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Experimental Study of the Effect of Circuit Inductance on Pinch-Time in Plasma Focus MTPF2.5 KJ

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ABSTRACT

This paper investigates the effect of circuit inductance on the pinch-time of plasma focus. The dense plasma focus is a plasma discharge powered by a capacitor bank. The Mather type Dense Plasma Focus is constructed in cylindrical geometry and is made up of coaxial anodes and cathodes with varying radiuses. An insulator sleeve separates the electrodes, and the cathode rode forms circles around the anode tube. Different parameters, such as geometry and structure of the anode bar and decreasing inductance, are involved in optimizing plasma focus. One way to increase the gain and optimization of pulsed plasma systems is to reduce the circuit's inductance. For this purpose, we investigate the effect of different values of total circuit inductance on pinch formation time. Experimental and simulation results are compared. The proposed system shows a decent functionality that if the inductance reduces, the system's efficiency will increase.

***Keywords*: Inductance, Plasma Focus, Circuit.**

I. Introductions

In recent years, there has been an increasing interest in small plasma focus (PF) devices. PF produces a pulse plasma discharge. A large amount of current is applied to a dilute gas inside the tube. This current initially ionizes the gas into a plasma. One of the most important issues to increase the focal plasma gain is to reduce the inductance of the whole circuit. Thus this issue is very effective in designing and manufacturing small focal plasma with low energies. The dependence of hard x-rays on the design parameters of a PF, especially the geometry of the electrodes, has been studied by M. Barbaglia, [1]. There is an optimum value for L_o below corresponding to each plasma focus capacitance of Co, which performance in terms of Ipinch and Yn does not improve. These experiments confirm the pinch current limitation effect in a plasma focus by S .Lee [2]. The variation of the inductance jump associated with the radial collapse stage is used to estimate the effective pinch length by Barbaglia M. [3]. asymmetry in the axial discharge current increased the plasma Impedance and consequently reduced the soft x-ray emission in this simulation done by Morteza

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Habibi [4]. The physics of the pinch regimes could be explained by using the two versions of Lee's computational model. The applicability and predictability of Lee's computational model, which predicted each of the scenarios and clarified, have been tested by D. Piriaei [5]. A new 1.5 kJ Mather type dense plasma focus (DPF) was designed and constructed at Sahand University of Technology. Plasma behavior in the plasma focus device was studied experimentally. Temporal changes in plasma focus discharge current confirmed pinch occurrence at a specific pressure and voltage of argon as filling gas by E. Ghareshabani [6]. But so far, not enough experimental research has been done to investigate the effect of total circuit inductance on pinch time. The experimental study of the inductance effect during pinch formation is an important issue that has been less discussed. In this paper, the simulation and experimental results of the inductance effect of the total plasma circuit at the pinch formation are studied [7,8].

II. Research Theories

A typical DPF consists of a central anode rod separated from a cathode plate with an insulator sleeve and has a static gas fill. A high voltage is applied to break down the gas across the insulator, and the magnetic pressure associated with the current pushes the gas/plasma down the anode. DPFs are generally designed to reach peak current when the plasma sheath comes the end of the anode, which is the beginning of the pinch-formation stage. While the increased inductance associated with the implosion can cause the current to decrease, the current remains roughly constant during this stage. When a capacitor bank voltage is applied to the electrodes, an electric field will be generated in the space between the electrodes. Due to this field, the electric discharge of gases is formed inside the chamber and on the insulation surface. Once the layer flow is formed, it begins to move and pressurizes the enclosed plasma as it progresses. The layer's movement continues until the plasma collects at one point on the surface of the anode and is firmly pressed, called a pinch. Plasma focus creates hot and dense plasma, which is the source of high-power rays. According to the study, the factors of voltage, inductance, type, and pressure of gas used in the main chamber of the device are influential at the time of pinch

III. Experimental

The mather plasma focus did the experiments. The schematic of this device is depicted in figure1. This device was constructed in the plasma and fusion research school. The DPF is 2.5-kJ Mather type. The capacitors used in the focal plasma device have the following specifications. The capacitance is 2.8μf, inductance is 20nH, and the maximum voltage is 60kV. The following figure 2 shows a schematic of the arrangement of capacitors.

IV. Simulation

First, an electric discharge circuit and the effect of circuit inductance on the physical plasma pinch process are simulated in MATLAB SIMULINK. The equivalent circuit of the system is L=L0+LP(t) which is shown in figure 3. In this equation, Lp is plasma inductance that, is a variable that has been obtained experimentally, and L0 is circuit inductance, including capacitor inductance, connection cable, and constant spark gap switch. Since the capacitor's inductance is consistent, to reduce L0, we must reduce the cable length and the number of connections in the transmission circuit as much as possible. In this way, it is better to design and build the transmission system in an integrated manner. This reduces L0 to such an extent that it reduces the pinch formation time. In this circuit, C0=16.8μF. The spark gap is an ideal switch. L_0 and r_0 are initial resistance and inductance, respectively. L_{leak} and R_{leak} are leakage inductance and resistance. The discharge voltage is

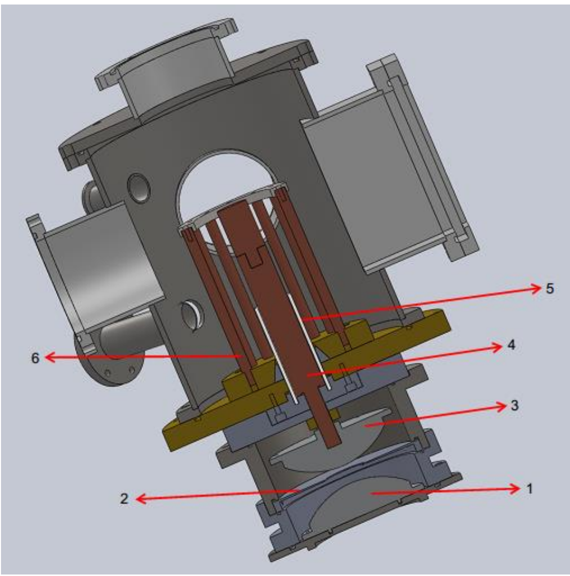

Fig. 1. Schematic of plasma focus:1.spark Gap, 2.Trigger, 3.Upper half Spark Gap, 4.anode, 5-insulator, 6-cathode.

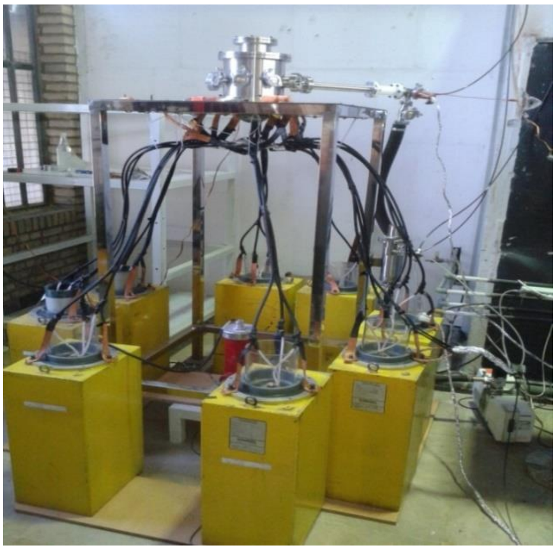

Fig. 2. Plasma focus 2.5Kj and its capacitors.

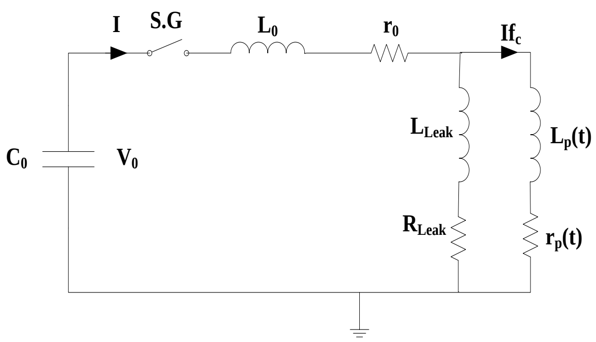

Fig. 3. The equivalent circuit of the system.

14kV. Total inductance and resistance are 105nH formation. and 17.1mΩ, respectively. To optimize the circuit, we must reduce the cable length and the number of connections in the transmission circuit as much as possible to reduce the inductance. For this purpose, it is better to design and build the transmission system in an integrated manner. We put the values obtained through laboratory results in the defined equivalent circuit and simulate it in MATLAB SIMULINK software. The current and current derived signal diagram is shown in Figure 4,5, measured by the Rogowski coil. The maximum discharge current is equal to 151 kA. The period time is T=8.3µs. In-circuit simulations, pinch formation times were evaluated for different inductances. Three different inductances are considered. The inductances are from a minimum of 90 nH for an integrated system and a maximum of 130 nH for a long cable system.

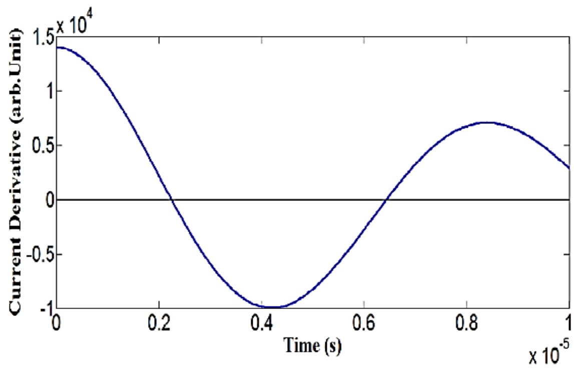

Fig. 4. Measuring Current Derivative Signal with Rogowski coil.

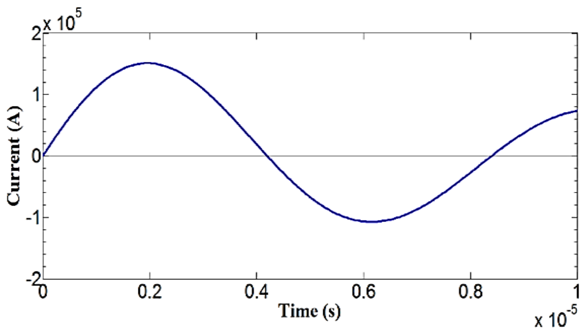

Fig. 5. Measuring Current Signal with Rogowski coil.

V. Results and Discussion

We examine the inductance process of a circuit in the process of plasma physics.

In-circuit simulations for different inductances, the pinch formation times were evaluated. Three different inductances were visible in terms of the practical operation of this device. The inductance is from a minimum of 90 nH for an integrated system and a maximum of 130 nH for a system with a longer cable. As shown in figure 6, in systems with lower inductance, the current rises up to peak faster, and the pinch forms faster near the peak current. for instance, pinch time is $2.32e^{-6}$ for L0=90nH and is $2.88e^{-6}$ for L0=110nH and $3.44e^{-6}$ for L0=130nH. Accordingly, fewer inductance results in a stronger pinch, which indicates an improvement in system performance. Using the results of experimental studies and simulations of others, we considered the plasma inductance values to be 0.22nH and 0.56nH. [7,8,9]. Reducing the number of capacitors reduces the connections and length of the cables, followed by a decrease in the overall inductance of the circuit. So one issue to reduce the circuit's inductance is to remove the capacitor bank and use a capacitor with more capacity. So one issue to reduce the circuit's inductance is to remove the capacitor bank and use a capacitor with more capacity. For this purpose, the capacitor, the spark gap switch, and the main chamber are fully integrated, and the current transfer circuit from the capacitor to the main chamber does not have a cable.

Increasing L_P at the time of the pinch formation causes a sudden decrease in the discharge current, and deeper fractures in the derivative current are shown in figure7. So it produces a more substantial pinch. If the plasma inductance increases, the pinch's magnetic field pressure rises. Experimentally, the plasma focus was improved by removing the cable, reducing the electrical connections, and changing the capacitor bank to one. As a result, the circuit's inductance was decreased from 100 nH to 27 nH. The improved device performance is shown in figure 8.

Measurement with the Rogowsky prob shows that the discharge period is 8.3 µs, and the pinch formation time is 2.7 µs is formed at approximately 0.63 microseconds after the maximum current. Comparing it with a similar device with more connections and higher inductance proves that the pinch happens faster than the other plasma focus.

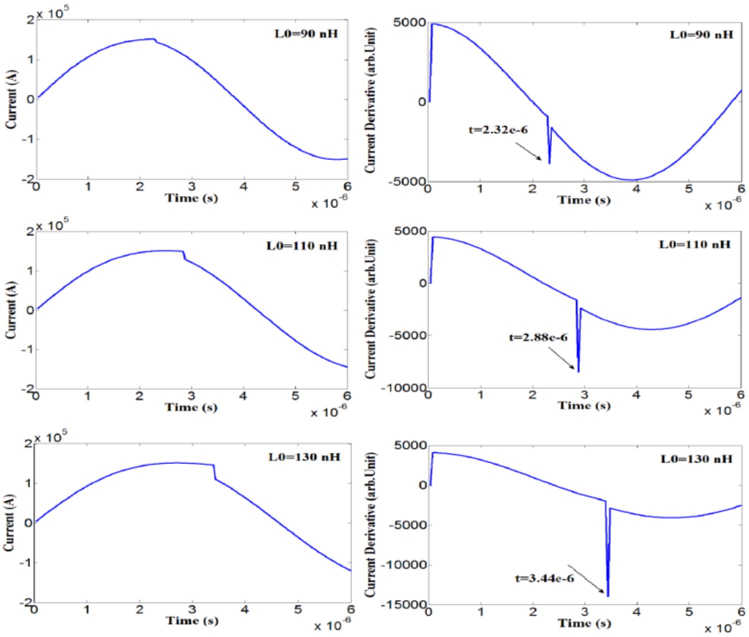

Fig. 6. The discharge current and current derivative waveform.

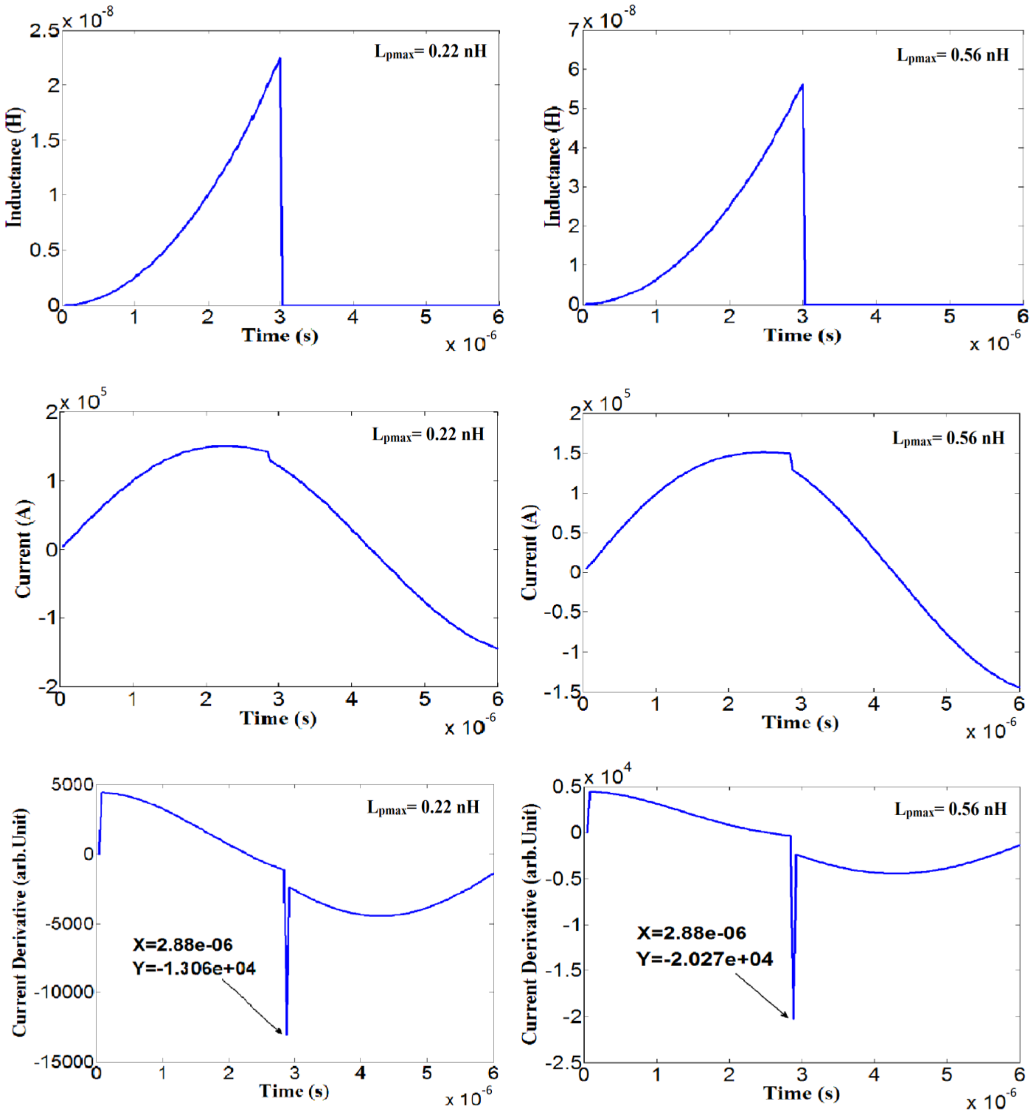

Fig. 7. The discharge current and current derive for Lp=0.22nH and Lp=0.56nH and L0=110nH.

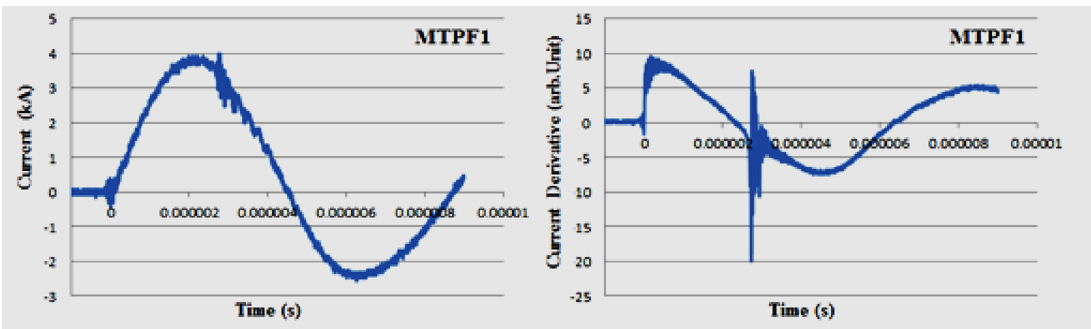

Fig. 8. The current and current derive in discharge voltage 14kV (by Rogowski coil).

VI. Conclusions

In this paper, the complete set of experiments accounts for a total of 150 discharges, which were processed to glean information regarding the correlation between the characteristic of each event. MATLAB SIMULINK has studied the effect of inductance on pinch formation time. Different inductance have been simulated using this model. Studying the calculated current waveforms and the inductance curves proved that the pinch time was the highest for the highest inductance. We conclude that by reducing the inductance of the transmission system and losses, the pinch is formed in a faster time at a point close to the maximum current, which indicates an improvement in device performance. When inductance is 90Nh, pinch time is $2.32*10^{-6}$. The pinch time is $2.88*10^{-6}$ when the inductance is 110Nh and $3.44*10^{-6}$ for 130Nh. Also, Increasing L_P at the time of the pinch formation causes a sudden decrease in the discharge current and deeper fractures in the derivative current. So it produces a stronger pinch. The performed experiments showed consistency with the simulation results, and it can be deduced that the modified model behaves appropriately.

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