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Ejected Plasma Parameters from Coaxial Discharge

by
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ABSTRACT

The main interest of this paper is to study the properties of plasma ejected from a coaxial discharge into an expansion chamber. It has been shown that the velocity of expanded plasma is near to that of sound similar to that of laser - produced plasma from a target. It has been found that the plasma expanded adiabatically in a shell like shape. The temperature and density spatial variation has been presented. The investigations have been carried out for a working argon gas of 0.1 torr pressure at peak discharge current of 38 kA with rise time of 6.2 μs.

KEY WORDS

Ejected Plasma , Coaxial Discharge , Expansion Chamber.

1. INTRODUCTION

Marshall [1] had firstly studied the coaxial high voltage discharge between two cylindrical electrodes. This main result was that he obtained ejected plasma, which carried 1 kJ of kinetic energy, which opened its use as a plasma accelerator.

At the start of the discharge a plasma current sheath is formed. It is subjected to Lorentz force ($J_r \times B_\theta$) that pushes it towards the muzzle.
It was found [2] that the plasma current sheath dynamics inside the coaxial accelerator follows the snow plough model which is useful to produce dense plasma. It has been stated that magnetic nozzles have great potential for improving the efficiency and performance of coaxial

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plasma accelerators in many applications, such as space propulsion and advanced manufacturing [3].

It has been shown [4] that the use of ferromagnetic material electrodes reduces the harmful deformation, and therefore erosion, of the side surface of the internal electrode. It has been shown also that the ejected plasma from the muzzle expanded in a shell form [5].

2. EXPERIMENTAL SETUP

An experimental set up is prepared for this study. It consists of the plasma source, expansion chamber, capacitor bank, triggering system and diagnostic tools as shown in figure (1).
The plasma source is a coaxial electrode type with 3.3 cm inner electrode diameter and 6.6 cm outer electrode diameter , both electrodes are made from stainless steel , each has 20 cm length.

The expansion chamber is fixed at the muzzle of the two electrodes, with length of 35 cm and 15 cm diameter. The current and voltage measurements are taken with Rogwski coil. The plasma temperature and density measurements are carried out by double electric probe. Electric and magnetic probes measure the plasma velocity. The discharge takes place in an argon gas with dynamic filling adjusted by needle valve to fix the pressure at 0.1 torr. The system is powered by a capacitor bank with a capacitance 38.55 μF charged at 8 kV.

The double electric probe, 3mm length, and 1 mm diameter, is inserted in the expansion chamber at distance varies from 5 to 35 cm from the breach of the coaxial gun. The voltage supply of the probe has been changed from (-27 to +27) volt in order to estimate the parameters required at constant charging voltage and constant pressure [6].

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The discharge current and voltage, figure (2), showed that the peak current 38 kA is at 6.2 μs for 8 kV bank charging voltage. The power transferred to the coaxial gun is 44 MW during the first half cycle of the discharge. The total resistance of the discharge circuit, obtained from the logarithmic curve of the peak current , figure (3), is 18×10^{-3} ohm while the circuit inductance is 0.5 μH.

The output signal of the double electric probe is given to digitizing oscilloscope , figure (4). The electric probe characteristic curve at each position is obtained by the change of the potential between the probes, figure (5). The corresponding plasma temperature from figure (5) is 7.5 eV and the electron density of the plasma is $7.375\times10^{13}\text{cm}^{-3}$.

The variation of the expanded plasma temperature with axial position z, figure(6) follows the relation $T_e = T_o Z^{-1}$,while The density variation with axial position follows the relation $N_e = N_o Z^{-2}$ figure (7). These result are in agreement with laser produced plasma expansion [7].

From the results obtained from double electric probe and magnetic probes the velocity of the plasma outside the gun variation with distance from the breach is shown in figure(8) . It has been found that the velocity is of the order of 2 x 10^4 cm/s. This velocity is nearly the velocity of sound which can be discussed as follow :

The compressed regions tends to expand into rarefaction for two reasons. First, the ion thermal motion spread out the ions. Second, the ions bunches are positively charged and tend to disperse because of the resulting electric field.

This field is largely shielded out by electron and only a fraction proportional to KT_e is available to act on the ions bunches. This effect gives rise to the first term in the square root of the dispersion relation for ion acoustic waves. The acoustic velocity is then given by :

$$v_s = \sqrt{\frac{KT_e}{M}}$$

Where $T_i << T_e$, is a common occurrence , M is the ion mass, T_i is the ion temperature, T_e is the electron temperature and K is the Boltzman constant.

From plasma density and temperature the calculated velocity of the sound wave for the plasma at the muzzle is about 2 X 10^4 cm/sec. This is in agreement with the expanded ejected plasma velocity outside the gun which indicates that the plasma expanded adiabatically in the expansion chamber.

4. CONCLUSIONS

It has been observed that the velocity of the expanded plasma is near to that of sound similar to laser produced plasma from a target. It has been found that the plasma expanded adiabaticlly.

The measured expanded plasma temperature and density variation with axial position follow the relations:

$T_e = T_o Z^{-1}$

$N_e = N_o Z^{-2}$.

Which are in agreement with adiabatic expanded plasma shell.The investigations have been carried out for working argon gas of 0.1 torr pressure and for peak discharge current of 38 kA with rise time of 6.2 μs.

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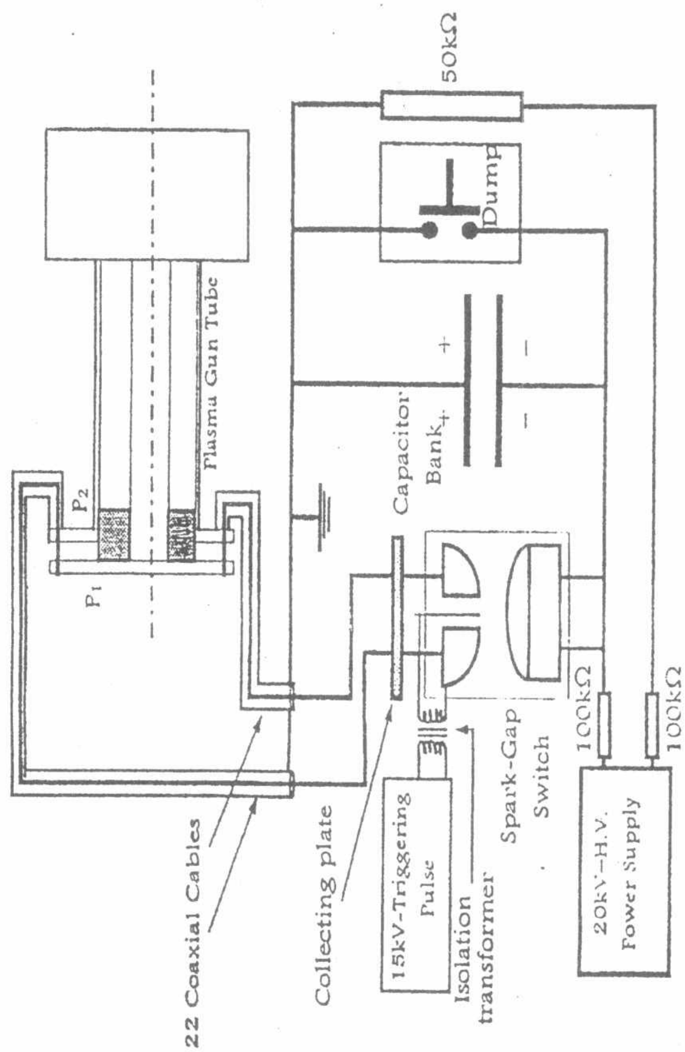

Figure (1) : Schematic diagram of the plasma gun system

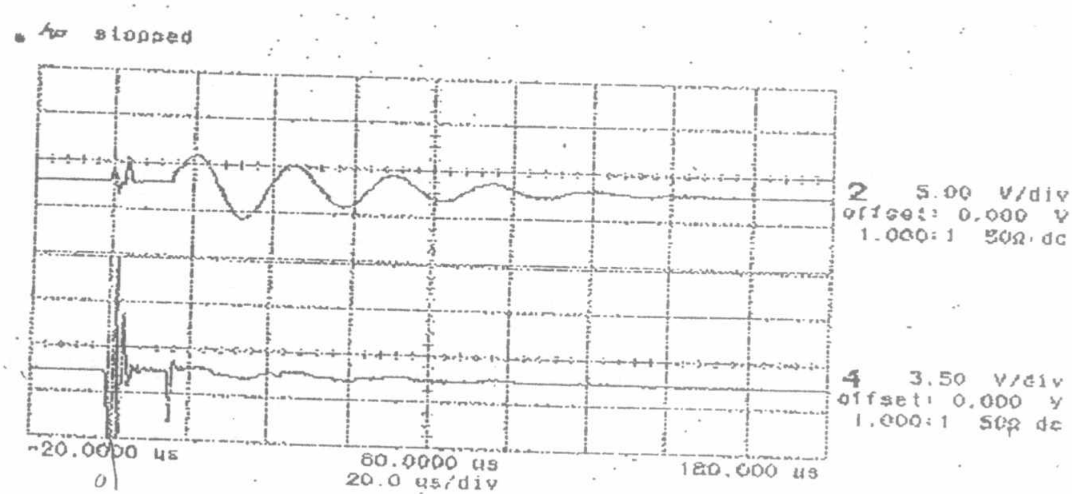

Figure (2) : Wave forms of discharge current and voltage for 9 KV capacitor bank charging voltage and Argon gas pressure of 0.1 Torr

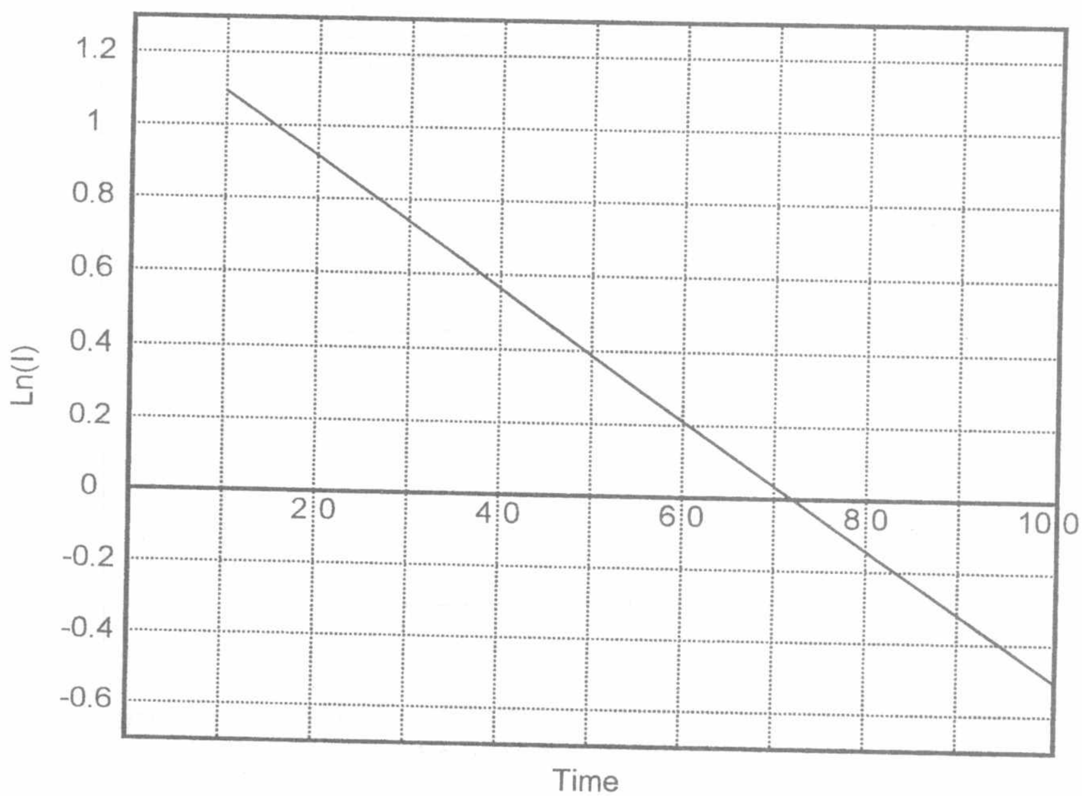

Figure (3) : Relation between Ln(I) and time (for 8 KV - 0.1 Torr pressure)

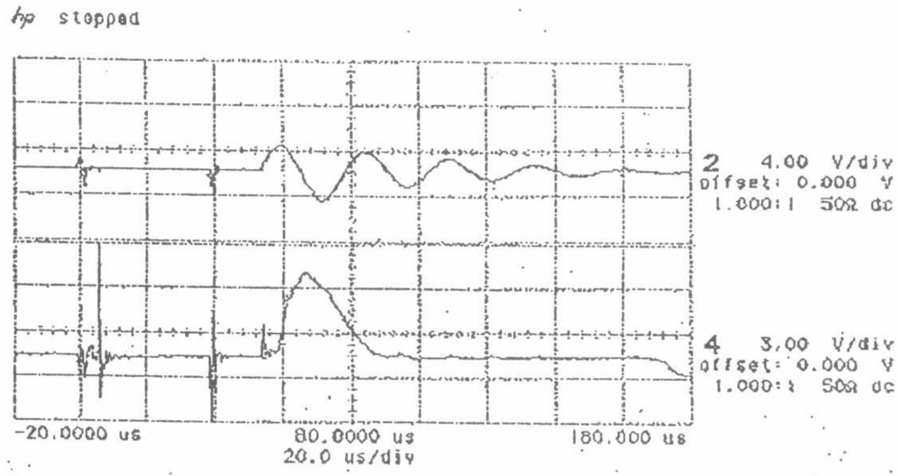

Figure (4) : Wave form output of the discharge current and output of the double electric probe at 8 KV , 0.1 Torr gas pressure at +27 volt between its two electrodes

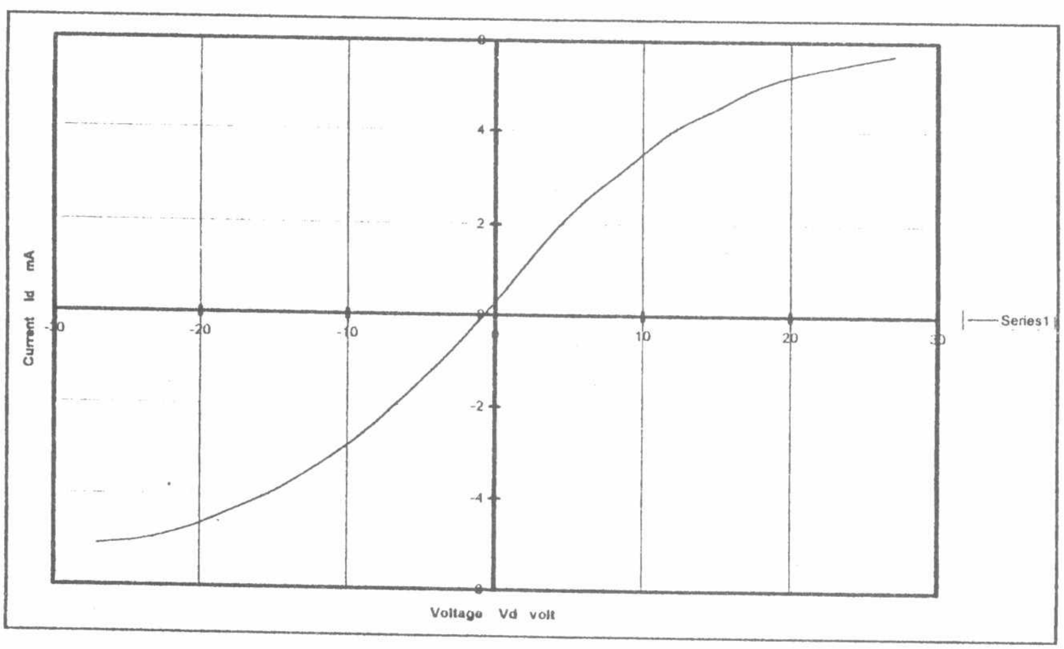

Figure (5) : I - V Characteristic curve of the double electric probe between the potential difference Vd and the probe current Id

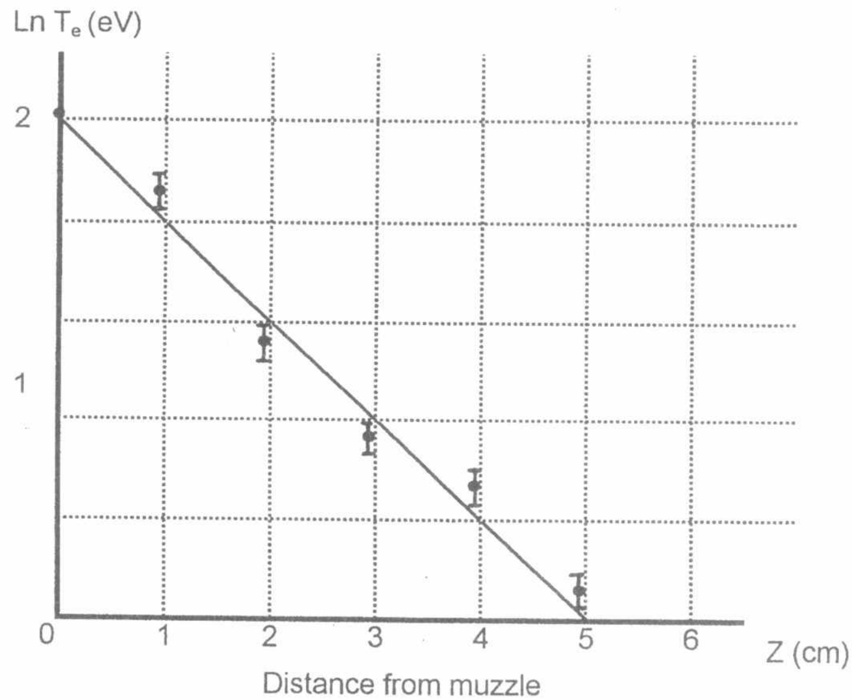

Figure (6) : Ejected Plasma Temperature variation with position

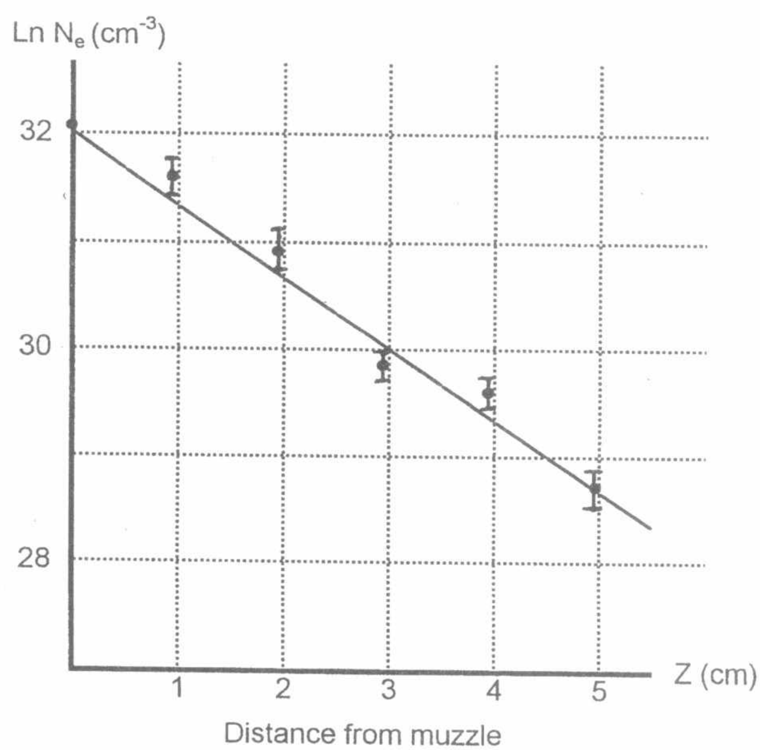

Figure (7) : Ejected Plasma electron density versus position

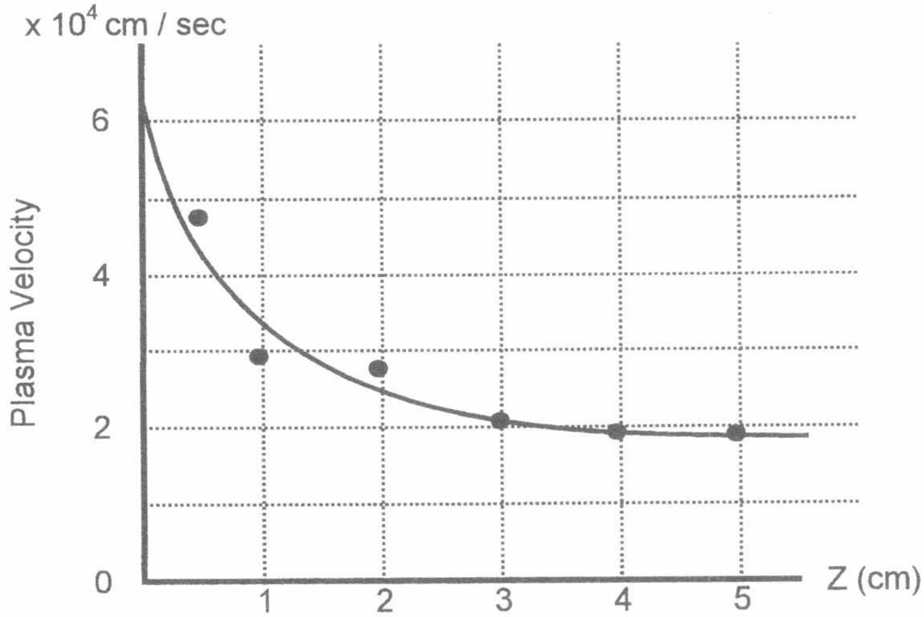

Figure (8) : Ejected Plasma velocity versus position