

Development of TPF-1 plasma focus for education

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Abstract. The plasma focus is a device that uses high voltage and electromagnetic force to induce plasma generation and acceleration, in order to cause nuclear reactions. Radiation of various types (X-ray, gamma ray, electrons, ions, neutrons) can be generated using this method during the pinch phase, thus making the plasma focus able to serve as a radiation source. Material testing, modification, and identification are among the current applications of the plasma focus. Other than being an alternative option to isotopic sources, the plasma focus, which requires multidisciplinary team of personnel to design, operate, and troubleshoot, can also serve as an excellent learning device for physics and engineering students in the fields including, but not limited to, plasma physics, nuclear physics, electronics engineering, and mechanical engineering. This work describes the parameters and current status of Thai Plasma Focus 1 (TPF-1) and the characteristics of the plasma being produced in the machine using a Rogowski coil.

1. Introduction

The dense plasma focus or simply the plasma focus is a device that can induce nuclear reactions using electromagnetic force generated between electrodes. The dense plasma focus was developed independently by J. W. Mather (US) and N. V. Filippov (USSR) during the early 1960s. The two designs are different in terms of shape (aspect ratio) but are similar in mechanism. The plasma produced in this type of machines has been shown to be hot (~ 1 keV) and dense ($\sim 10^{19}$ cm⁻³) with short lifetime (~ 50 - 100 ns). Thai Plasma Focus 1 (TPF-1) is a domestically designed and developed device mainly for education. TPF-1 is a Mather-type [1] plasma focus based on UNU/ICTP design [2] that can be further developed into a radiation source and material testing platform. The type of radiation can theoretically be determined by the starting gas. For example, deuterium can be used for neutron and gamma generation, xenon for extreme ultraviolet (EUV), and argon for X-ray. Due to its relatively small size and non-radioisotopic nature, the plasma focus can be a useful alternative for some applications of linear accelerators, radioisotopes, and fission research reactors. It also serves as a small platform to study plasma physics and nuclear fusion reactions in place of large facilities such as tokamaks, stellarators, or other inertial confinement fusion devices. Applications such as lithography [3] and material testing [4] are also possible.

For the design and prediction of the TPF-1's characteristics, Lee model [5] has been used. In this work, the focus has been on the optimization investigation of the plasma focus design, in order to achieve pinch condition.

2. Materials and Methods

A common plasma focus consists of several main components: 1. Vacuum chamber, 2. Power supply, 3. Capacitor, 4. Trigger system, 5. Electrodes, 6. Feed gas, 7. Vacuum pump, and 8. Diagnostics. The plasma focus is initiated by first charging the capacitor bank which then is discharged using the trigger system.

The components of TPF-1 is shown in Fig. 1.

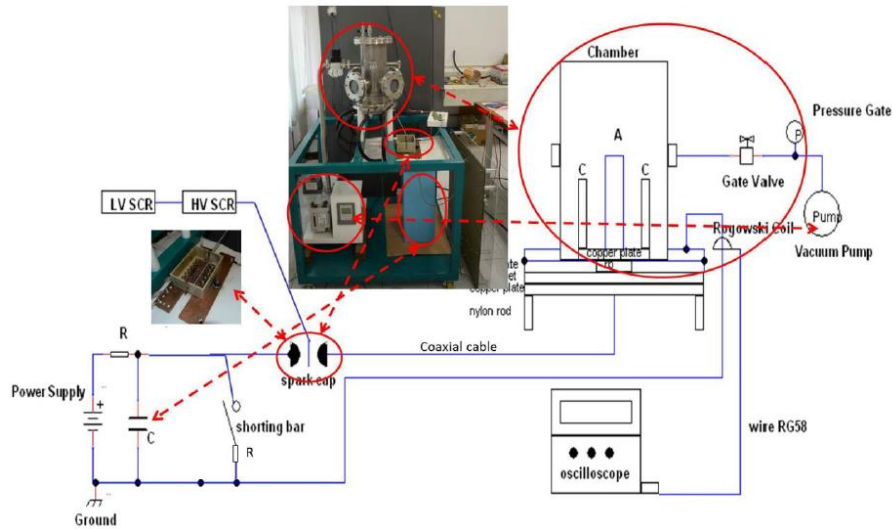


Figure 1. Diagram showing TPF-1 components. In the chamber part, A and C denote anode and cathode, respectively.

For TPF-1 system, capacitance (General Atomics Electronics System model 33464) of $30 \mu\text{F} \pm 10\%$ is used. The high-voltage power supply (TDK-Lambda model 402L) provides adjustable output up to the maximum of 20 kV. Input voltage is 380 V-AC (three-phase power). The charging and discharging are done using a pneumatic switch connected to a spark gap made of brass and copper. The trigger system is shown in Fig. 2. This switch increases the distance between the operator and the high voltage portion of the plasma focus, which improves operational safety compared to manual discharging using a grounding rod. The feed gas is air for this testing stage.

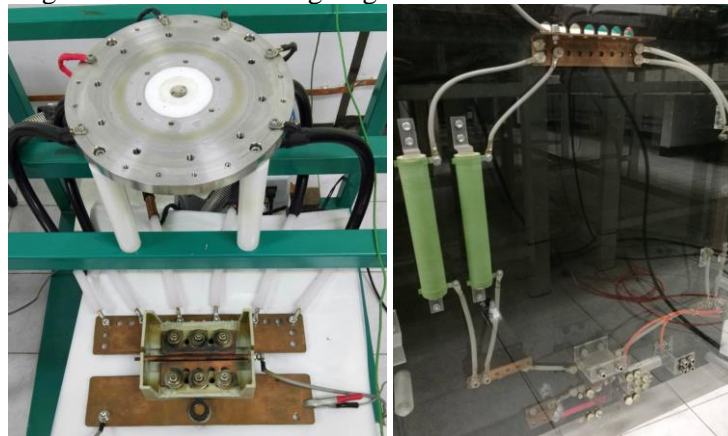


Figure 2. The trigger system. The spark gap is shown here with the chamber base, sans chamber (left) and the discharging panel (right). The top part of the panel is connected to the spark gap, whereas the bottom part is connected to the power supply.

The vacuum chamber is made of stainless steel, SS304. Inside the chamber, the electrodes made of copper are arranged coaxially. The anode rod of TPF-1 has the diameter of 19.5 mm and the length of 126 mm. Each cathode's diameter is 9.5 mm and its length is 125 mm. The anode-cathode distance is 31.75 mm. The anode is connected to the circular base which is made of brass. This anode base connects to the electrical wires from the spark gap and also provides mechanical stability by being attached to the main stainless steel base. A nylon ring with high electrical resistance is also used to insulate the anode base from other parts of the plasma focus to prevent accidental discharges. The cathode rods are connected to the cathode base, made of brass. The orientation of the electrodes is shown in Fig. 3.

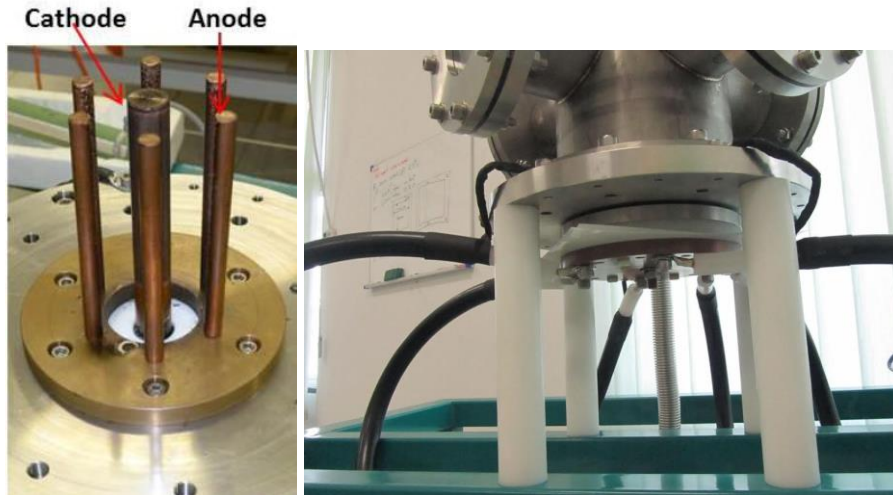


Figure 3. The arrangement of anode and cathode electrodes (left) and the view from the bottom of the chamber (right). Six poles are currently used for the current cathode configuration.

The conceptual operation of the plasma focus is shown in Fig. 4. The plasma sheet is produced from a high electric potential difference between the anode (central axis) and cathode (outer fences) once the discharge is conducted through the spark gap. The high-power discharges are done quickly and lead to heating and ionization. The plasma focus devices use metal walls to minimize the influence of material contamination from ceramic walls such as those in Z-pinch devices and increase radiation production capability. Another important component of the plasma focus is the insulator sleeve (pyrex glass in TPF-1), which partly controls the initial shape of the sheet, covers the base of the anode rod. The plasma sheet travels upward according to the Lorentz force and compression (also known as pinch or focus) at the top leads to plasma interactions that can lead to radiation production. The operation creates pinches in pulse mode.

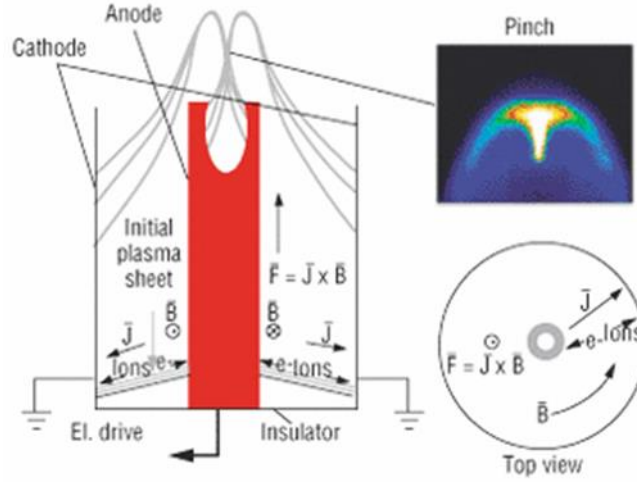


Figure 4. Cross sectional view of the plasma focus showing the directions of the electric current J , magnetic field B , and Lorentz force F . The pinch phase occurs at the top of the anode. [source: <http://www.plasmafocus.net>]

3. Results and Discussions

The experiments were set up with the high voltage of 9 kV and pressure of 0.5 mbar. The signals from the Rogowski coil of plasma discharge #0003 - #0006 are shown in Fig. 5(a). The signals can be fitted to the function: $V = Ae^{-bt} \cos(\omega t)$, yielding the fit parameters of $b = 6.35 \times 10^4$ and $\omega = 3.86 \times 10^5$. The average time period calculated from the half-cycle times T1, T2, T3 and T4 from four plasma discharges is 8.1250 μ s.

To characterize the system's electrical property, the inductance (L) of the system is calculated using the relation:

$$\frac{2\pi}{T} = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \quad (1)$$

where T is the time period ($2 \times 8.1250 \mu$ s), C is the capacitance (30 μ F). The obtained inductance is 229.5 nH and resistance 29.2 m Ω .

The integrated Rogowski coil signal is shown in red line in Fig. 5(b), which unfortunately, suggests that the pinch did not occur and that improvements are needed to be made.

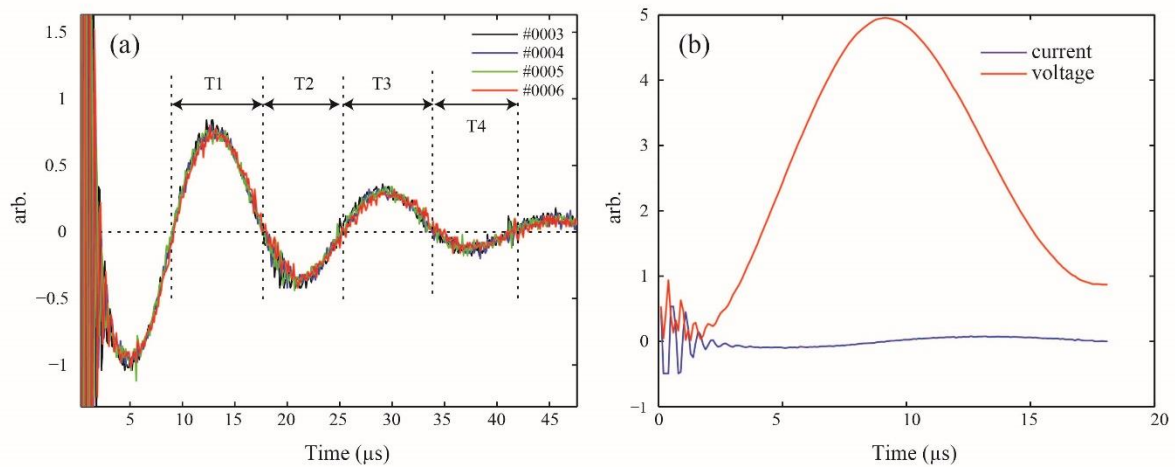


Figure 5. (a) The voltage measured by the Rogowski coil for three discharges. (b) The voltage and the current obtained from the time integration of the Rogowski voltage.

4. Conclusions

TPF-1 is the first dense plasma focus devices constructed in Thailand. Its aim is primarily for education and training of science and engineering students. The current status of TPF-1 is that its platform is being upgraded and will need some more fine-tuning (for example, using different gases, rebuilding the trigger system and electrodes) to achieve pinch conditions to be able to serve as a research and development platform primarily for plasma and material science.

Acknowledgments

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References

- [1] Mather, J W 1971 *Methods in Experimental Physics* **9** 187
- [2] Lee S, Tou T Y, Moo S P, Eissa M A, Gholap A V, Kwek K H, Mulyodrono S, Smith A J, Suryadi, Usada W and Zakaullah M 1988 *American Journal of Physics* **56.1** 62
- [3] Kalaiselvi S M P, Tan T L, Talebitaher A, Lee P, and Rawat R S 2013 *Physics letters A* **377.18** 1296
- [4] Bhuyan M, Mohanty S R, Rao C V S, Rayjada P A and Raole P M 2013 *Applied Surface Science* **264** 674
- [5] Lee S 2014 *Journal of Fusion Energy* **33.4** 319