LANGMUIR PROBE MEASUREMENTS IN A VACUUM ARC PLASMA CENTRIFUGE

R.S. Dallaqua, E. Del Bosco
Laboratório Associado de Plasma - LAP/INPE
12201-970 - São José dos Campos, SP - Brazil

R.P. da Silva
Instituto de Física - Universidade de São Paulo
01498-970 - São Paulo, SP - Brazil

ABSTRACT

A series of measurements using Langmuir probes in a rotating magnetized plasma column produced in a pulsed vacuum arc plasma centrifuge is presented. The parameters measured were: electron temperature, particle density, space potential and the angular velocity of the plasma column. The measurements were carried out in magnesium and carbon plasmas for an arc current of $I_a = 1.5$ kA and an externally applied axial magnetic field of $B_z = 0.1T$.

INTRODUCTION

An increase in the utilization of stable isotopes in areas such as nuclear physics, nuclear medicine, biomedical science, geoscience has been observed in the 80's. Previsions indicate that the consumption of stable isotopes in the early future will be even higher [1]. Within this picture new methods of isotope separation were proposed and developed, among them, the vacuum arc plasma centrifuge [2]. For the feasibility of a isotopic separator based on plasma it is necessary to produce a plasma with: high density; high ion angular velocity and low temperature. The results of the measurements of these parameters at PCEN, a vacuum arc plasma centrifuge developed at LAP/INPE, are described. The experimental results were compared with the predictions of a simple MHD model for a plasma column rotating as a rigid body [3].

THE VACUUM ARC CENTRIFUGE DEVICE

Fig. 1(a) shows a schematic diagram of the apparatus. The vacuum vessel is a stainless steel cylinder with diameter of 0.22 m and an axial length of 1.05 m. The base pressure is about $1 \times 10^{-4} Pa$. The cathode is a small rounded tip rod with $\sim$ 12 mm in diameter and the anode is a tungsten mesh, placed at 60 mm apart from the cathode. The power supply for the arc discharge is an electrolytic capacitor bank configured as a LC network. A high power CO_2 laser (3J) triggers the discharge between the cathode and anode. The interaction of the radial component of the arc current with the external axial magnetic field causes the rotation of the plasma column. Fig. 1(b) shows a typical arc current pulse obtained in this device for a cadmium cathode with $B_z = 0.1T$.

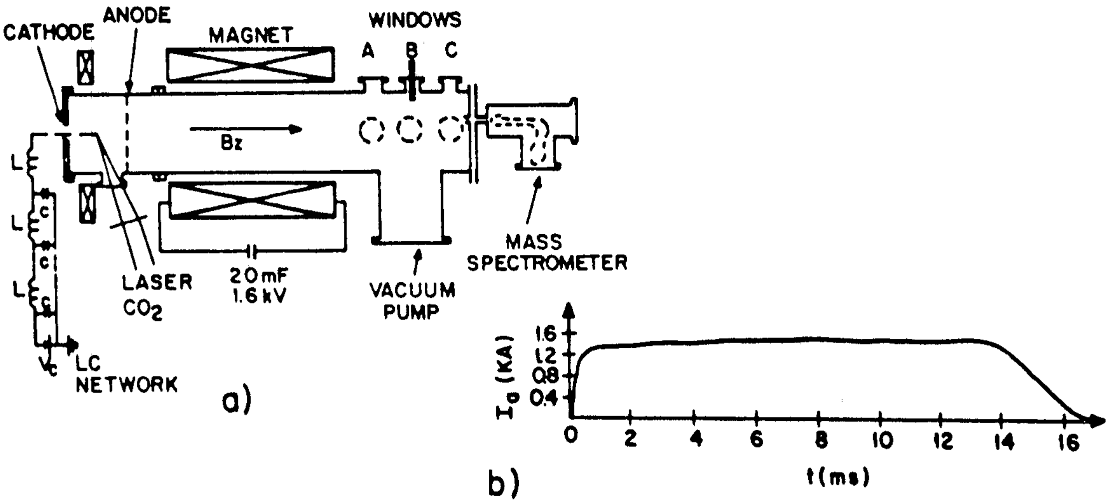

Fig. 1. (a) Schematic diagram of PCEN, a vacuum arc plasma centrifuge developed at LAP/INPE; (b) typical arc current pulse obtained in this device.

THE MEASUREMENT SET UP

A cylindrical Langmuir probe, with diameter of $200\mu m$ and length of $4mm$, was used for the measurements. The probe was biased by a proper sweep generator with triangular waveform. The signals (probe voltage and current) were acquired by a digital scope and immediately transferred to a micro-computer where data were stored for subsequent analysis. The electron temperature, T_e, was obtained from the slope of the logarithm of the Langmuir characteristic, curve in the interval dominated by thermal effects; $T_e = 1/tan\beta$, where $\beta = \partial lnI_e/\partial V_p$ (I_e is the electron current in the probe and V_p is the probe voltage). The plasma produced in a vacuum arc discharge has an axial drift velocity, v_z, as high as $10^4 m/s$. For the conditions of the present experiment $\sqrt{\frac{k_BT_i}{m_i}} << v_z << \sqrt{\frac{k_BT_e}{m_e}}$, and also, the ions are multiply ionized which means that the neutrality condition is given by $n_o = \Sigma Z_i n_i = n_{e0}$. For magnesium plasmas $\bar{Z} = 1.5$ and for carbon plasmas $\bar{Z} = 1$, where $\bar{Z}$ is the average value of Z. Taking in account these features the plasma density, derived from the ion saturation current is given by $n_0 = I_i/2rlev_z$, where I_i is the ion saturation current, e is the electron charge, r and l are the probe radius and length, respectively. The particle density, n_p, can be obtained from $n_p = n_0/\bar{Z}$. The space potential was obtained of the relations $\phi_s(V) = \phi_f(V) + 2.9T_e(eV)$ for carbon and $\phi_s(V) = \phi_f(V) + 4.3T_e$ (eV) for magnesium plasmas. These relations follow from equalizing the electron current with the ion saturation current collected by the probe at the floating potential [4].

RESULTS

Fig. 2(a) shows the radial profile of the electron temperature for carbon and magnesium plasmas. The plasma column can be considered isothermal in the range $r \leq 30mm$ for carbon and in the range $r < 20mm$ for magnesium plasmas. The radial profile of the plasma density together with the best Gaussian curve fitting are shown in Fig. 2(b).

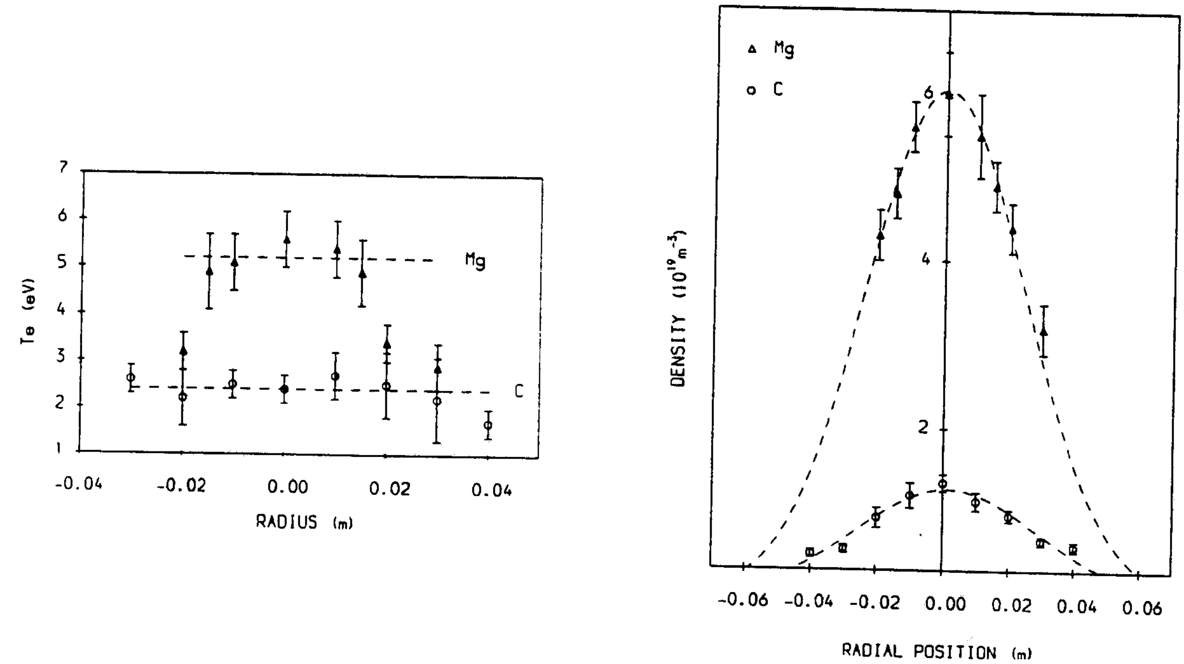

Fig. 2. Radial profiles for carbon and magnesium plasmas: (a) electron temperature and (b) plasma density (n_0) and the best Gaussian curve fitting.

Fig. 3 shows the floating and space potential for carbon and magnesium plasmas, and the best parabolic curve fitting to the experimental data. The radial electric field present in the plasma column can be obtained from $E_r = -d\phi_s/dr$.

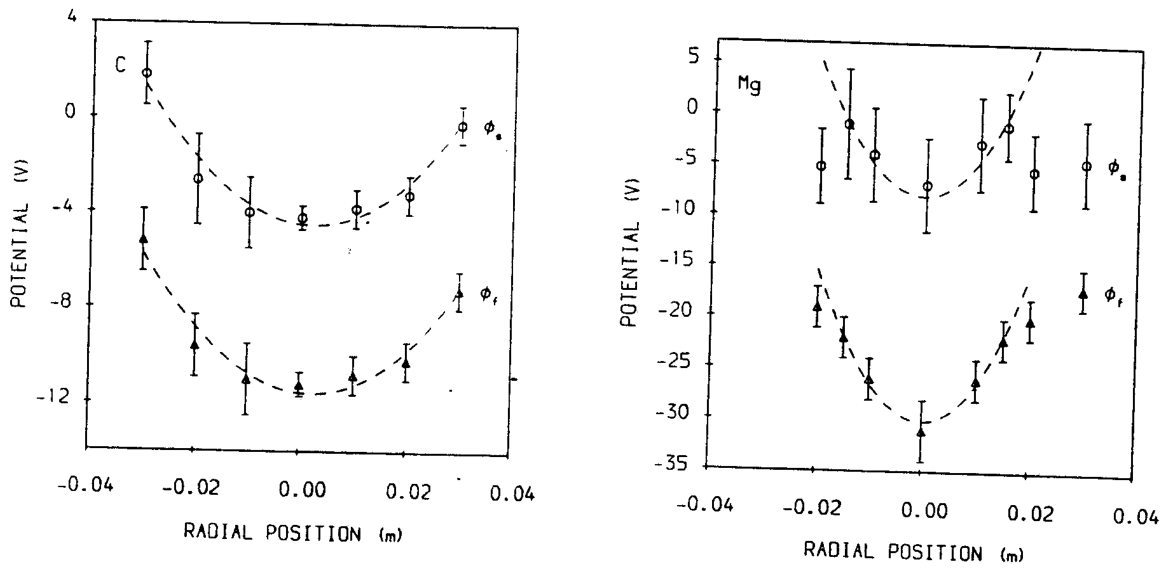

Fig. 3. Radial profiles of the floating and space potential and the best parabolic curve fitting: (a) carbon and (b) magnesium plasmas.

The measurements of the ion angular velocity was made using two probes at the floating potential placed at same radius but 90° apart in azimuth[5]. From the time difference,

Δt_f, between the floating potential fluctuations as shown in Fig. 4, the ion angular velocity can be determined as $\omega_i = \pi/2\Delta t_f$. The results of these measurements were: $\omega_i = 4 \times 10^4 rad/s$ for carbon and $\omega_i = 2.5 \times 10^5 rad/s$ for magnesium plasmas.

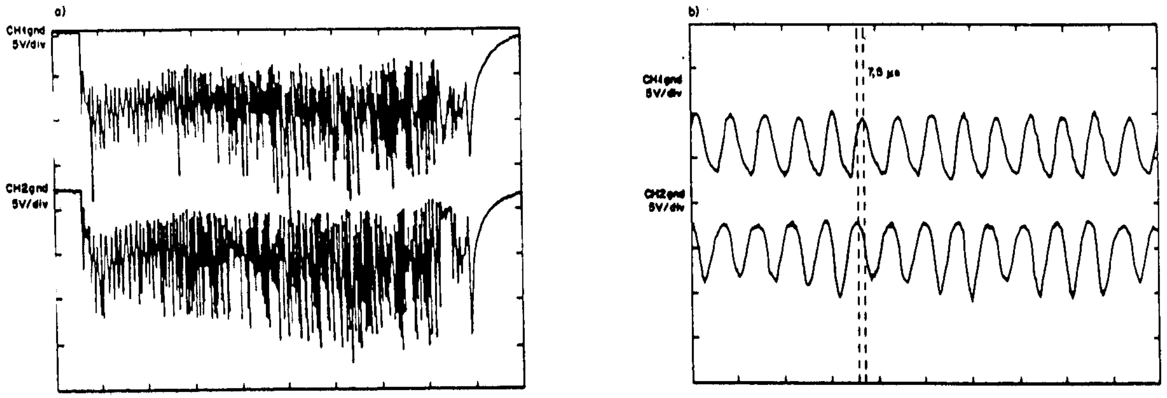

Fig. 4. (a) Floating potential fluctuations exhibited by the probes (hor. scale 2ms/div) and (b) expanded signals of the probes (hor. scale 50μs/div).

A fluid model for a isothermal plasma column rotating as a rigid rotor predicts [3]: 1) A Gaussian radial profile for the plasma density; 2) A parabolic radial profile for the space potential and 3) An ion angular velocity expression given by:

$$\omega_i = \frac{1}{2}\Omega_{ci}\left\{-1 + \left[1 - \frac{4E_r}{rB_z\Omega_{ci}} + \frac{4k_BT_i}{m_ir\Omega_{ci}^2}\frac{dln(n_0)}{dr}\right]^{1/2}\right\}$$

where $E_r = -d\phi_s/dr$, $\Omega_{ci} = ZeB_z/m_i$.
Using the radial profiles shown in Fig. 2 and 3 it was obtained $\omega_i = 7 \times 10^4 rad/s$ for carbon and $\omega_i = 4 \times 10^5 rad/s$ for magnesium plasmas. It was assumed that $T_e \sim T_i$ for a vacuum arc plasma centrifuge.

CONCLUSION

The results of the measurements of the radial profiles of the electron temperature, plasma density, space potential and ion angular velocity shown that it is possible a description of a multispecies rotating plasma column by a single fluid model.

REFERENCES

[1] G.Friendlander and H.N. Wagner Jr. (Eds.), "Separated Isotopes", Vital Tools for Science and Medicine, Washington, DC: Nat Acad. Press, 1982.
[2] M.Krishnan, M.Geva and J.L.Hirshfield, "Plasma Centrifuge", Phys.Rev.Lett., Vol. 46, pp.36-38, Jan.1981.
[3] J.A. Bittencourt and G.O. Ludwig, "Steady State Behaviour of Rotating Plasmas in a Vacuum Arc Centrifuge", Plasma Phys., Vol. 29, no. 5, pp. 601-620, Oct. 1987.
[4] F.F. Chen, in "Plasma Diagnostics Techniques" (R.H.Hudlestone and S.L.Leonard, Eds.), Academic Press: New York, 1965, pp.178.
[5] E. Del Bosco, S.W. Simpson, R.S. Dallaqua and A. Montes, "Speed of Rotation in a Vacuum Arc Centrifuge", J.Phys. D: Appl. Phys. Vol. 24, pp. 2008-2013, 1991.