TÜRKİYE ATOM ENERJİSİ KURUMU

ÇEKMECE NÜKLEER ARAŞTIRMA VE EĞİTİM MERKEZİ

Araştırma Raporu No: 236

DENSITY DISTRIBUTION IN A MAGNETO—PLASMA SYSTEM

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C O N T E N T S

T A B L E S

F I G U R E S

A B S T R A C T

DENSITY DISTRIBUTION IN A MAGNETO-PLASMA SYSTEM

In a magneto-plasma system, density distribution and temperature have been measured by means of two Langmuir probes which can be moved axially and radially by an electric motor. A plasma column of 100 cm length, in a pyrex cylinder of 6 cm in diameter, has been produced by ionizing the argon gas in the magneto-plasma system. Discharge was maintained by applying 3.5 kV, 15 mA at max. range to a water-cooled hollow cathode. Plasma column was confined by means of a magnetic field of 1000 Gauss.

Ö Z E T

BİR MAGNETO-PLAZMA SİSTEMİNDE YOĞUNLUK DAĞILIMININ İNCELENMESİ

Bu çalışmada bir magneto-plazma sisteminde yoğunluk dağılımı ve sıcaklık, motorla radyal ve boylamsal olarak hareket edebilen iki Langmuir sondası yardımıyla incelenmiştir. Plazma kolonu, uzunluğu 100 cm, çapı 6 cm olan cam bir silindir içersinde, argon gazının iyonizasyonu ile elde edilmiştir. Deşarj, su soğutmalı içi oyuk katoda maksimum 3.5 kV, 15 mA uygulanarak sağlanmıştır. İyonize olan tanecikler, maksimum 1000 Gauss'luk magnetik alan yardımıyla sıkıştırılarak plazma kolonu oluşturulmuştur.

1. INTRODUCTION

After the Langmuir and his coworkers pioneering work, the probe method as one of the most powerful means of plasma diagnostics has been used widely. In the beginning of 1960's the experimental techniques and the theory of probes have been refined by many workers. Attempts have been made to extend the probe method to parameter ranges for which Langmuir's theory fails. In this connection plasmas at higher gas pressures and plasmas under the influence of strong magnetic fields are to be mentioned as the most important extension of classical probe theory (1,2). Compared to many other diagnostic tools the probe is distinguished by the possibility of direct local measurement of plasma parameters. This advantage of probes, however, is closely connected to other main shortcomings. The local measurement requires the probe to be inserted into the plasma being investigated by means of a probe holder whose surface area in most cases is many times larger than the probe itself. The probe system forms a "wall" in addition to the already existing plasma boundaries and at least in its close proximity the plasma parameters may deviate seriously from those in the absence of the probe. In spite of this Langmuir probe is the most important diagnostic tool for the local measurements. For instance, in fusion reactors such local density and temperature measurements have great importance and the interactions between the plasma and the container wall are investigated by the Langmuir probe method (3).

In this work, the density distribution and the temperature of a magnetized plasma system (Magneto-plasma 1) were measured by means of two radially and axially movable Langmuir probes.

2. THEORY

An outline of the essentials of the Langmuir probe method as commonly used plasma diagnostic method is briefly given as follows.

When a potential difference is applied between two electrodes immersed in a partially ionised but macroscopically neatural gas, the positive ions will be attracted towards the negative electrode and electrons towards the positive electrode. Hence, the resultant electrode current is obtained. This phenomenon is the well-known current-voltage characteristic of the probe. Such a characteristic can be used to determine the plasma parameters providing that the certain conditions are satisfaid (4). In this experiment, a cylindrical tungsten wire is used as the probe and the circuit is completed through one of the discharge electrodes. When no potential difference exists between the probe and plasma, the carrier current reaching the probe is equal to the random current density multiplied by the probe's surface area A_p.

$$I = A_p \frac{1}{4} \frac{N_c \bar{c}}{K} q \qquad (1)$$

Where N_c, $\bar{c}$ and q are the carrier density, mean speed and charge respectively. K is a multiplication factor which depends on the probe geometry. If the polarity of the probe to plasma potential is such that carriers are attracted, the probe current is greater than that given by Eq.I. As a result of the applied probe to plasma potential, a space charge sheath which consists of charge carriers of opposite sign to the probe potential is formed around the probe. Outside of this sheath region the concentrations of charge carriers are assumed to be equal and the undisturbed plasma is neatural.

The thickness of this sheath depends on the temperature of plasma particles (mean kinetic energies of charge carriers). The electron concentration N_c at sheath boundary is given by;

$$N_e = N_\infty \exp\left(\frac{eV_p}{kT_e}\right) \qquad (2)$$

Where N_∞ is the electron concentration in the undisturbed discharge, V_p is the potential drop between the sheath edge and the undisturbed plasma. Electron concentration within the sheath region varies with the value and the sign of this potential drop. And this concentration is proportional with the electron current reaching to the probe. This current is given by;

$$I_e = I_o \exp\left(\frac{eV_p}{kT_e}\right) \qquad (3)$$

Where I_o is the electron current reaching the probe when the latter is at plasma potential (V_p=0). The plasma to probe potential is defined by;

$$V_a = V_p + V_{AS} \tag{4}$$

Where V_a is the applied potential and V_{As} is the anode-sheath potential. It can be written as V_p=V_a-V_{As}. When the applied potential V_a is adjusted such that there is no potential drop between the probe and discharge (V_p=0), the electron current I_o is determined as the saturation current. This is given by;

$$I_o = \frac{1}{4} N_\infty \bar{C}_e e A_p = N_\infty e A_p \left(\frac{kT_e}{2\lambda m_e} \right) \tag{5}$$

Where A_p is the surface area of the probe, $\bar{c}_e$ is the mean thermal speed of an electron in the discharge and T_e is the electron temperature. In order to get a usefull equation for electron current in terms of applied potential V_a, using the eq.4, it can be written as;

$$I_e = I_o \exp \left[\frac{e(V_a - V_{AS})}{kT_e} \right] \tag{6}$$

This exponential equation indicates that the graph of $\ln I_e$ versus V_a is linear, having a slope (e/kT_e).

$$\ln I_e = \ln I_o + \frac{e}{kT_e} \left(V_a - V_{AS} \right) \tag{7}$$

By using this graph, the electron temperature, T_e and electron saturation current can be determined. Substituting the value of electron saturation current into the eq.5, the plasma electron density, N_{eo} can be found.

3. EXPERIMENTAL SET-UP

The experiment was performed at the Magneto-plasma I system. Argon plasma was produced in a pyrex cylindrical tube 160 cm in length and 6 cm in diameter by using a hollow-cathode (5). The water-cooled hollow cathode is a stainless steel cylinder having an inner radius, r_i=3,5 mm outer radius r_o=13,5 mm and a length of 120 mm. The discharge voltage and discharge current are 3.5 kV,15 mA respectively at max.range.

Plasma column is obtained by confining the plasma particles by means of a magnetic field, of 1000 Gauss at max. value. The initial pressure of the system is 10^{-4} torr. The experimental set-up is schematically shown in Fig.1. The radial probe has been set in a distance of 6 cm from the plasma source and it can be moved within a length of 1 cm radially.

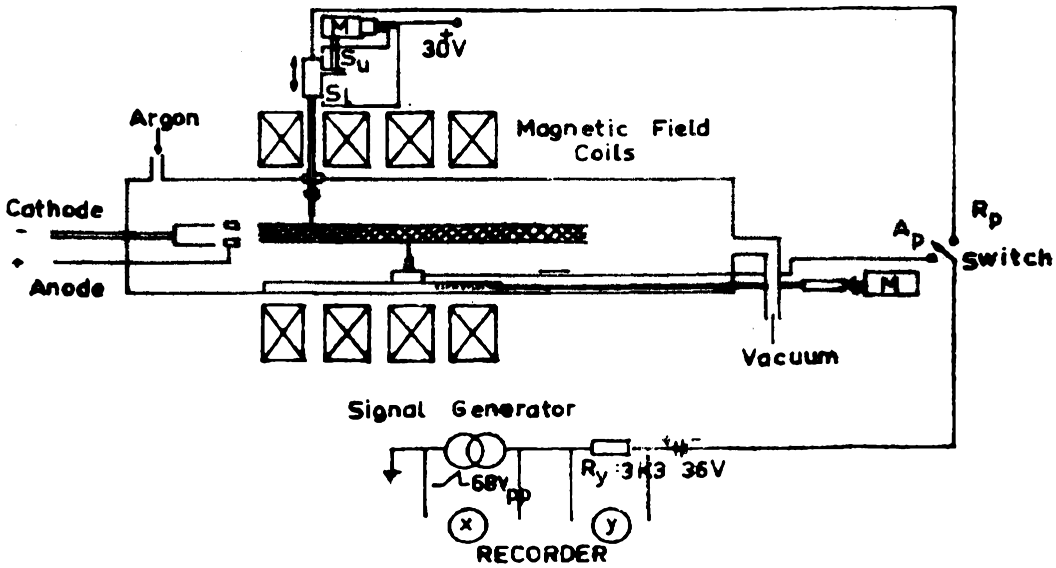

Fig.1. Block diagram of the Magneto-Plasma I system

With this probe, measurements were taken for each 2 mm. The axial probe which is mounted on an isolated carriage can be moved within a distance of 20 cm. Axial measurements with this probe were obtained at intervals of 2 cm. The probe was biased at -36 V, floating potential and then a sawtooth voltage pulse, V_{pp}=68 Volts, was superimposed on this floating potential. The probe current as a potential drop across the load was plotted by means of a X-Y recorder. Hence, the current-voltage curve which is called the probe characteristic was obtained. By conveying this curve on a semilogaritmic graph and using the simple probe theory as described above, the electron temperature, T_e and density can be obtained. General view of Magneto-plasma I system is shown in Fig.2.

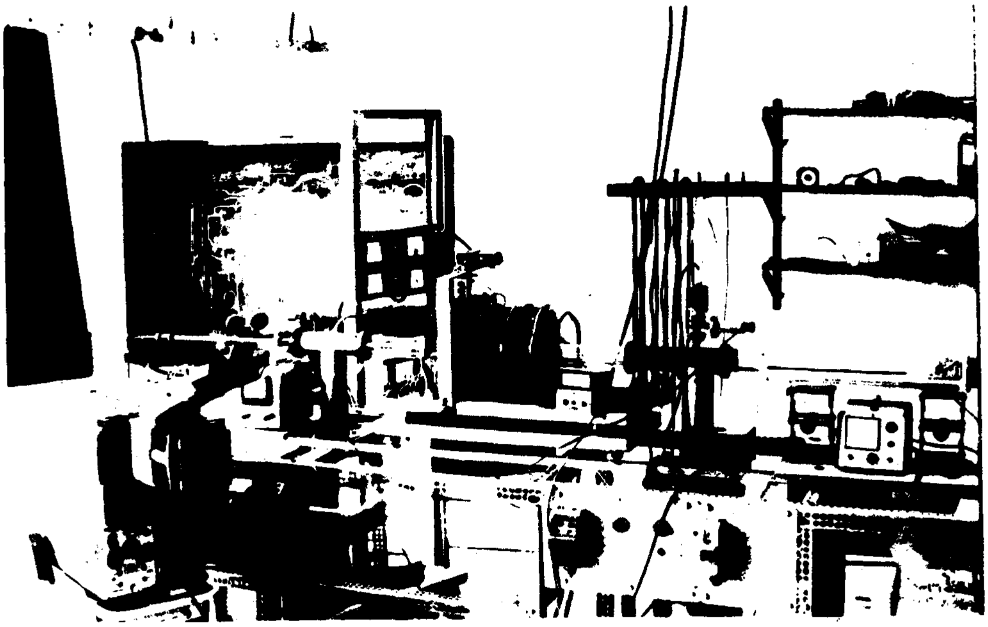

Fig.2. Magneto-plasma I system

4. MEASUREMENTS

The axial probe measurements at three different pressures for a constant discharge current, I_d=6 mA, are shown in Fig.3. The measurements were taken with 2 cm intervals, from 6 cm to 26 cm away from the plasma source. At the same discharge current, The measurements taken by the radial probe within a distance of 10 mm at intervals of 1 mm for three different pressures are shown in Fig.4. In addition, axial density and temperature gradients for various discharge currents at three different pressures are given by the Table 1.

Discharge current I_d mA	$\Delta n/\Delta x$ $(\times 10^{10})$			$\Delta T/\Delta x$ (eV/cm)		
	4×10^{-2} Torr	6×10^{-2} Torr	8×10^{-2} Torr	4×10^{-2} Torr	6×10^{-2} Torr	8×10^{-2} Torr
1	0.0099	–	–	0.0268	-	-
2	0.0073	0.0174	-	0.0283	0.0433	-
4	0.0065	0.0126	0.0516	0.0238	0.0408	0.0473
6	0.0056	0.0084	0.0126	0.0209	0.0332	0.0384
8	0.0048	0.0069	0.0112	0.0201	0.0390	0.0380
10	-	0.0062	0.0098	-	0.0317	0.0392
12	-	0.0051	0.0061	-	0.0305	0.0361
14	-	-	0.0047	-	-	0.0356

Table 1. Axial density and temperature gradient at three different pressures for various discharge currents

The electron temperature computed from the slope of $\ln I_e - V_a$ graph lies, according to the discharge current, between I.0 eV and 2.5 eV. Using the electron saturation current equation (eq.5), electron density can be computed by;

$$N_{eo} = \frac{4 I_{eo}}{e A_p} \frac{1}{\bar{C}_e} \qquad (8)$$

Where I_{eo} stands for the electron saturation current obtained by graphical method; $e = 4.8032 \times 10^{-10}$ statcoulomb, electron charge; $A_p = 0.02199$ cm probe area and $\bar{c}_e = (8kT_e/m_e)$ the mean velocity. The mean velocity can be stated in terms of temperature (^{o}K) by taking $k = 1.3807 \times 10^{-16}$ erg/^{o}K, $m_e = 9.1095 \times 10^{-28}$ gr.

$$\bar{C}_e = 0.6212 \times 10^{6} \left[T_e(^{o}K)\right]^{1/2} \quad \text{cm/sn.} \qquad (9)$$

A numerical equation for the electron density can be written by;

$$N_{eo} = 18.288 \times 10^{14} \; I_{eo}\,(A)/T_e(^{o}K) \quad \text{cm}^{-3} \qquad (10)$$

The computed electron density lies between 1.0×10^{10} cm^{-3} and 1.5×10^{10} cm^{-3}.

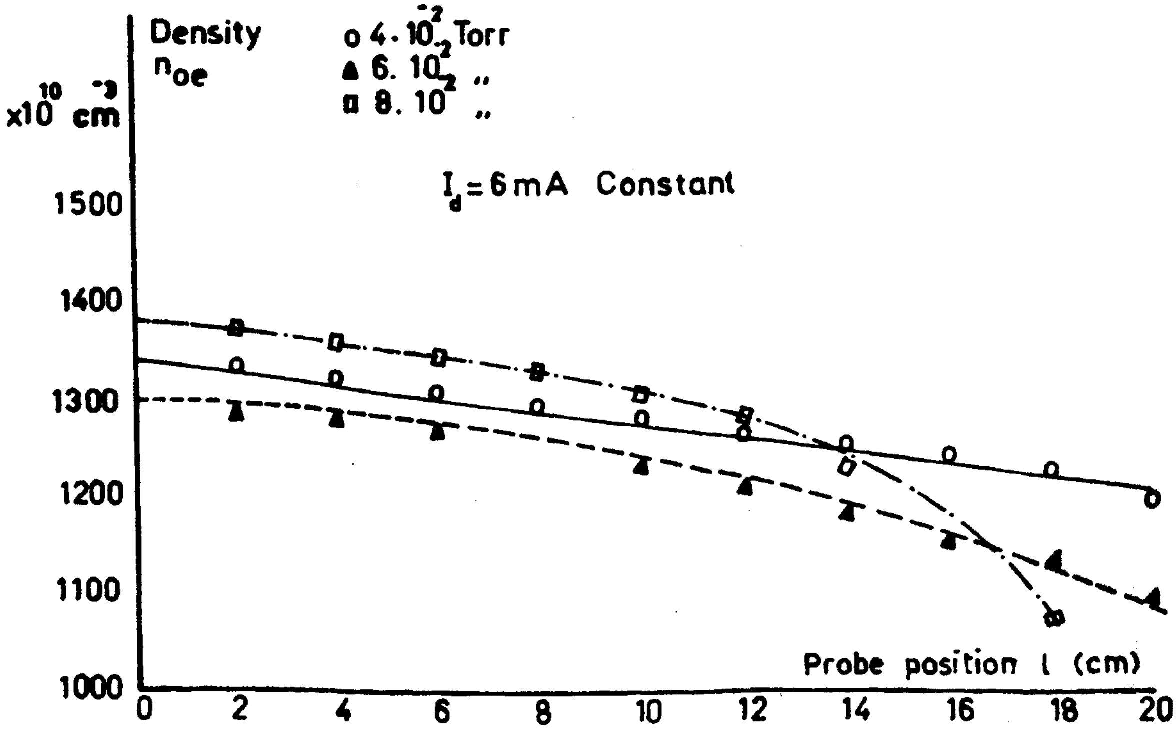

Fig.3. Axial density gradient

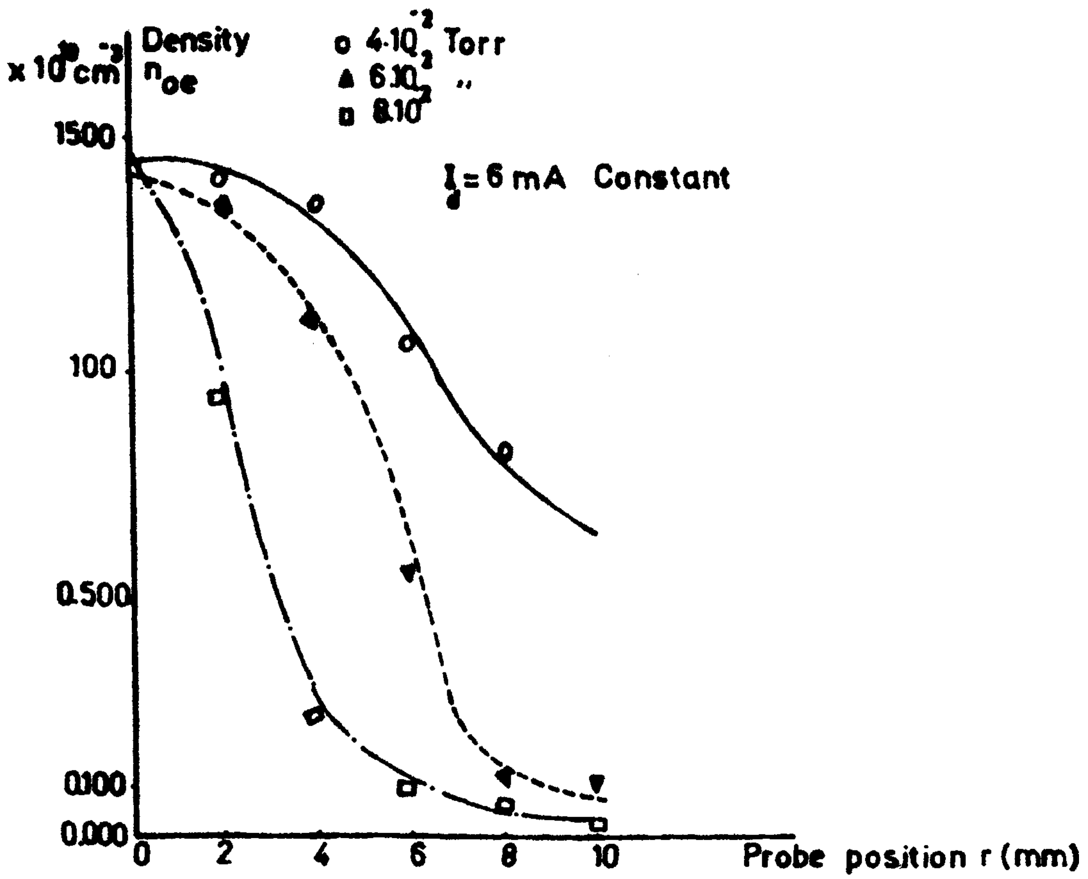

Fig.4. Radial density profile

5. CONCLUSION

As shown in Fig.3 axial density gradient is approximately linear so that the slope corresponding to each pressure is different. Deviation from the linearity at high pressures arises from the presence of the more neaturel particles. As it can be seen from the table 1, when high discharge currents are obtained by increasing the discharge voltage at high pressures, the slope gradually decreases and the rate of deviation from linearity also decreases. It can be stated that there is a discharge current value which gives smooth density distribution for each of these three pressures. Radial density profiles for three different pressures are given in Fig.4. These density profiles fit in with the statement which is given, theoretically for a low-temperature cylindrical plasma column in a uniform magnetic field, by

$$n\,(r)=n_0 \exp(-r^2/r_0^2) \tag{11}$$

Where n_o is the central density; r_o, r are the plasma column radius and the radial probe position respectively. In Fig.4, the fast decrease of radial density at high pressures for the same discharge current, I_d=6 mA, can be seen. This is due to the same reason to that of axial density distribution stated above, i.e. the frequent collisions between charged and neatural particles. For each pressure, there is a discharge current giving a density profile which fits in with theoretical exponential curve. As shown in Table 1, temperature gradient is comperatively high where the greater axial density variation occurs. This is due to energy loss of charged particles through the collisions with neatural particles.

Consequently, it is well understood that a plasma col mn having smooth density and temperature gradients can be obtained by use of Magneto-plasma I system within the pressure range of $4x10^{-2}$ -$8x10^{-2}$ torr and at discharge currents from 4 mA to 12 mA.

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