Correlation between Plasma Pinch Intensity and Current Sheath Symmetry in Amirkabir Plasma Focus Facility

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In this paper we studied the effect of plasma current sheath symmetry on pinched plasma intensity in Amirkabir Mather type plasma focus (APF) facility (16kV, 36μf, and 115nH) by the three magnetic probes spaced equally around the periphery of the outer electrode at the heights of z_1=4.3 cm and z_2=6.3cm from the cathode collector plate. The arrival times of current sheath reaching to the probes and also the signal of current discharge recorded simultaneously on a four channel 100MHz PC based oscilloscope. Simulated trajectory, velocity and intensity of current sheath compared with the experimental results when Argon puffed into the chamber. There was a good accordance among plasma current sheath symmetry in the axial acceleration phase of plasma focus performance and intensity of pinched plasma current in the radial phase of current sheath. Velocity of current sheath examined experimentally and compared with the simulation result.

Keywords: magnetic probes- plasma focus- current discharge- plasma pinch intensity

1. Introduction

The plasma focus devices, known as non-cylindrical high-density Z-pinch facilities, have been investigated in various laboratories for many years, since their construction is relatively simple and cheap and they can generate dense magnetized plasma of fusion parameters [1, 2]. In this device a high-voltage discharge of a capacitor bank is produced in a coaxial electrode gun surrounded by filling gas at several millibars. A plasma sheath with a thickness of about 1mm travels along the coaxial cavity and, at the end of the gun, starts a radial implosion towards the gun axis and shapes a cylinder of dense plasma [3]. High current pulse discharges of plasma focus devices can produce high temperature plasmas within the pinch regions, which are sources of the intense electromagnetic radiation and corpuscular emission. It has been recognized that overall performance in plasma focus operation depends critically on current sheet formation. It is a well-known fact that formation and behavior of the current sheath before the pinch is relevant for optimized operation of plasma focus devices [4,5]. For good performance of the device the development of a thin current sheath on the insulator surface is considered necessary in the initial stage of the discharge.

One of the diagnostics to study the behavior of the current sheath is magnetic probe. The signals obtained by magnetic probes contain valuable information about the current sheath, and its behavior. The passage of the current sheath driving the plasma layer may be measured as a sharp rise in magnetic field as the sheath sweeps past the probe [6]. In this paper an experimental description of the function of a magnetic probe, inserted into the discharge chamber of APF plasma focus facility operated in argon gas filling is presented. Using these probes, some experimental measurements of temporal evolution of the current sheath in the axial acceleration phase of the plasma focus discharges, have been performed. Correlation of plasma pinch intensity and current sheath symmetry discussed and velocity of current sheath compared with the simulation result.

2. Theoretical background

Assuming the snow plough model velocity of current sheath in the axial phase is given by $V = \frac{I_0}{2\pi}(\frac{\mu_0 \ln(b/a)}{\rho(b^2 \quad a^2)})^{\frac{1}{2}}(cm/\mu s)$, where I_0, μ_0, ρ, a, b are peak of discharge current, permeability of free space, the density of the gas, inner radius of the central electrode, and outer radius respectively [3]. We solved the axial phase current sheath equation coupled with equivalent plasma focus circuit equation based on a 4.5 kJ plasma focus system powered by a single $V_0 = 16kV, C_0 = 36\mu f, and L_0 = 115nH$ capacitor in which $V_0, C_0, and L_0$ are capacitor voltage, capacitance, and circuit inductance respectively. Formation of plasma pinch at the first peak of current signal and also variation of current sheath velocity in the axial phase simulated as it presented in fig.1.

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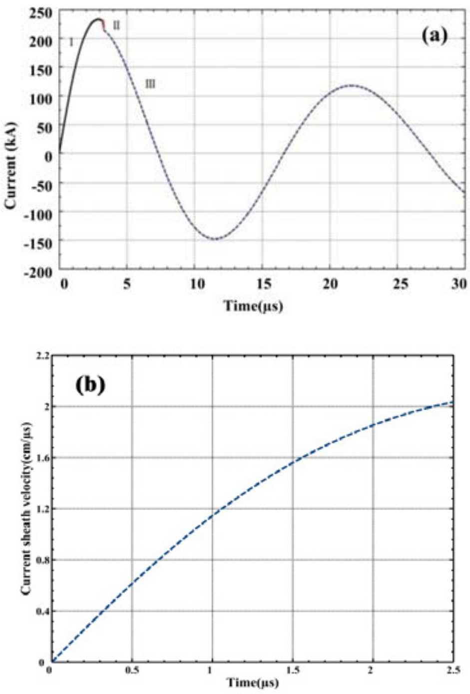

Fig.1 (a) - Computed discharge current before and after plasma pinch formation. I) current at the axial phase, II) current disruption and plasma pinch formation, III) current at the expanded plasma column phase, (b) – simulated velocity of current sheath in the axial phase until t=2.5µs

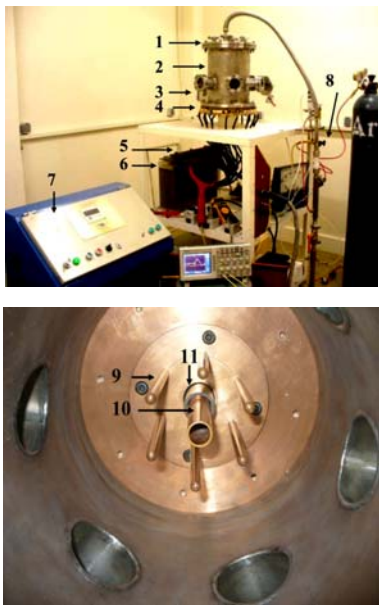

Fig.2 A view of APF device, 1- upper cover of chamber, 2- vacuum chamber, 3- six lateral windows, 4- rogowski coil, 5- rail gap switch, 6- capacitor, 7- control and command unit, 8-gas puffing system, 9-cathode bare, 10-anode bare, 11-insulator sleeve

The magnetic probe consists of a small coil that is oriented in azimuthal direction of the device so that the magnetic flux will pass through the coil axis. The output of the coil is taken by a pair of wire to the oscilloscope via an integrating circuit. The voltage entering the oscilloscope is given by the expression $V = nAB/RC$ where n is number of turns of probe cross section A, RC is integration time constant, and B is magnetic field being measured. As the current sheath sweeps past the probe, the coil will pick up a sudden increase of B_θ from 0 to $\mu_0 I / 2\pi r$ where I is current of plasma sheath and r is radial position of magnetic probe. As the current sheath moves past and away from the coil, the coil continues to be immersed in this value. If the value of I is rising as the current sheath sweeps past and continues rising, the output of the coil will first show a sharp rise.

3. Experimental setup

The experiments are performed in a Mather type plasma focus, which is powered by a 36µf capacitor bank, operating at 16 kV [7].

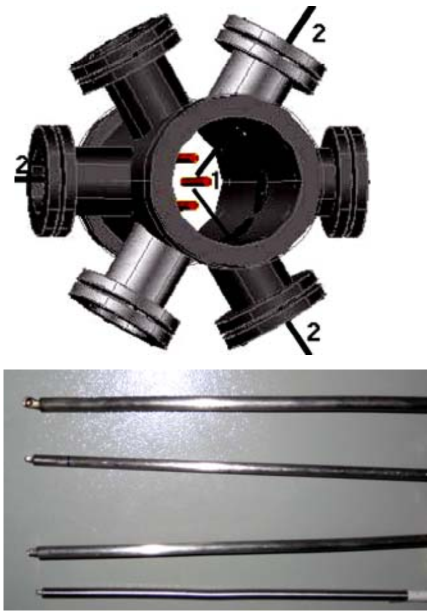

Fig.3 Setting positions and a picture of magnetic probes, (1)-cathode bars, (2)-magnetic probes

As shown in fig.2, the anode is a cylindrical hollow tube with a length of 14.8 cm, and a diameter of 2.78 cm. The cathode is in the form of a squirrel cage consisting six rods arranged concentrically around the anode with a diameter of 4.47 cm, and a length of 14.5 cm. The discharge chamber which serves also as the cathode is a stainless steel cylinder of 26.5 cm in internal diameter and 38 cm height.

As it shown in fig .3, the magnetic probe consisted of a 3-turn coil of 3 mm diameter enameled tungsten wire. The probe was jacketed into a stainless steel tube with a diameter of 7 mm, and a length of 30 cm. The probes were calibrated by using a four-turn Helmholtz coil of radius 4 cm and discharging a capacitor of 1 μf through it. Maximum voltage, coefficient of V/B, and RC of integrator part are 11.17 mV, 0.00725 T/V, and 0.2 μs respectively. The constructed magnetic probes inserted directly into the discharge chamber to measure the current flow in the plasma. Signals of magnetic probes at 8mm inside the outer electrode surface is recorded using a set of three radial probes spaced equally around the periphery of the outer electrode at the heights of z_1=4.3 cm and z_2=6.3cm from the bottom of the anode.

4. Experimental Results

In this device optimum pressure with Ar at the applied voltage of 11.5 kV determined 0.95 torr [7]. Typical discharge current signals obtained by a rogowski coil when Ar puffed into the vacuum chamber at the optimum pressure is shown in fig.4.

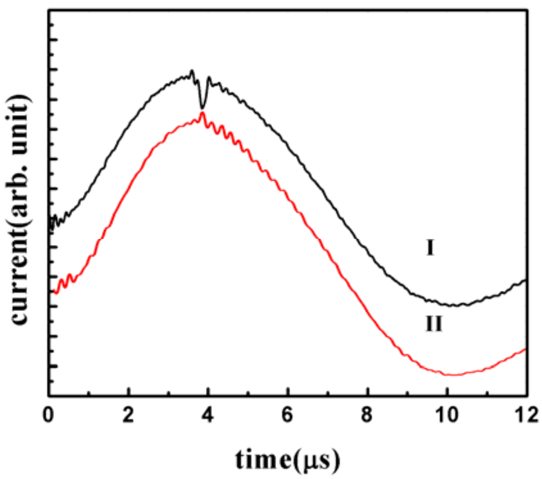

Fig.4 Typical current signals measured by a Rogowski coil with (I) - Ar(11.5kV, 0.95torr) with plasma pinch , (II) - Ar(11.5kV, 0.95torr) without plasma pinch

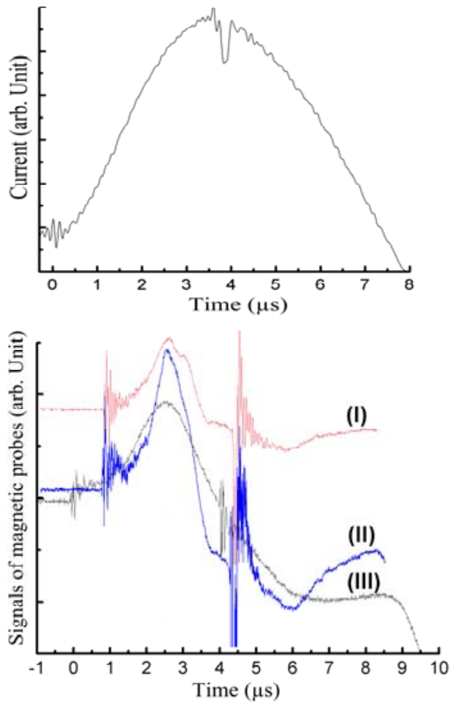

Fig.5 Recorded signals by three symmetric magnetic probes and discharge current signal with Ar (11.5kV, 0.95torr). The first peak of signals recorded by magnetic probes occurred at the same time.

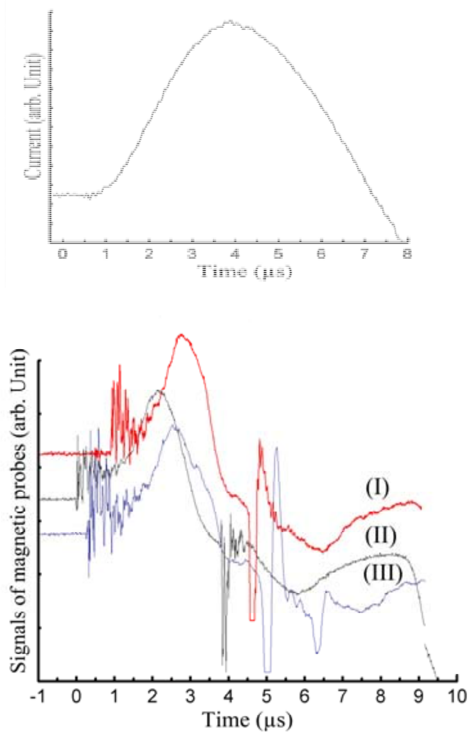

Fig.6 Recorded signals by three symmetric magnetic probes and discharge current signal with Ar (11.5kV, 0.95torr). The first peak of magnetic signals registered at the different times.

During discharges at different pressures of argon, signals obtained by each probe together with discharge current signal recorded on the four channels oscilloscope simultaneously. Typical signals by three magnetic probes with argon are presented in figures 4 and 5. As we know, the pick of signals by the probes indicate the moment when the current sheet touches the probe [8]. In fig. 7 visible light emitted by plasma pinch column correlated to magnetic probes signals recorded in figures 5 and 6 are shown. Although some data of the experiments in the same conditions suffered some variations, but the results presented in figures 5 and 6 were reproducible clearly.

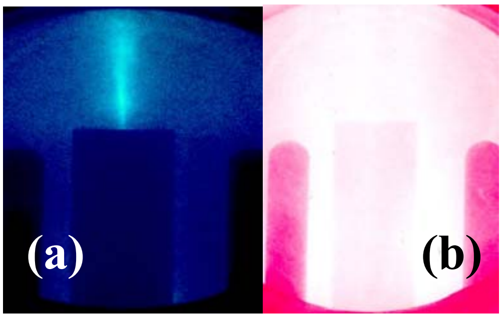

Fig.7 Visible light emitted by dense plasma pinch. a) Ar(11.5kV,0.95torr) correlated to magnetic probes signals recorded in fig.4 , b) Ar(11.5kV,0.95torr) correlated to magnetic probes signals recorded in fig.4

5. Discussion

According to figures 5 and 6, when discharge current resulted to a high intensity plasma pinch, the first peak of signals recorded by magnetic probes occurred at the same time obviously. On the other hand, when the first peak of magnetic signals registered at the different times, occurrence of plasma pinch disruption at the first peak of discharge current wasn't observed. High intensity light emitted by dense plasma column is in accordance with the data. In the same working conditions as it shown in figures 5, and 6, quality of plasma layer formation on the insulator surface can influence on the degree of current sheath symmetry and also plasma pinch intensity. Therefore as it shown in figures 6, and 4(II), asymmetric current signals result to a nearly simple RLC discharge current. The results show that there is a noticeable correlation between plasma pinch intensity and current sheath symmetry. The probes were placed 43mm above the cathode collector plate and the arrival time of current sheath up to the probe location characterized by the first peak of magnetic probe signals. Therefore velocity of current sheath at this point obtained $1.72\,cm/\mu s$. It is comparable to the theoretical value of current discharge velocity that was equal to $2.02\,cm/\mu s$. Correlation of hard X-ray signals emitted by the device with the magnetic probe signals will be investigated.

6. References

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