Study of Current Sheath Velocities in Tridimensional with Sahand Plasma Focus

M.A. Mohammadi, H.Alinejad and A.Piri

***Abstract*—**The current sheath dynamics in plasma focus facilities is the most important factors. In this paper the current sheath velocity at three dimensional with Sahand plasma focus facility is investigated. For this purpose the discharge is produced in argon gas with deposited energy lying in the range of 20-37kJ. The current sheath is monitored using two tridimensional magnetic probes. These probes installed near the surface of the interior electrode (anode) at 125mm from the anode axis (pinch place). The effect of gas pressure on the current sheath velocity also is investigated.

***Keywords*—**Plasma focus, Current sheath, magnetic probe

I. INTRODUCTION

THE plasma focus (PF) devices are a simple facilities that makes a plasma with high density $\left(\square 10^{25} - 10^{26}\,\mathrm{m}^{-3}\right)$ and high temperature (~1-2 keV) within lifetime of about 50- 100ns [1, 2]. The dense plasma focus (DPF) historically established as a fusion device due to the intense bursts of neutrons it produces when operated in deuterium. Te DPF is not only a source of neutrons [3] but also produces high energy ions [4], relativistic electrons [5], and an abundant amount of soft and hard X-rays [6-10]. Because of application of DPF in contact microscopy, X-ray and electron beam lithography, X-ray radiography and micro machining [11- 16], this device favored by scientists. In the Mather type plasma focus the dynamics of the plasma is generally divided into three phases: the breakdown phase, the axial acceleration phase and the radial collapse phase but in Filippov type device the radial and axial phase is down simultaneously. When the high voltage pulse is applied across the electrodes at an appropriate filling gas pressure, electrical breakdown is formed at the surface of insulator. This phase referred as a breakdown phase. An axially symmetric current sheath is formed by the end of this phase. The Lorentz ($\vec{j} \times \vec{B}$) force accelerates the conducting plasma sheath upwards along the anode until it reaches the anode tip at its axis of symmetry.

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Axial phase after breakdown phase is made. In this phase the current sheath accelerated in the forward z-direction by the axial component of its own Lorentz force towards the open end of the anode. The radial collapse phase begins with the current sheath reaching the end of the anode and starts to slide across the face of the anode in the radially inward direction. The radial collapse phase has been, conventionally, divided into four sub-phases. (i) *Compression phase,* (ii) *Quiescent phase,* (iii) *Unstable phase* and (iv) *Decay phase* [17- 18].
One of the important factor in all phases is the current sheath velocity. The dependence of velocity on the pressure and working voltage cases to we studied of current sheath velocity at different pressure and voltages. In this paper we made three-dimensional magnetic probes and we studied tridimensional dependence of current sheath velocity on working gas pressure and working voltage.

II. EXPERIMENTAL SETUP

Our experiments carried out with Sahand as a Filippov type plasma focus device [19]. Sahand is a 90 kJ Filippov type machine whose main parts are shown in Fig. 1. In the Sahand the discharge chamber which serves also as the cathode is a stainless steel cylinder of 76 cm in diameter and 26 cm height. The anode is a copper disc with 50 cm in diameter. It placed on a ceramic cylinder of 48 cm in diameter and 11 cm height. Because of the erosion of the central part of the anode, a replaceable anode insert is installed in that portion. Anode is connected to the spark gap via 24 copper rods. As the working gas, we use deuterium, noble gases and their mixtures with the pressure of 0.5 ÷ 5Torr in Sahand facility. The required energy for the production of discharge and focusing it is provided by a capacitor bank of $288\,\mu F$ which consists of 24 capacitors. The maximum charging voltage is 25 kV and the maximum stored energy is 90 kJ which induces a discharge current of ~1.1 MA. For the study of current sheath dynamics in three dimensional, we used argon as a working gas in Sahand. The discharge current and current derivative were monitored by means of a Rogowski coil. The typical current derivative and current signals are shown in Fig. 2. Due to rapid increase in inductance a dip was found in current derivative signal with pinching, ‘‘focusing’’ of the plasma column. For the same time measurement investigation of current sheath velocity we used two tridimensional magnetic probes. Magnetic Probe works on the basis of Faraday’s law of electromagnetic induction. The induced electromotive force V_i produced in such a coil due to change in the magnetic field, for a coil of n turns and a cross-sectional area A small enough such that the magnetic field does not vary over it then, is given by

$$V_i = nA\left({dB}/{dt}\right) \qquad (1)$$

where B is the component of magnetic field parallel to the axis of the coil.

A schematic diagram of the tridimensional magnetic probe assembly is shown in Fig. 3. We placed one of tridimensional magnetic probe 5mm and another 35mm above anode surfaces. Diameter of each probe is 1mm. The small size of each probe ensured only very small disturbance to the current sheath. These position are used for studying of current sheath velocity in tridimensional. The signals delivered by magnetic probes were registered with a four-channel, 200MHZ and 2 GS/s digital storage oscilloscope.

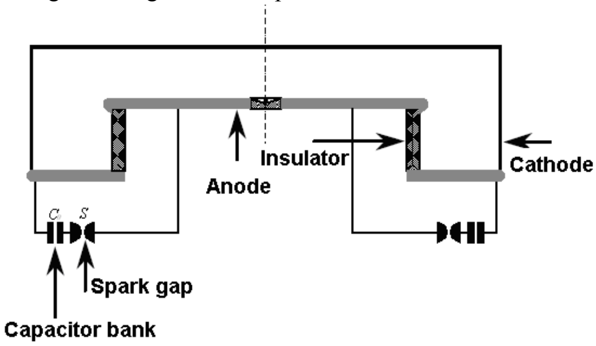

Fig.1 Schematic view of Sahand plasma focus

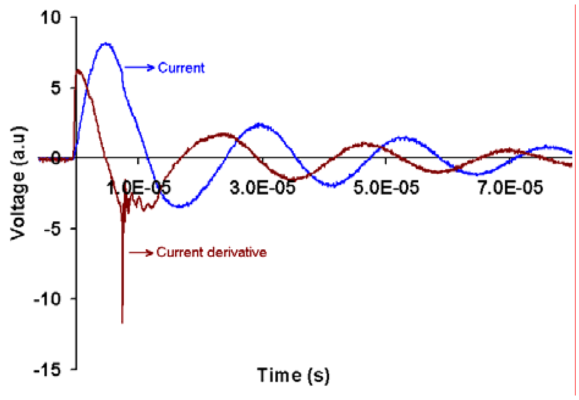

Fig.2 Typical signals of current and current derivative

III. Results and Disscution

For the studying of current sheath symmetry we placed two tridimensional magnetic probes at same distance from anode surface. The probes are located 250mm from each other. In Fig. 4 the sample signals from two magnetic probes is shown. With this figure we can see that the current sheath is symmetric. Typical signals from two magnetic are shown in Fig. 5. One can already observe the axial and radial CS motion. This figure also shows that the current sheath is curvature. From this figure we can also conclude that the broadening of current sheath in z direction is greater than y direction. For the calculation of CS velocity we located probes as it shown in Fig. 3. For velocity calculation, we worked with energy between 20 and 37 kJ. Cs velocity in y direction is shown in Fig. 6. Maximum and minimum velocity in y direction are 6.84 $cm\mu s^{-1}$ for 16 kV at 0.25 Torr and

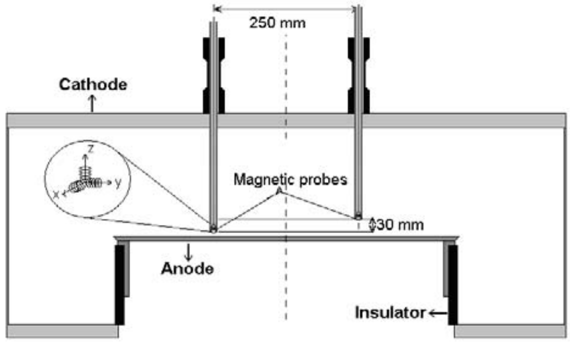

Fig.3 Magnetic probes position in Sahand

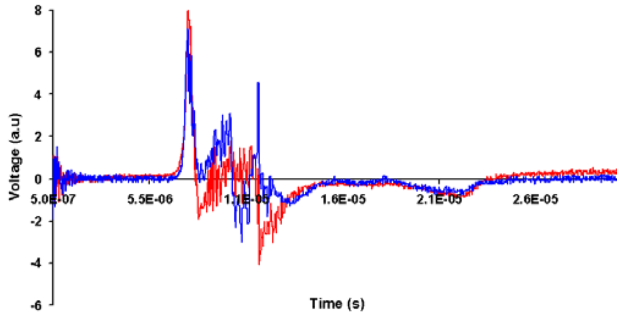

Fig.4 Sample signal from magnetic probes at different position and same place from anode

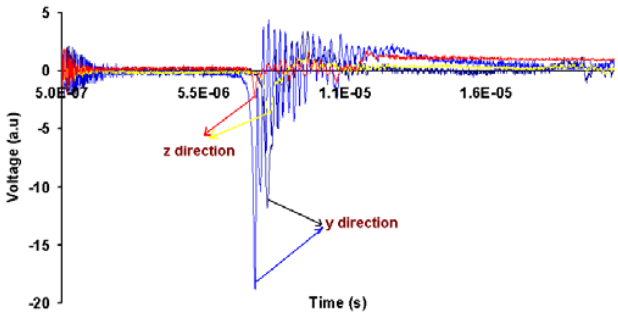

Fig.5 Typical signals from magnetic probes

2.01 $cm\mu s^{-1}$ for 12kV at 0.5Torr respectively. From this result we can conclude that at higher pressure the velocity of current sheath is decreased. At higher pressure the CS mass is more then velocity of that is decreased. At higher voltage more energy will be converted into CS then it will be accelerated more than lower pressure. In Fig. 7 the CS velocity in z direction is shown. 5.74(cm/μs) for 16kV at 0.25 Torr and 1.48(cm/μs) at 12kV at 0.5 Torr are calculated as a maximum and minimum velocities respectively. This figure also confirm that at higher voltage velocity increased and in higher pressure it will be decreased. One of interesting result we get in this paper is in z direction the current sheath velocity is less than y direction. The velocity ratio of y direction on the z direction is shown in Fig. 8. This result confirms that the elongation in y direction is more than in z direction and the fraction plasma will be contributed in focused plasma.

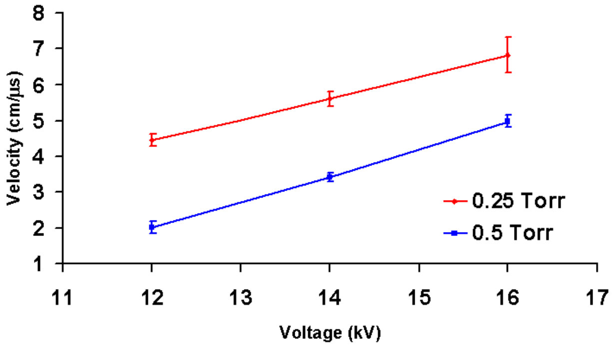

Fig. 6 CS velocity in y direction at different voltages and different pressures

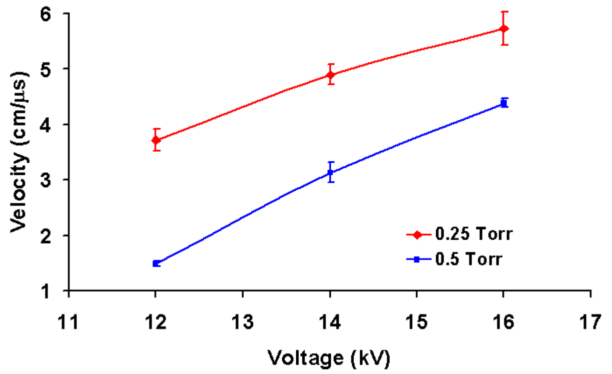

Fig. 6 CS velocity in z direction at different voltages and different pressures

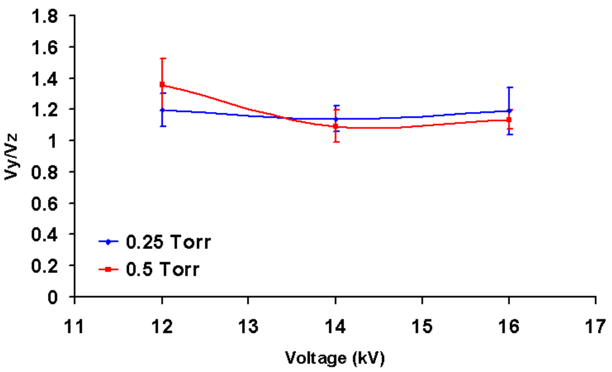

Fig. 8 Ratio of y velocity on z velocity

IV. Conclusion

In this paper we calculated CS velocity at three dimensional simultaneously in Sahand as a Filippov type plasma focus. We first showed that the current sheath is symmetric. Maximum and minimum current sheath velocity in y direction are $6.84\,cm\mu s^{-1}$ for 16kV working voltage at 0.25Torr and $2.01\,cm\mu s^{-1}$ for 12kV working voltage at 0.5 Torr respectively. In z direction we found that maximum and minimum velocity are 5.74(cm/µs) for 16kV at 0.25 Torr and 1.48(cm/µs) at 12kV at 0.5 Torr respectively. It found that the CS velocity in z direction smaller than y direction. We also found that the small fraction of plasma contributed in focused plasma.

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