

PROBE STUDIES IN THE TOROIDAL DEVICE “BLAAMANN”

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This paper reports on measurements of probe current densities j and their first derivatives j' with respect to the probe potentials V in helium low-pressure (gas pressure $p = 0.03\text{-}0.3$ Pa) magnetized (toroidal magnetic fields $B = 0.004\text{-}0.32$ T) plasmas of the toroidal device “Blaamann” of the University of Tromsø (Norway). The measurements lead to the obtaining of electron energy distributions (EED) in the plasma.

“Blaamann” is a toroidal device with stainless steel walls [1]. The torus has major radius 651 mm and minor radius 134 mm. It has a tungsten filament (cathode) heated by DC and a water-cooled copper limiter (anode) that is located at a toroidal angle 150° with respect to the filament. The plasma is produced by a low-pressure arc discharge. The range of discharge currents I_{dis} is between 50 and 700 mA.

Two cylindrical probes with radii $R = 0.25$ mm and lengths $L = 5$ and 3 mm which have their axes perpendicular (“perpendicular” probe) or parallel (“parallel” probe) to the magnetic field have been used for measurements. For the measurements of j and j' a linear swept voltage with peak-to-peak amplitude 55 V and repetition frequency 1 kHz was applied to the probes. The signal, which was proportional to j , was measured over a resistor of 100 ohm in the probe circuit. A differentiating circuit was used for measurements of j' . The signals are necessarily averaged for up to 1000 sweeps to increase the signal-to noise ratio.

The kinetic probe theory has been used for calculations of the EED from the measurements [2,3]. It is valid for the case when the linear size of the probe distributed region is much less than the electron energy relaxation length. In this case, the electron probe current density is

$$j_e(V) = \frac{8\pi e}{3m^2} \int_{eV}^{\infty} \frac{(W - eV) f(W) dW}{\gamma(W)(1 + (W - eV)\Psi(W)/W)}, \quad (1)$$

where e and m are the electron charge and mass, f is the EED, W is the electron energy, γ is a geometrical factor and Ψ is a diffusion parameter. For the cylindrical probe in the “Blaamann” plasma (the near-probe sheath of non-quasineutral plasma is thin) the diffusion parameters are

$$\Psi = \frac{R \ln(\pi L / 4R)}{\gamma R_L} \quad (2)$$

and

$$\Psi = \frac{\pi L}{4\gamma R_L} \quad (3)$$

for the “perpendicular” and “parallel” probe, respectively. Here, R_L is the electron radius. In strong magnetic fields ($\Psi \gg 1$) it is possible to obtain

$$f(eV) = -\frac{3m^2 R \ln(\pi L / 4R)}{8\pi e^3 R_L V} \frac{dj_e}{dV} \quad (4)$$

and

$$f(eV) = -\frac{3m^2 L}{32e^3 R_L V} \frac{dj_e}{dV} \quad (5)$$

for the “perpendicular” and “parallel” probe, respectively.

The above formulas have been used for the calculations of the EED from the measured j' . It was found, that under some conditions in the plasma a rather sharp “knee” on j' measured by the “perpendicular” probe is clearly observed. It allows us to determine rather reliably the plasma potential. Such a “knee” is easily visible, for example, on j' measured by the “perpendicular” probe, shown in Fig. 1. In these conditions ($\Psi \gg 1$) the use of formula (4) for strong magnetic fields to calculate the EED is possible. The result of the calculation of the EED is given in Fig. 2. The measured EED can be approximated by the two-temperature Maxwellian EED

$$f(W) = \begin{cases} N_1 \left(\frac{m}{2\pi T_1} \right)^{3/2} \exp(-W/T_1), & W < W_b \\ N_2 \left(\frac{m}{2\pi T_2} \right)^{3/2} \exp(-W/T_2), & W > W_b \end{cases} \quad (6)$$

Parameters T_1 , T_2 , N_1 , N_2 , W_b and electron densities N_e are given in the figure caption. For comparison, in Fig. 1 the results of calculations of j' for “perpendicular” and “parallel” probes using the theory for arbitrary magnetic fields and obtained f are shown. The parameters of the EED (6) have been iterated to get the best fit. The new corrected parameters are given in the caption. In Fig. 3 the result of the direct solution of the integral equation for j' (obtained from (1)) are shown too. It is possible to see that all results are in good agreement.

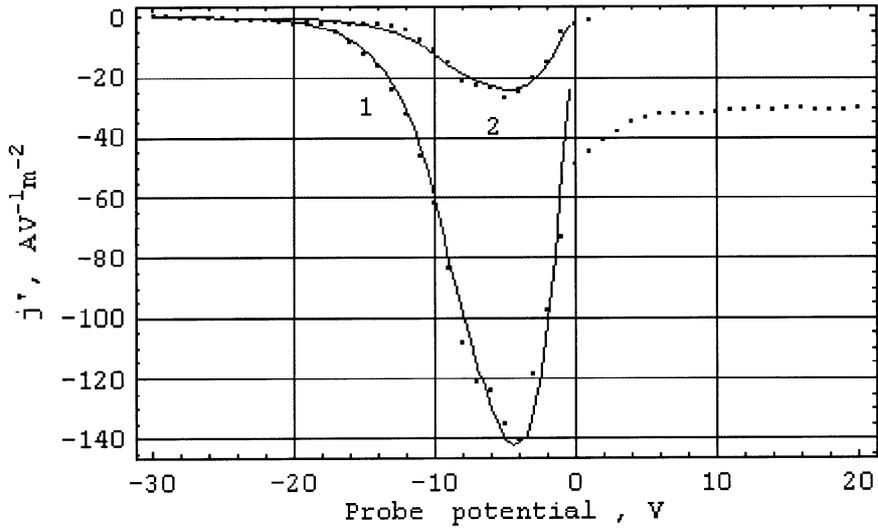


Fig. 1. Measured j' (points) and calculated j'_e (solid curves). $I_{dis} = 700$ mA, $p = 0.2$ Pa, $B = 0.28$ T, $L = 5$ mm. $T_1 = 3.24$ eV, $T_2 = 2.34$ eV, $N_1 = 5.3 \cdot 10^{17}$ m $^{-3}$, $N_2 = 9.8 \cdot 10^{17}$ m $^{-3}$, $N_e = 5.1 \cdot 10^{17}$ m $^{-3}$, $W_b = 9$ V. 1 – the probe is oriented perpendicular to the magnetic field, 2 – the probe is oriented parallel to the magnetic field.

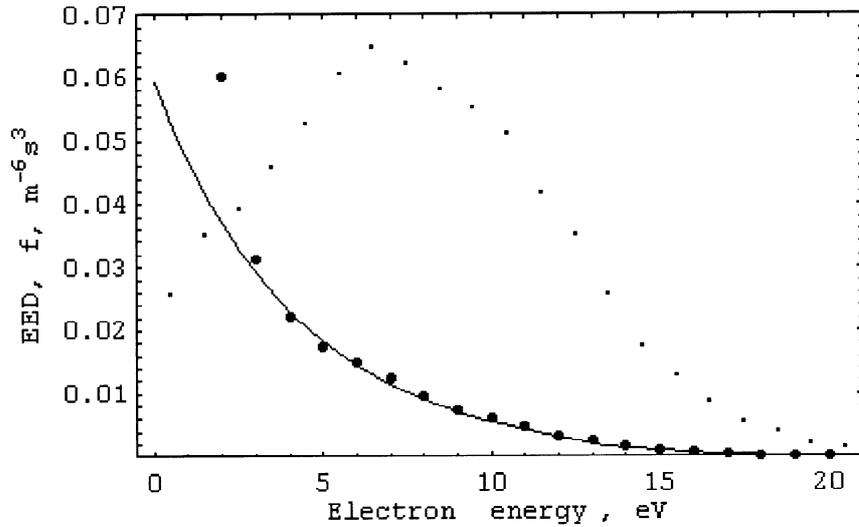


Fig. 2. The measured EED (big points) and its approximation (solid curve). $|j'|$ (small points) as a function of W/e . $I_{dis} = 700$ mA, $p = 0.2$ Pa, $B = 0.28$ T, $L = 5$ mm. $T_1 = 3.1$ eV, $T_2 = 2.2$ eV, $N_1 = 5.3 \cdot 10^{17}$ m $^{-3}$, $N_2 = 9.5 \cdot 10^{17}$ m $^{-3}$, $N_e = 5.1 \cdot 10^{17}$ m $^{-3}$, $W_b = 9$ V. The probe is oriented perpendicular to the magnetic field.

For different plasma conditions it is not possible to see a sharp “knee” at j' (see, for example, Fig. 4). In these cases the EED may be approximated by Maxwellian EED and electron density N_e , temperature T_e and plasma potential V may be obtained from the above formulas to get the best fit. The derived V may be used to obtain the new EED. Then the procedure may be repeated to get the best fit. The results of calculations of the EED using different theories are shown in Fig. 4.

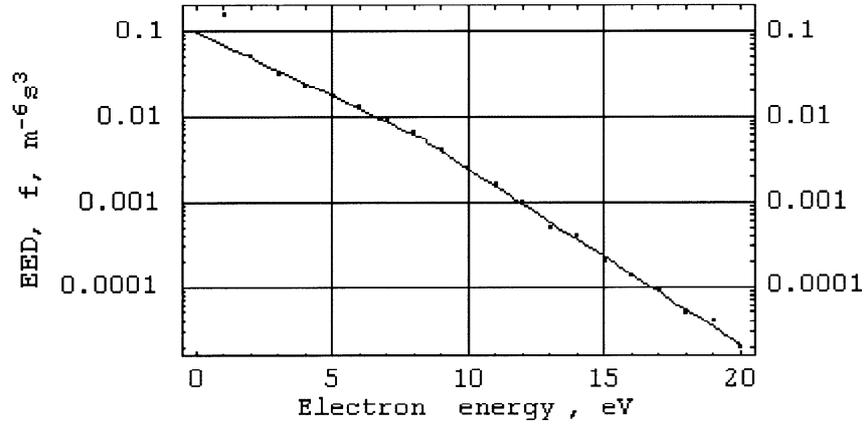


Fig. 3. The measured EED (points) and its approximation (solid curve). $I_{dis} = 700$ mA, $p = 0.2$ Pa, $B = 0.28$ T, $L = 5$ mm. $T_1 = 3.2$ eV, $T_2 = 2.3$ eV, $N_e = 5.3 \cdot 10^{17} \text{ m}^{-3}$. The probe is oriented perpendicular to the magnetic field.

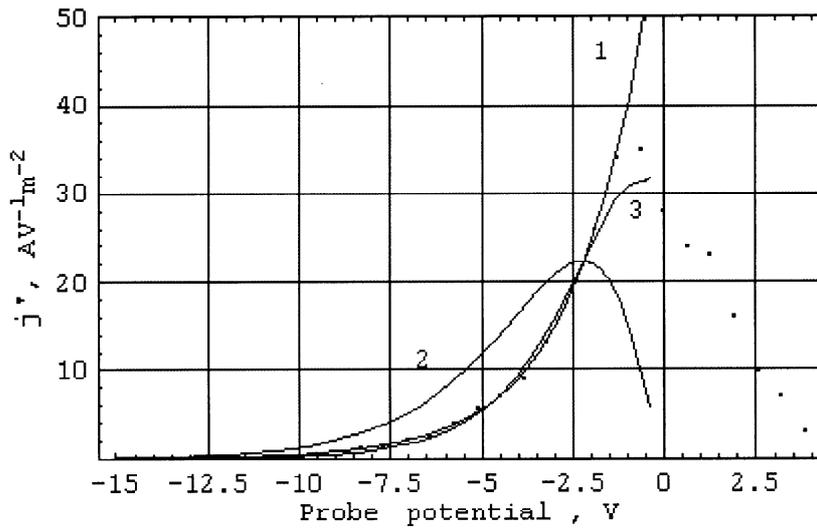


Fig. 4. Measured j' (points) and calculated j'_e using the theories for weakly (1), strongly (2) and arbitrarily (3) magnetized plasmas. $I_{dis} = 250$ mA, $p = 0.05$ Pa, $B = 0.04$ T, $L = 3$ mm. For (1) $T_e = 2$ eV, $N_e = 3.5 \cdot 10^{15} \text{ m}^{-3}$. For (2) and (3) $T_e = 1.5$ eV, $N_e = 10^{16} \text{ m}^{-3}$. The probe is oriented perpendicular to the magnetic field.

Thus, the electron energy distributions in the plasma of toroidal device “Blaamann” have been measured by probes using kinetic theory.

References

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