ROTATION OF A MAGNESIUM PLASMA COLUMN IN A BACKGROUND GAS

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Abstract

Measurements of the angular velocity of a plasma column in a surrounding gas atmosphere are presented. The plasma is produced by a pulsed, high current arc discharge in the presence of an axial magnetic field. The angular velocity is measured using the cross correlation technique applied to the floating potential signals measured by two Langmuir probes. The main result is that when gas is added to the discharge the angular velocity is always lower than the case when there is no gas, this effect been more pronounced in the beginning of the discharge. For pressures higher than $\sim 2 \times 10^{-2}$Pa there is a strong effect of the gas on the plasma column rotation and the angular velocity diminishes even at the end of the discharge.

Introduction

Vacuum arc discharges have been extensively employed to produce fully ionized plasmas. When a proper magnetic field is present the produced plasma column can rotate at very high angular velocities, due to the $\vec{J} \times \vec{B}$ interaction. This scheme, called vacuum arc centrifuge, was firstly proposed by Krishnan et al [1], and has also been developed in other laboratories [2,3,4], in order to investigate isotope enrichment of stable elements.

For purpose of element or isotope enrichment analysis, it is appropriate to define the separation factor parameter, α , as $(n_1/n_2)_t/(n_1/n_2)_p$, where n_1 and n_2 denote the number densities of any two species considered and the subscripts "t" and "p" refers to natural and processed abundance, respectively. A high value for the α parameter is always desirable for an enrichment scheme. For a rigid rotor equilibrium, and considering that the species have the same temperature and charge, the separation factor can be expressed as [5]:

$$\alpha(r) = \exp[\Delta m \omega^2 r^2)/2k_B T] \qquad (1)$$

where Δm is the mass difference of the two ion species, ω is the angular velocity of the particles, r is the radial position, k_B is the Boltzmann's constant and T is the ionic temperature.

From the above equation it is clear that high separation factor values can be achieved increasing the angular velocity or decreasing the temperature. The main advantage of the vacuum arc centrifuge scheme over the conventional gas centrifuge is that the angular velocities are not limited by the material strength of the vessel components, since there is no movable parts. By the other hand, the drawback is the relatively high temperature of the particles.

It is speculated that the presence of a background gas can reduce the plasma temperature and stabilize the discharge, then increasing the separation factor. However, it is expected that the neutral gas can also reduce the angular velocity. This paper presents results concerning the influence of a controlled background gas on the angular velocity of the plasma column produced by a vacuum arc discharge.

Experimental Apparatus

The measurements were carried out in an upgraded version of the vacuum arc plasma centrifuge device developed at LAP/INPE [6]. The apparatus consists basically of a stainless steel cylindrical vacuum vessel (length: 1.05m, diameter: 0.22m), evacuated to $\sim 1.0 \times 10^{-4}$Pa, that encompasses the electrodes: an axial rounded tip as cathode (diameter: $\sim 12 \times 10^{-3}$m) and a circular metallic (tungsten) mesh as anode, placed 6cm apart from the cathode.

The arc current ($I_{max} \sim$ 3kA, flat-top of $\sim$ 14ms) is produced discharging a capacitor bank, configured as a LC network circuit (22 x 7.5mF x 350V), between the electrodes. A high power CO_2 laser (3J, 100ns) triggers the discharge. The axial magnetic field ($B_{max} \sim$ 1T) is generated by a set of eight coils encircling the vacuum vessel and connected to a capacitor bank (5mF, 1.6kV). The plasma expands through the semi-transparent mesh (anode) and is put in rotation by the $\vec{J} \times \vec{B}$ force.

Results and Discussions

The angular velocity of the plasma column was estimated from the cross correlation analysis of the floating potential signal measured by two Langmuir probes. These probes are placed 90° apart one of the other in the azimuthal direction, both at $\sim$ 70cm from the anode. This technique has already been used in this apparatus and described somewhere [6]. Essentially, the phase difference of the probe signals is one fourth of the rotation period of the plasma column, taken the short way around between the probes (90°).

Figure 1 shows two typical floating potential signals measured by a Langmuir probe and the arc current signal measured by a Rogowski coil. It can be observed in Figure 1.b, when there is no added gas, the presence of a large amplitude, high frequency fluctuations superimposed to the main signal. These fluctuations that last practically the entire discharge, are associated with the instabilities of the plasma column. The cross correlation can be applied to any time interval of the discharge. Figure 1.c shows a shot taken with a background pressure of argon gas (5×10^{-2}Pa). A characteristic feature of the discharge with a background gas is that the regular fluctuations are presente only for part of the discharge and with frequencies lower than the case when there is no added gas. This effect should be associated with the decreasing of the instabilities in the plasma column. If it is confirmed then the separation factor of the vacuum arc plasma centrifuge, with added gas, can be enhanced even if the angular velocity is not increased.

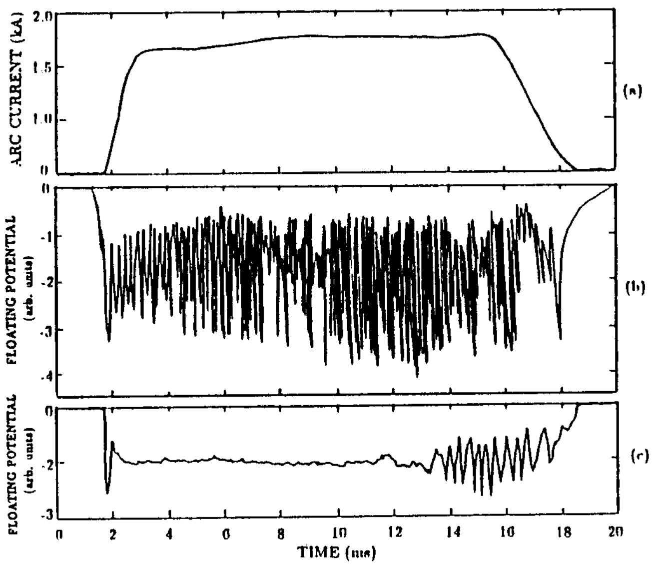

Figure 1: Typical (a) arc current and floating potential: (b) at vacuum, (c) with gas.

The variation of the angular velocity during the plasma pulse, for three different gases (H_2, He, Ar), with the pressure as parameter, is shown in Figure 2. All measurements presented in this paper were taken for an arc current of 1.5kA and a magnetic field of 0.1T. Two basic conclusions can be taken from these results: firstly, the angular velocity of the plasma column with added gas is always smaller than the case when there is no gas (dark circles); secondly, at the beginning of the discharge, with a background gas, the angular velocity can be almost 30% smaller than the case with no gas. However, these values increase as the discharge goes on, eventually, approaching the value of ω in the vacuum. A possible explanation for this behavior can be the viscous effect of the background gas on the fully ionized magnesium plasma column, mainly in the beginning of the discharge, when the gas is not ionized. As the discharge goes on the gas is becoming more ionized by the magnesium plasma, and then, is also put in rotation by the $\vec{J} \times \vec{B}$ force.

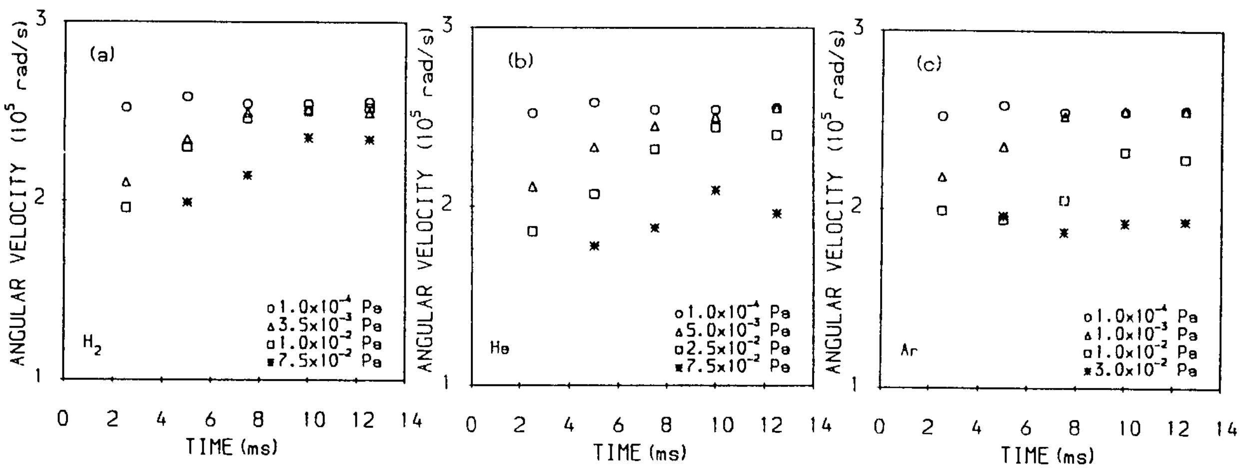

Figure 2: Time dependence of the angular velocity for three different gases. (a) hydrogen, (b) helium, (c) argon, with the pressure as parameter, measured at r = 1.5cm.

The dependence of the angular velocity on the gas pressure for three different instants of the discharge (2.5ms, 7.5ms and 12.5ms) with the gas as parameter, is shown in Figure 3. The dashed line is the angular velocity (ω_0) measured with no added gas ($\omega_0 \sim 2.5 \times 10^5$rad/s) which is practically constant during the shot. Again, it can be observed that the introduction of gas reduces the angular velocity of the plasma column. For pressures smaller than $\sim 1 \times 10^{-2}$Pa ω comes close to ω_0 when the equilibrium is reached (end of the discharge). However, for $P \geq\sim 1 \times 10^{-2}$Pa, ω is always smaller than ω_0.

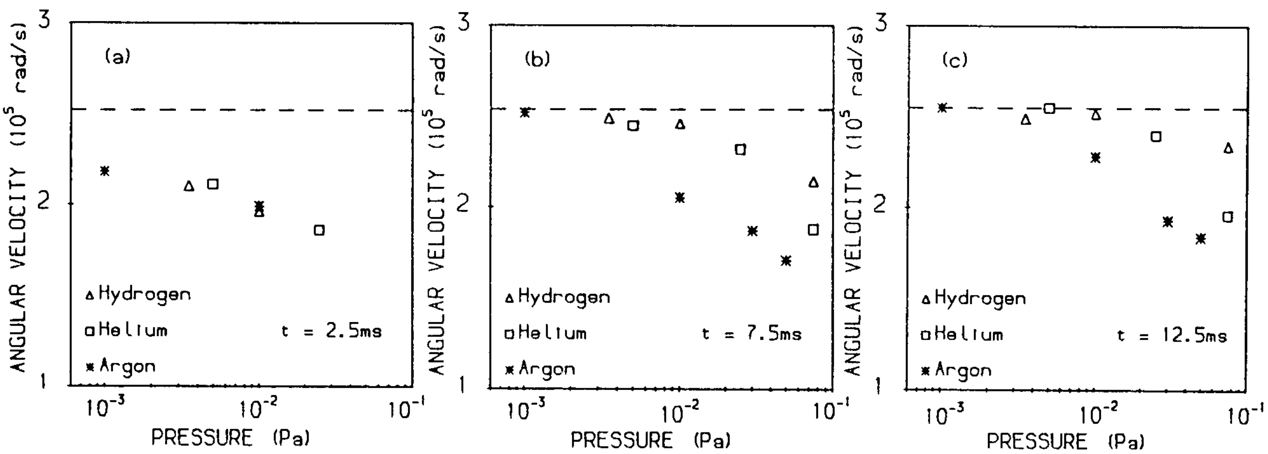

Figure 3: Dependence of the angular velocity on the gas pressure for: (a) t = 2.5ms, (b) t = 7.5ms and (c) t = 12.5ms, for H_2, He and Ar.

The plasma column in the vacuum arc centrifuge rotates as a rigid body for radii smaller than

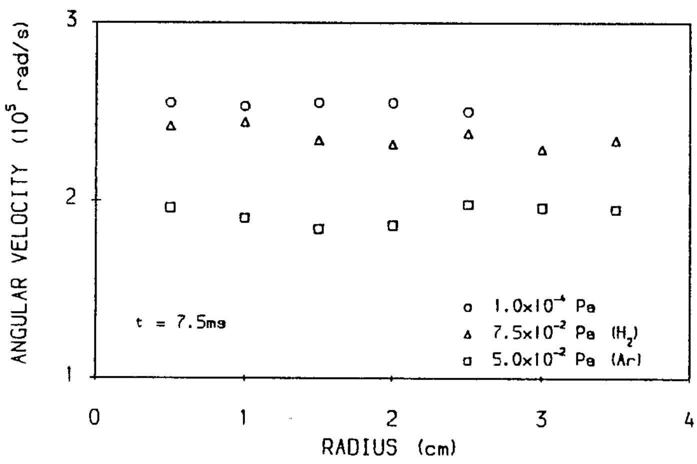

Figure 4: Angular velocity dependence on the plasma radius.

a critical value [6]. This result was also confirmed in this upgraded apparatus, as shown by the results (dark circles) presented in Figure 4. The background gas do not affect the rigid body rotation as can be seen in Figure 4, at least for $P \lesssim 1 \times 10^{-2}$Pa and $r \leq 4$cm.

Conclusions

Results concerning the influence of a background gas in the angular velocity of a plasma column, produced by a vacuum arc discharge, are presented. Angular velocities as high as $\omega_0 \sim 2.5 \times 10^5$rad/s were measured with no added gas. As expected, the introduction of gas reduces the speed of rotation. Nevertheless, for $P \lesssim 1 \times 10^{-2}$Pa, ω increases during the discharge, eventually, approaching ω_0. For $P \gtrsim 1 \times 10^{-2}$Pa the angular velocity is always smaller than ω_0. Concerning the separation factor parameter, α, it is expected to enhance its value when a proper background gas pressure is utilized, since ω is not appreciably affected, the discharge seems to be more stable and the temperature is reduced.

References

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