ESTIMATION OF CURRENT SHEATH CURVATURE IN PLASMA FOCUS DEVICE USING MAGNETIC PROBES

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Abstract. The dynamics of current sheath, in terms of its speed and sheath curvature, in dense plasma focus device was investigated in its axial acceleration phase using multiple magnetic probes. The investigation was performed for different filling gas pressures of neon. The relative X-ray yields were estimated using a diode X-ray spectrometer. A possible correlation between the current sheath curvature and the X-ray emission was explored. The investigation demonstrates the effective use of relatively simple diagnostic tool, magnetic probes, in the estimation of current sheath axial speeds and curvatures.

Key words: plasma focus, plasma sheath.

1. INTRODUCTION

Initially perceived as a potential source of thermonuclear energy, plasma focus device has been more recently used for X-ray lithography [1], thin film processing [2, 3] and deposition of thin films [4]. It is also a suitable device for understanding the problems of plasma physics such as plasma dynamics, micro-instabilities, turbulence, etc. In the present investigation we have estimated the current sheath curvature in different filling pressure of neon gas using simple magnetic probes placed at various positions in the plasma focus machine. The X-ray yield is also measured at different filling gas pressures of neon and a possible correlation between current sheath curvature and the relative yield of soft X-radiation is explored.

2. EXPERIMENTAL SET-UP AND METHODS

The present investigation is performed on a simple single-capacitor dense plasma focus device designated at the United Nation University/International Center for Theoretical Physics Plasma Focus Facility (UNU/ICTP PFF) [5].
Fig. 1 – Positioning of magnetic probes in axial and radial directions.

It is a Mather-type focus device, energised by a single 30 μF, 15 kV fast discharging capacitor, with maximum energy storage of 3.3 kJ.

In our investigation, the device was operated at the charging voltage of 14.0 kV and with neon as the filling gas. The device was operated at four different filling gas pressures of 3.0, 4.0, 5.0 and 6.0 mbar of neon.

The magnetic probes used in the present investigation are 10-turn coil made by winding SWG 40 enamelled copper wire onto a small plastic sleeve of about 1 mm diameter. The coil and connecting wire are enclosed in a glass tube of 6 mm outer diameter to provide the electric insulation and protection against the plasma.

The magnetic probe picks up the magnetic field signal only when current sheath sweeps past it. Four magnetic probes, along the radial direction, were placed at 1.7, 2.1, 2.5 and 2.9 cm away from the center of the anode, respectively. As shown in Fig. 1 the probe closest to the anode captures the field and the earliest and the farthest probes will be the last to record the signal. The time difference (Δt) between the signals of two consecutive radial direction probes depends on the curvature and the velocity of the current sheath at different radial positions. From the signals obtained by the probes inserted along the radial direction, we computed the time difference (Δt) between different points on the current sheath reaching the probes. This computed time difference can be used to estimate the curvature of the current sheath provided the axial speed of the current sheath at three radial positions of 1.7, 2.1 and 2.5 cm is known all along the focus tube. In order to estimate the axial plasma sheath speed at different axial positions, we placed seven probes in one glass tube such that they were 3.5, 5.5, 7.5, 9.5, 11.5, 13.5, 15.5 cm from the back-wall plate along the axial direction, respectively, as shown in Fig. 1. The axial speed measurements were done at three different radial positions of 1.7, 2.1 and 2.5 cm. The combination of four magnetic probes along the radial direction was placed at three different axial positions of 3.8, 7.8 and 11.8 cm from the back-wall plate.
The relative X-ray yield at different filling gas pressures of neon was estimated using a five-channel Diode X-ray Spectrometer (DXS). The diodes used in the DXS are planar silicon PIN photodiodes (BPX65) without glass windows. Each of the photodiodes is covered with a suitable filter combination. For the estimation of the relative soft X-ray yield from neon plasma, we only used the two channels of the DXS that were covered with 12 µm and 24 µm aluminized Mylar filters. 1 Gsa/s, 250 MHz Hewlett Packard (HP™) digital logic analyser (DSO) of model 16500A was used to collect up to 8 channels of data for one discharge. The data taken by the DSO were then transferred to a PC via GPIB using a C-program.

3. RESULTS AND DISCUSSION

The typical magnetic probe signals from seven magnetic probes inserted along the axial direction are shown in Fig. 2. In order to maintain the consistency in estimating the time difference between the consecutive magnetic probe signals the timing instants of the arrival of current sheath at each of the probes were taken at 10% of the amplitude of the first magnetic probe signal. These time differences were averaged over 10 focus sample shots. The maximum standard deviation was found to be only 4.04 percent. Since the error involved in the estimation is quite small, comparable to or even smaller than the size of the dots being used for graphical presentation, the error bars have not been drawn on the curves of Fig. 3 and Fig. 4.

![Fig. 2 – Typical magnetic probe signals for axial speed measurement.](image-url)
Fig. 3 – Estimated axial speed at three different radial positions of (a) 1.7 cm, (b) 2.1 cm, and (c) 2.5 cm. At each radial position the axial speed is measured for four different gas pressures of (1) 3 mbar (*), (2) 4 mbar (♦), (3) 5 mbar (▲), and (4) 6 mbar (■).

Fig. 4 – Current sheath curvature at the height of 3.8 cm with different filling gas pressures.

Fig. 3 shows the estimated axial speeds at different axial positions at three different radial positions (1.7 cm, 2.1 cm and 2.5 cm). The experiments were conducted for four different filling gas pressures. It can be observed that at all radial positions for each of the different filling gas pressures the axial speed initially increases. This is because initially the rate of increase of the discharge current dominates over the rate of increase of the mass of the filling gas snowplowed by the moving current sheath. In most of the cases, particularly at lower filling gas pressure, the axial speed reaches its maximum value at the axial position of about 10.5 cm. However, at higher filling gas pressures the current sheath is found to attain maximum axial speed at lower axial positions. This may be because of the fact that at higher filling gas pressure the current sheath is not as
diffused as it is in the case of low filling gas pressure and so its mass plowing efficiency is much improved. The increased snowplowing efficiency along with more mass being available for plowing (due to higher gas pressure) results in early attainment of the maximum axial speed. The increase in the filling gas pressure results in more gas particles per volume unit and so the current sheath scoops up more gas resulting in a drop in sheath speed. This explains the overall decrease in the axial speed of the current sheath with the increase in the filling gas pressures at all radial positions.

It has also been noticed that the axial speed of the current sheath decreases, invariably, as it reaches towards the top of the anode. This is not only due to the ever increasing mass of the gas being scooped by the current sheath but also to the fact that the current flowing through the plasma starts decreasing by that time.

It may also be noted that the initial current sheath speed (at the axial position of 4.5 cm) at the radial position of 1.7 cm is the smallest and it increases as one moves radially outwards. This is simply because of the curvature of the current sheath. At the same axial but radially outward position the current sheath will reach later as it is curved and hence it will be accelerated to higher speeds.

The estimated sheath curvatures at all filling gas pressures show that the curvature of the current sheath initially increases and then later on gets almost stabilized as it moves up the anode axis. In fact at higher filling gas pressure the curvature of the sheath is found to reduce again. This may be attributed to the early decrease in current sheath speeds at higher pressure, as pointed put and explained earlier. Fig. 4 shows the estimated current sheath curvatures at the same height of 3.8 cm with different filling gas pressures. It has been estimated that the curvature of the current sheath increases initially with the increase in filling gas pressure from 3 to 4 mbar and then it decreases continuously with the further increase in pressure.

The relative X-ray yield was estimated by calculating the area under the observed X-ray peaks from the DXS channels covered with 12 and 24 µm aluminized Mylar filters. The estimated relative X-ray yield at different filling pressures of gas is plotted in Fig. 5. The relative X-ray yield is found to be the highest at 3 mbar and then it decreases with the increase in the filling gas pressure.

The sheath estimated curvatures show that the maximum curvature was at the 4 mbar. However, the relative X-ray yield is found to have the maximum at 3 mbar.

This points to probably not much of a correlation between the curvature of the current sheath and the relative X-ray yield. It is however important to note that the X-ray filters (12 and 24 µm aluminized Mylar filters) used in this investigation can not filter out the relatively hard X-ray emission corresponding to the copper $K_\alpha$ line emission of the copper anode being bombarded by relativistic electrons. Bulk of the X-ray signal therefore can be contributed by the copper $K_\alpha$ line instead of the characteristic soft X-ray line emission of non-gas. At this juncture, therefore, it
would be difficult for us to justify the existence or non-existence of any correlation between the current sheath curvature and the soft X-ray emission from the neon plasmas of the focus device.

4. CONCLUSIONS

The use of magnetic probes proved to be relatively simple yet effective for the estimation of axial speed and thus the curvature of the current sheath in plasma focus device. The typical initial axial speed of the current sheath at the axial position of 4.5 cm was found to be in the range of 3.2 to 5.2 cm/µm, with speeds being on the lower side at the combination of higher pressure and closer radial position and on the higher side for combination of lower filling gas pressure and outer radial position. The maximum axial speed was found to be in the range of 5.1 to 6.7 cm/µm. The curvature of the current sheath, at lower filling gas pressures, was found to initially increase before being stabilized as current sheath moves up the anode axis. At higher filling gas pressures the curvature of the sheath reduces again as the current sheath reaches towards the top of the anode. The relative X-ray yield was the highest at 3 mbar and found to decrease with the increase in the filling gas pressure.

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