass through the hotter central region.

For several reasons it is important to know properties of the edge. There is a strong coupling between the edge and the first wall. The heat and particle fluxes from the edge determine melting and sputtering of the first wall, and thus the impurity influx. Instabilities and turbulence in the edge increase heat loss from the center. Understanding these may lead to ways of reducing the loss.

Langmuir probes are convenient diagnostic tools for studying local plasma properties such as electron density and temperature since they are simple to build and operate. The theory for interpreting the measurements is well developed for plasmas in weak magnetic fields and with ion temperatures much lower than electron temperatures.¹ In the edge of tokamaks, where the magnetic fields are large and the ions appear to be as hot or hotter than the electrons, the theory is less certain. Thus, Langmuir probe measurements in tokamaks contain large systematic uncertainties due mainly to difficulties in interpreting them. Nevertheless, they have yielded unexpected and useful indications about conditions in the edge.

Results from Langmuir probe measurements in FLT,² PDX,^{3,4} and other tokamaks⁵ have been reported. This paper differs in that the data is extensive, and a non-linear curve-fitting routine was used to deduce electron temperature and density profiles.

2. Experimental Procedures

The probe for the PDX measurements had a single tip consisting of a short, stubby, steel cylinder supported by a concentric alumina insulator in a carrier tube. The radius was 2.7 mm and the exposed length was 5 mm. The cylinder was close to the midplane of PDX and near the outer limiter. It was oriented with its axis approximately perpendicular to the toroidal field and its radial position could be varied.

Several circuits were used for biasing the probe and recording the voltage and current. The most successful is shown in Fig. 1. The PDX timer triggered a train of waveforms (typically a pulse lasting 2 ms followed by a dwell lasting 20 ms) which was amplified by a bipolar operational amplifier (BOP). The BOP biased the probe relative to the vacuum vessel. A voltage divider and a current monitor measured the voltage and current between the probe and the vacuum vessel. An analog-to-digital converter recorded the signals, which were archived. Current-voltage characteristics were generated from the archived data.

For the FLT measurements, two probes were used. These were nearly identical antenna which were also used for radio frequency pickup measurements. Each consisted of a tee made of a steel rod 1.6 mm in diameter. The cross piece of the tee was 15 mm long, oriented along the magnetic field lines, and extended 2 mm past a co-axial tube with an inner diameter of 7.6 mm. The probes were about 10 cm above and below the midplane, and were at the same toroidal location, about a meter away from a lower hybrid waveguide.

The FLT probes could be biased in either single or double modes, i.e., either the tee, or the tube, could be biased with respect to the vacuum vessel, or they could be biased with respect to each other, with both

electrically isolated from the vacuum vessel and floating. The circuits were essentially identical to those used for PDX.

3. Data Analysis

A simple approximate model for the current-voltage characteristic $I(V)$ of a single Langmuir probe results from subtracting the ion current flowing at the sound speed from the electron thermal current in a retarding potential.

$$I = I_e - I_i$$

$$I_e = e \frac{n_e A}{4} \left(\frac{8 T_e}{\pi m_e} \right)^{1/2} \exp \left[-e \left(\frac{V - V_s}{T_e} \right) \right]$$

$$I_i = e \frac{n_i A}{2} \left(\frac{T_e + T_i}{M_i} \right)^{1/2}$$

A is the effective area of the probe, n_e is the electron density, and V_s is the space potential. This model only applies to the left part of the $I(V)$ curve, i.e., when the probe potential V is sufficiently negative for ion saturation and incipient electron collection.

For double Langmuir probes, the current collected by one electrode equals the current emitted by the other. A simple approximate model for $I(V)$ is

$$I = \frac{e n_e A_1}{2} \left(\frac{T_e + T_i}{M_i} \right)^{1/2} \left\{ \frac{\exp \left(\frac{eV}{T_e} \right) - 1}{1 + \frac{\lambda_1}{\lambda_2} \exp \left(\frac{eV}{T_e} \right)} \right\},$$

with λ_1 and λ_2 the effective areas of the electrodes, and V their relative voltage.

There are uncertainties as to the effective areas of probes in magnetic fields since the orbits for particles flowing to the probe are complicated. For this study, the effective areas used were between twice the projected area normal to the magnetic field and the total geometric area.

The $I(V)$ characteristics were fitted using the above equations and adjusting the parameters n_e , T_e , and V_B to minimize Chi squared. A program based on the algorithm of Marquardt was used.⁶ The effective areas were $A = 0.5 \text{ cm}^2$ for PDX, and $A_1 = 0.8 \text{ cm}^2$, $A_2 = 1.0 \text{ cm}^2$ for PLT. The ion temperature T_i was fixed by assuming $T_i = 3 T_e$ since there are indications that the ion temperatures are in the several hundred eV range.⁷

4. Results

In PDX, plasmas with several divertor and limiter configurations have been constructed.⁸ Two of the divertor configurations, the inner D and the outer D, result from choosing small (138 cm) or large (150 cm) major radii for the plasma. In these configurations the plasma exhausts mainly to the inner or outer set of neutralizer plates, respectively.

Fits to measurements in PDX are given in Fig. 2-4. Figure 2 shows the density profiles for ohmically heated, inner D plasmas with three different line-averaged central densities. The measurements were made during the plateau region of the discharges, where the central densities and plasma currents were stationary. Lines drawn through the data are guides for the eye. In this configuration there was an inner separatrix calculated⁹ to be at a major radius of about 175 cm and an outer separatrix at about 185 cm. The profiles appear to break at 185 cm and are flatter at smaller radii. The edge density increased with the line-integrated central density.

Figure 3 compares the profile for one of these inner D cases with profiles for an outer D, and for a circular plasma (with the plasma contacting the outer limiter at 178 cm.) The profile for the outer D is very similar to the outer profile of the inner D displaced outward. The circular plasma has a lower edge density and a longer scrape-off length. The longer length could be due to the longer parallel connection length i.e., the increased distance

along field lines for particles in the edge to travel before hitting obstacles.

Figure 4 compares the electron temperature profiles corresponding to the cases in Fig. 3. There is a large spread in the fits from shot to shot, probably due to difficulties in making the fits. The temperatures are low and relatively flat; however, they must have a very sharp gradient at smaller radii since the temperature in the center reaches about 1 keV. Langmuir probes melt when pushed in much closer than the range shown in Fig. 4.

The PLT vacuum vessel has a major radius of 132 cm and a minor radius of 50 cm. The configuration consisted of top and bottom limiters at a minor radius of 40 cm, an outside limiter at 42 cm, and a lower hybrid waveguide at 45 cm. The plasma major radii were approximately 130 cm.

Figure 5 shows the electron density profiles at different times during a PLT run. The profiles tend to become broader even though the central line-integrated density remained constant from 300 to 500 ms and then dropped.

Fig. 6 shows the electron temperatures corresponding to Fig. 5.

5. Discussion

According to the $I(V)$ models in section 3, the density varies inversely with the effective area of the probe and with the square root of the temperature. This implies that uncertainties about the effective area lead to a large, systematic uncertainty in the absolute value of the density. Relative density measurements with the same probe are fairly accurate and reproducible.

The densities and temperatures measured in PDX are close to the values measured with a double Langmuir probe near the neutralizer plate.³ For PLT, there was a larger difference between the projected area and the total area of the probe, so the uncertainty in the density normalization was larger.

Nevertheless, the density agrees approximately with previous FLT measurements.²

The electron density in the outer edge (past the main separatrix or in the shadows of limiters) is large. This requires either lots of ionization in the edge, or rapid cross-field flow into the edge. According to sheath models, electrically floating objects receive heat fluxes of about $10 n_e v_{th}^e T_e$ where v_{th}^e is the thermal electron velocity. With edge densities of 10^{12} cm^{-3} and temperatures of 10 eV, this flux is several kilowatts/cm². Structures cannot withstand such fluxes for long durations. Also, large edge plasma density has adverse implications for lower hybrid heating, for which the density should be low to avoid ionization within waveguides. The electron temperature in the edge is low and its scrape-off length is longer than expected.

Acknowledgments

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References

- ¹F. F. Chen, "Electric Probes," in Plasma Diagnostic Techniques, edited by R. H. Huddelstone and S. L. Leonard (Academic Press, NY 1965) pp. 113-200.
- ²C. W. Barnes, S. A. Cohen, and H. F. Dylla, Bull. Am. Phys. Soc. 22, 1140 (Nov. 1977).
- ³D. K. Owens, *ibid* 25, 941 (Oct. 1980).
- ⁴R. Budny, D. M. Meade, and J. A. Schmidt, *ibid* 25, 928 (Oct. 1980);
R. Budny, R. Motley, H. Hsuan, and D. Ho, *ibid* 26, 864 (Sept. 1981).
- ⁵L. S. Scaturro and B. Kusse, Nuclear Fusion 18 12 (1978)-Letters, 1717; S. J. Zweben and R. J. Taylor, "Edge Plasma Measurements on the UCLA Tokamaks," PPG-543 (March 1980); W. Namkung, A. C. England, and O. C. Eldridge, "Langmuir Probe Measurements of the Scrape-Off Plasma in ISX-A, ORNL/TM-6621; R. L. Kabana, "Fluctuations in a Tokamak Plasma," Cal. Tech. Ph.D Thesis, 1978.
- ⁶P. R. Bevington, Data Reduction and Error Analysis for The Physical Sciences McGraw-Hill (1969).
- ⁷S. Cohen, H. F. Dylla, W. R. Wampler, and C. W. Magee, "Deuterium Ion Fluxes to Probes in the PLT Edge Plasma," J. Nucl. Mater. 93 & 94, (1980), 109-114.
- ⁸D. Meade, et al, "PDX Experimental Results," Eighth International Conference on Plasma Physics and Controlled Thermonuclear Fusion, Brussels, 1980, IAEA- CN-38/X-1.
- ⁹M. Okabayashi, private communication.

Figure Captions

- Fig. 1. Circuits for biasing the probes and measuring their voltage and current.
- Fig. 2. Density profiles in PDX inner D discharges with three different central column densities.
- Fig. 3. Density profiles in PDX for inner D, outer D, and circular discharges.
- Fig. 4. Electron temperature profiles in PDX corresponding to the densities in Fig. 3.
- Fig. 5. Density profiles in PLT versus radius from the plasma centerline.
- Fig. 6. Electron temperature profiles in PLT corresponding to the densities in Fig. 5.

Figure 1

Figure 2

Figure 3

Figure 4

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Figure 5

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Figure 6