Study of the Correlation between the Plasma Sheath Dynamical Behavior and the Best Focus Action

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ABSTRACT

This paper deals with investigations of the plasma current sheath (PCS) axial phase dynamics which is actually based on measurements of its axial velocity. The plasma focus parameters which include the energy dissipation, plasma inductance, load impedance, minimum radius of plasma focus column and the pinch ratio are detected. Also, the soft x-ray emission during the plasma focus formation is measured. All measurements mentioned above are performed at Argon gas pressures ranging from 0.5 to 2 Torr and charging voltage in the range from 8 kV to 12 kV. The diagnostic tools employed for the experimental work included a Rogowsky coil, resistive potential divider, magnetic probes and pin-diode. The experimental results illustrated that the best focus action is detected at the discharge conditions of the optimum dynamical behavior of PCS along the coaxial electrodes.

Keywords: Plasma Current Sheath / Plasma Focus / X-ray / Axial phase dynamics.

INTRODUCTION

The plasma focus (PF) device was independently developed in the early 1960 by Mather[1] and by Filippov[2] in two configurations which mainly differ in the macroscopic direction of the motion of the accelerated plasma in axial and radial directions[3]. In general the dense PF device[2, 4] is a simple pulsed coaxial plasma accelerator that forms a finite two dimensional non-cylindrical Z-pinch, at the end of central electrode to compress the plasma to very high temperature (~ 1 – 2keV) and very high densities (10^{25} – 10^{26} m^{-3}). The focus formation is accomplished by two basic processes; (i) A gas discharge starts at the insulator end of the coaxial electrodes and an umbrella-like plasma layer is formed[5]. The azimuthal magnetic field, B, located in the torus enclosed by the radial current density, J, produces a (J_xB_z) force that accelerates the sheath toward the open end of the coaxial electrodes (muzzle). (ii) The sheath collapses on the axis in the form of a thin filament of extremely hot and dense plasma cylinder (focus)[6].

Some of previous experimental data of plasma focus action[7,14] were found that, there exist a number of factors which affect on successful operation of PF devices, some of them are listed as follows:

a) the polarity of the central electrode[7,8],
b) the location of the forming current sheath during the breakdown phase[9],
c) type of filling gas and its pressure within the focus chamber[10,11],
d) material type and length of insulator sleeve[12], and
e) geometry, length and material of plasma focus electrodes[13,14].

The main aim of this paper is to investigate the influence of the dynamical behavior of plasma current sheath in axial phase on the plasma focus formation. The experimental
results are taken from an average of 5 shots at least for every discharge condition under consideration.

**EXPERIMENTAL SETUP**

The experimental work has been carried out using a (1 – 2.2 kJ) Mather-type plasma focus device energized by a 30.84 µF capacitor bank and the device has been operated in Argon gas at a pressure in the range from 0.5 to 2 Torr. The schematic diagram of the coaxial electrodes system and the cross section of the plasma focus device as a whole are shown in Fig.1 and Fig.2 respectively. Figure 3 shows the electrical circuit of the device under consideration. The structure of the electrode system consists of a stainless-steel inner electrode 13 cm long and 4 cm in diameter. The outer electrode consists of eight stainless-steel rods, each of 0.8 cm diameter and 13.6 cm in length and are uniformly spaced on a brass circular plate of 11 cm diameter at the breech of the coaxial electrode system. Inner and outer electrodes are separated at the coaxial electrodes breech by an insulating Teflon ring. The coaxial electrode system is enclosed in stainless-steel chamber of length and diameter 40 cm and 38 cm, respectively.

![Fig.1 A Schematic diagram of the coaxial electrodes system.](image1)

![Fig.2 A cross section of the discharge chamber and vacuum system](image2)

1-Coaxial cables (24 cables). 2- Rubber tube. 3- Rotary pump. 4- Copper flange. 5- Connection points. 6,7- Teflon insulators. 8- Outer electrode. 9- Inner electrode. 10- Diagnostic tools. 11- Gas inlet. 12- Vacuum gauge. 13- Glass slits.
The main purpose of our experimental work is divided into two parts; the first part deals with the characterization of plasma focus action while the second is devoted to dynamical behavior of plasma current sheath along the coaxial electrodes system.

In order to get the optimum discharge condition under consideration for formation of a best focus action, it is important to study the characteristics of plasma focus which formed at a different filling Argon gas pressures and charging voltages under consideration, such as the power flow, \( P = IV \), where \( I \) and \( V \) are the discharge current and voltage which are measured by Rogowsky coil and resistor potential divider tools, respectively, the energy dissipation through the plasma during the focusing time, \( \int IV \, dt \), the plasma focus inductance, \( L_{PF} \), the load impedance, \( Z \), the radius of plasma focus column, \( r_p \), where \( b \) is the radius of outer electrode of coaxial electrodes system (= 5.5 cm) and \( z_F \) is the length of PF column (taking it = 1.5 cm), plasma focus volume, \( V_{PF} \), the pinch ratio, \( \alpha \), where \( a \) is the radius of inner electrode = 2 cm and the intensity of X-ray emission during the plasma focus formation time, measured by using a pin diode of type PBX 65, which is placed at axial distance = 25 cm from the coaxial electrodes muzzle.

Fig.4 (a, b) shows the arrangement of soft X-ray detector (a), the biasing circuit (b).

Figures 5, 6 present the variation of the power flow and the energy input to the plasma focus column, at the maximum value of plasma focus formation time with charging voltage and at different Argon gas pressure.

![Diagram](image)

\[ L_{PF} = \frac{\int IV \, dt}{\int I \, dt} \]

\[ r_p = b e^{-\frac{2L_{PF}}{\alpha z_F}} \]

\[ m r_p^2 z_F \]

\[ = \frac{r_p}{\alpha} \]

Fig.4 (a) The arrangement for the soft x-ray detector. (b) Biasing circuit for the x-ray diode.
Plasma inductance, load impedance, minimum radius of plasma focus PF column, $r_p$, plasma focus volume and pinch ratio, $r_p/a$, as a function of charging voltage, at different Argon gas pressures and during focusing time, are illustrated in Fig.7 (a, b) and Fig.8 (a, b, c), respectively. Figure 9 shows the variation of the intensity of X-ray emission from a plasma focus region against charging voltage and at different Argon gas pressures. All of the above experimental results reveal that, the optimum discharge conditions for best focus action formation are detected at Argon gas pressure = 1.5 Torr and charging voltage = 12 kV.
Fig. 7: (a) Variation of plasma inductance versus charging voltage at different gas pressures. (b) Variation of load impedance versus charging voltage at different gas pressures.

Fig. 8: The relation of charging voltage at different gas pressures and:
   a) minimum radius of PF column
   b) plasma focus volume
   c) pinch ratio
The axial plasma current sheath dynamics in terms of its velocity, $v_z$, along the coaxial electrodes and at radial distance equal to the average of inner and outer electrodes radii is estimated from the data of azimuthal magnetic field induction associated with the plasma current sheath, and consequently the axial velocity distribution profiles of the plasma current sheath along the axial inter-electrode space are computed from the variation of plasma current sheath position, $z$, along the coaxial electrodes and its arrival time, at the same discharge conditions mentioned above. Figure 10 (a, b, c) describes the variation of $\ln v_z$ against $\ln z$ at different discharge conditions under consideration. It can be seen that the rate of change of axial PCS velocity, $v_z$, with axial distance, $z$, is a constant value $= 2.8 \times 10^5$ sec$^{-1}$ from approximately a distance close to the breech until the coaxial electrodes muzzle at 1.5 Torr Argon gas pressure and 12 kV charging voltage.
Fig. 10 (a) \( \ln v_z \) versus \( \ln z \) for charging voltage 8 kV and at different Argon gas pressure.

Fig. 10 (b) \( \ln v_z \) versus \( \ln z \) for charging voltage 10 kV and at different Argon gas pressure.
CONCLUSION

The experimental results of the plasma focus PF characteristics such as a power flow, $P$, energy dissipation through plasma focus column, $E$, PF inductance, $L_{PF}$, PF load impedance, $R$, a minimum radius of PF column, $r_p$, and the X-ray emission intensity from a PF column, $I_{X-ray}$ as a function of different discharge conditions under consideration, demonstrated that the best PF formation is detected at 1.5 Torr gas pressure and 12 kV charging voltage. This discharge condition corresponding to a maximum value of $P$, $E$, a minimum value of $L_{PF}$, $R$, $r_p$ and highest yield of X-ray emission.

The experimental study of the dynamical behavior of PCS during the axial phase at the same discharge conditions used for detection of best PF action, confirmed that the PCS axial velocity increases gradually with axial distance for most discharge conditions, but at 1.5 Torr gas pressure and 12 kV charging voltage, the results indicated that the rate of change of axial velocity, $v_z$ with axial distance, $z$, $\left( \frac{dv_z}{dz} \right)$ is approximately a constant value from axial distance closes to the breech up to the co-axial electrodes muzzle end. That is, the best dynamical behavior of PCS along the coaxial electrodes is found to be at the same discharge condition for best PF formation.

In general, the experimental results illustrated that the best focus action is seen to be strongly dependant on the dynamical behavior of PCS during the axial phase, i.e., a correlation exists between the PCS dynamical behavior and the best focus action.
REFERENCES