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Design and construction of a 20- kJ filippov-type plasma focus

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Abstract: UIPFF1 is a new Filippov-type plasma focus facility, constructed and built in Esfahan University. This paper reports on the design of the UIPFF1. The main stages of the construction, design and the preliminary X-ray detection tests on the UIPFF1 are mentioned concisely. Measurement results show that in a typical discharge experiment, the discharge current =181 kA, period of current signal = 7.9 µs, the total inductance of the device =132 nH and electrical resistance of the circuit = 77 mΩ. The calibration factor is measured as 121 kA/V by averaging from data obtained with a set of 5 experiments. Temporal changes in plasma focus discharge current, confirmed occurrence pinch at a specific pressure of argon, neon and nitrogen gases.

Keywords: Filippov- Type Plasma Focus, Plasma Pinch, Fusion, Discharge Current

1. Introduction

The plasma focus was discovered independently by Mather (USA) [1] and Filippov (USSR) [2] in 1965, although the devices investigated by these two pioneers had significantly different geometries.

Many plasma focus devices have since been built by other investigators, but all broadly conform to one of the two original geometries, and can be classified as being either of the Mather or Filippov type [3,4]. These devices have been built with stored bank energy ranging from 1 kJ to 1 MJ with consequent variation in physical sizes of the device [5,6,7,8,9]. The plasma focus is well known as both a source of fusion neutrons and a source of x-rays [10,11,12,13]. Since 1965, a large range of investigations has been performed on both types. The obvious differences between the two configurations lie in the electrode dimensions and the aspect ratio (diameter/length) of the inner electrode [4,14]. The Filippov-type device has a large aspect ratio, usually greater than 5 with an inner electrode diameter of 50 ~ 200 cm [15]. The Mather-type device has a small aspect ratio of typically below 0.25, with an inner electrode diameter of 2 ~ 22 cm [16]. The electrodes are usually made of copper or stainless steel [17]. The anode may be a solid cylinder or a cylindrical tube in order to avoid excessive hard x-ray emission due to electron bombardment. The cathode is in the form of a squirrel cage consisting 6 ~ 24 rods arranged eccentrically around anode. The insulator may be made of Pyrex, glass, alumina or ceramic [17,18]. The Filippov machine was developed as a modification of the straight Z-pinch to hide the insulator zone from the pinch region and prevent restrikes caused by radiation from the hot plasma. The operating principle of The Filippov machine is simple: the energy stored electrically in a capacitor bank is rapidly transferred to the electrodes by means of a fast switch. In its geometry, the current discharge initiates along the surface of cylindrical insulator in a coaxial electrode region. By the Lorentz force action the conducting plasma sheath accelerates and the sheath reaches the axis of symmetry of the electrodes [17]. To optimize the machine; one chooses the dimensions of the electrodes (length and diameters) and the operational pressure in relationship to the characteristics of the energy source, so that the current is maximum when the sheath reaches the axis. At this instant a filament of hot and dense plasma (pinch) is formed in front of the inner electrode (usually the anode). After a very short time due to instabilities the plasma column breaks up and decays [19]. Details of the time scale and other plasma parameters will be given later. Recently, a new model called the ML model is developed; taking into account the Lee model, and is presented for Filippov- type plasma focus [20]. To design and build a Filippov-type plasma focus device by using the ML model is aim of this paper. Plasma focus device of UIPFF1 was designed and built in the energy range of 20 kJ. Design of facility components based on ML and a number of empirical relationships have been confirmed in various plasma focus facilities [17,20,21]. Usually it is done an initial design in manufacturing a plasma focus device. After making an initial testing machine, the specific objectives designed to achieve the desired output type are determined to be correct.

2. Methodology and Interpretation in Design and Construction of the Device

To describe the plasma behavior in the Filippov type PF devices, the theoretical ML model has recently been presented [20]. According to this model, the formation of the CS leads to a sudden change of the azimuthal magnetic field and thereafter the creation of a shock front, SF. During its motion, the SF ionizes the gas and so a plasma layer form. This plasma layer (or the so-called slug) [22] is confined between the magnetic piston and the shock front. Using MATLAB 7.12.0 application package and Euler's method, the model equations could be solved numerically and time dependent solutions for electrical and geometrical characteristics in UIPFF1 plasma focus were obtained. The simulations were performed in argon gas. As the initial values, it was assumed that at t_0 (i.e. Time Zero), the axial magnetic piston, the axial SF and the total current are close to zero and the radial magnetic pistons and the radial shock fronts are close to the assumed anode radius (i.e. Anode radius a = 7.5 cm).

UIPFF1 is a 20 kJ Filippov-type machine whose various parts are shown in Figure (1). The discharge chamber which serves also as the cathode is a stainless steel cylinder of 40 cm diameter and 15 cm height. Anode, which is a copper disc of 15 cm diameter, is placed on a polyethylene cylinder of 12 cm internal diameter and 11 cm height. Anode is connected to the spark gap via 24 copper cables. As the working gas, we use deuterium, noble gases and their mixtures with the pressure range of 0.1– 0.9 Torr in UIPFF1 machine.

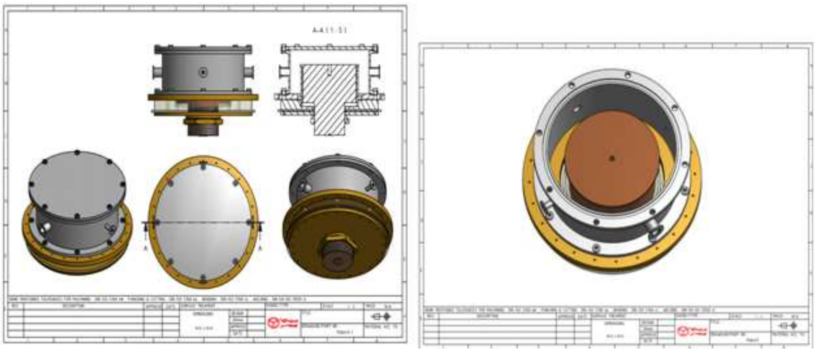

Figure 1. *The technical scheme of electrodes*

The energy required for production of discharge and focusing is provided by a 48 μF capacitor bank. The maximum charging voltage is 28.9 kV and the maximum stored energy is 20 kJ. In the present experiment, to study the current sheath dynamics, we used argon as working gas in UIPFF1 focus in the pressure range of 0.1–1.0 Torr. The discharge current was monitored by means of a Rogowski coil (Fig. 2). The results of the design and operating parameters that test on device are summarized in Table1.

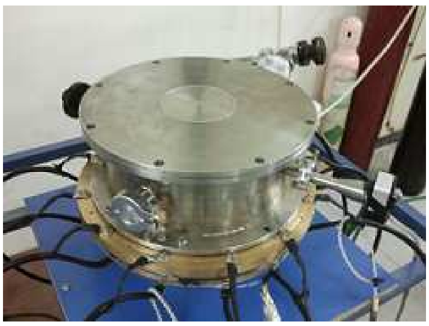

Figure 2. *UIPFF1 Filippov type plasma focus set up*

Table 1. *Characteristics of UIPFF1 device*

Element	Average Value
energy of capacitor bank	21.6 kJ
Capacity of capacitor bank	48 μF
Anode radius	7.5 Cm
Working voltage of the capacitor bank	28.9 kV
Effective length of the insulator	8 Cm
Effective length of the anode	8 Cm
Inductance	132 nH
Radius of the chamber	20 Cm
Anode length	20 Cm
Height of chamber	13 Cm

3. Preliminary Results of the UIPFF1

The first experiment carried out on the machine is vacuum test. This test does ensure the vacuum stability. In other words, this test ensures that there is no leakage from the chamber. If there is leakage from chamber, ambient air enters the chamber and Impurities in the gas increase. Because the surrounding air pressure of chamber is more than gas pressure inside the chamber. After ensuring non leakage in the chamber, air pressure inside the chamber must be lowered to 2×10^{-3} mbar using a Rotary pump. Then, by charging the capacitor up to required energy, an electrical discharge occurs. After the first electrical discharge (shot); due to bombarding anode surface with high-energy electrons, anode surface atoms are separated and enter the chamber. The gas pressure inside the chamber; due to anode material and pollutions of the chamber inner surface, increases in about 1 mbar [21,23,24]. Performing next electrical discharges, the pressure increase will be less. After each electrical discharge, the numbers of separated surface atoms is decreasing and any electrical discharge requires decreasing gas pressure to 2×10^{-3} mbar by the rotary pump. This makes the chamber obtain a lower level of pollution in per shot compared to the previous shot. The capacitor bank of 48 μF is charged up to 28.1 kV with a Charging device. The UIPFF1 is filled with the desired gas at the operational range 0.1-1 torr. The distance between the spark gap's electrodes could be regulated in order to start the discharge in the desired voltage. A Rogowski coil has been used for measurement of the discharge current experimentally. Equal electrical circuit of the device is RLC circuit; therefore the discharge current has a sinusoidal shape whose amplitude decreases exponentially with time. The current signal contains a set of data from physical processes in the device, as well as discharge current characteristic CS. Measurement results show that in a typical discharge experiment, the discharge current = 181 kA, period of current signal=7.9 μs, the total inductance of the device =132 nH and electrical resistance of the circuit = 77 mΩ. The calibration factor is measured as 121 kA/V by averaging from data obtained with a set of 5 experiments. Temporal changes in plasma focus discharge current, Confirmed that the occurrence pinch at a specific pressure of argon, neon and nitrogen gases. UIPFF1 has been tested between 15-25 kV and wide range of pressure for various gases. Experiments at various pressures and voltages, has also confirmed reproducibility and stability of the plasma focus device. Figure (3) shows the output signal of the Rogowski coil on the oscilloscope taken by current derivative at around the optimum conditions of the UIPFF1 with Argon operational gas.

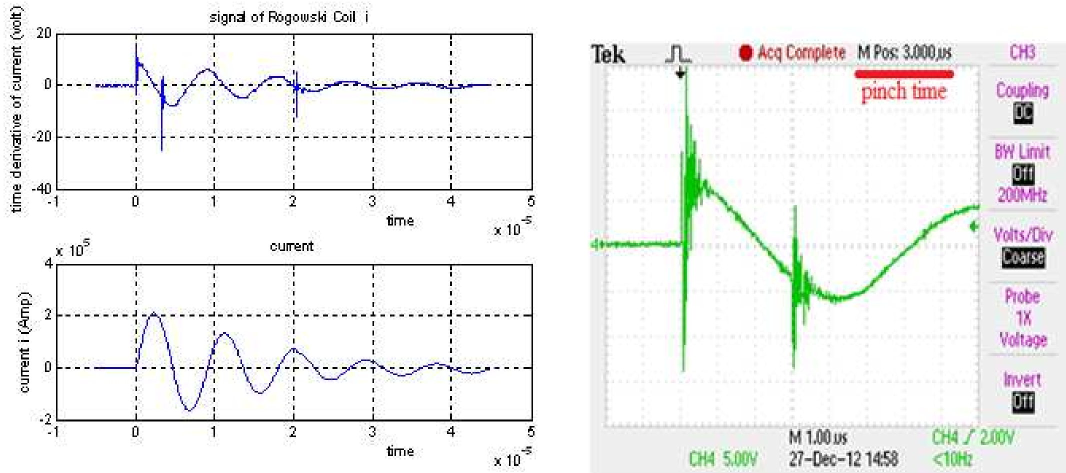

Figure 3. *The output waveform of the Rogowski coil and integration of the Rogowski coil output wave with trapezoidal integration method*

The values of I_{pinch} to the variation of pressure can be seen in figure 4. However, the theoretical estimation of these values is obtained from a simulation of models. In this study the values were determined for argon at a specific discharge voltage; A comparison between the experimental data and the predicted data is done, so that the differences became as low as possible. The difference between the experimental data and predicted data is due to uncertain f_m and f_i. Values and f_m and f_i considered in theoretical estimating are unreliable. Values of f_m and f_i are changed in each experiment. In addition, different mass of CS layers in each three phases (i.e. outward, inward and axial phases) leads to the difference between the experimental data and predicted data. Also, the comparison between the experimental data and the predicted data confirms that at a certain voltage, the device has an operating pressure range. Outside this domain, pinch current is reduced and device loses its effectiveness.

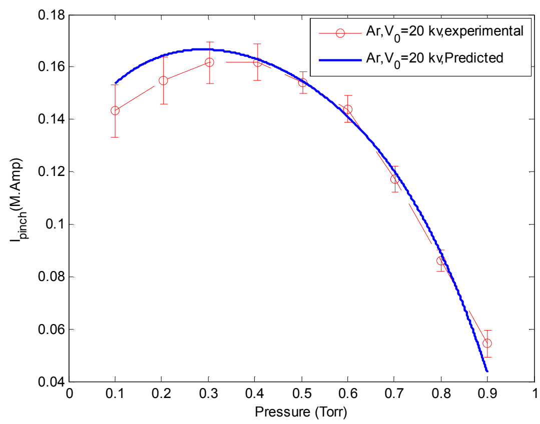

Figure 4. *Predicted and experimental current as a function of pressure*

4. X-ray Emissions from the UIPFF1

Generation of pulsed hard and soft X-rays in the UIPFF1 is investigated. By injection of Argon gas in UIPFF1 and using plastic scintillation detector BC-400 and a semiconductor SXR detector, a relative measure of the HXR yield and a rough estimation of soft X-ray flux can be done respectively. Figure (5) shows the output signals of the X-ray detectors on the oscilloscope taken by current derivative around the optimum conditions of the UIPFF1 with Argon operational gas. The intensity of hard X-ray emission is due to the bombardment of anode tip by the electrons. Hard X-ray emission started a little after starting the pinch phenomena and reached its maximum later. The device has been used for contact radiography.

5. Conclusion

Temporal changes in plasma focus discharge current, Confirmed that the occurrence pinch at a specific pressure of argon, neon and nitrogen gases. UIPFF1 has been tested between 15-25 kV and wide range of pressure for various gases (0.1- 0.9 mbar). Experiments at various pressures and voltages, also have confirmed reproducibility and stability of the plasma focus device. Experimental results on device demonstrate the feasibility of this PF device as a source for X-ray radiography.

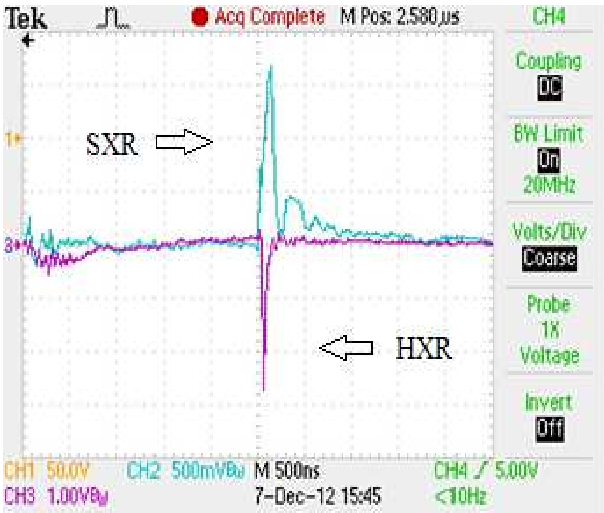

Figure 5. *The output waveform of the plastic scintillation detector BC-400 and semiconductor SXR detector*

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