Determination of the total inductance of TPF-I

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Abstract. Thailand Plasma Focus I (TPF-I) is a dense plasma focus device which was developed as a collaborative project among Thailand Institute of Nuclear Technology, Sirindhorn International Institute of Technology and Thammasat university. It aims to be a radiation source for academic research. This device has a power of 6 kJ. In this work, a Rogowski coils was used for measuring high speed current pulse to capture electric signal during operation TPF-I. By determining period of the discharge, it was found that the total inductance of TPF-I is about 216±12 nH, which is in agreement with Lee model.

1. Introduction
Dense Plasma Focus (DPF) is a device, which was invented in 1964 by J.W. Mather [1] and N.V. Filipov [2]. DPF can produce a short-lived plasma that is hot and dense by electromagnetic acceleration and compression enough to produce many products, for example, neutron [3], electron [4], proton [5], x-ray [6], etc. The electromagnetic compression of the plasma is called a pinch. The signals from DPF can be obtained by using Rogowski coil and we can compare with the signal from Lee model code [7-8]. The electrodes are enclosed in a vacuum chamber with a low pressure gas (the fuel for the reaction) filling the space between them.

Thailand Plasma Focus I (TPF-I) was developed as a collaborative project among Thailand Institute of Nuclear Technology, Sirindhorn International Institute of Technology and Thammasat university. It aims to be a radiation source for academic research. A diagram of this device’s assembly is shown in figure 1.

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2. Components of TPF-I and design parameters
The TPF-I consists of 7 subsystems; 1.) 20 kV dc power supply, 2.) a 30 µF 20kV capacitor bank, 3.) trigger system, 4.) chamber, 5.) measurement system, 6.) vacuum system and 7.) gas system. The design parameters are given in table 1.
Table 1. Parameters of TPF-I.

| Parameter | Description | Value       |
|-----------|-------------|-------------|
| a         | Anode radius | 0.95 cm.    |
| b         | Cathode radius | 1.85 cm.   |
| z₀        | Anode length  | 13.5 cm.    |
| c₀        | Capacitance  | 30 µF       |
| V₀        | Voltage      | Up to 20 kV |

3. Determining of total inductance of TPF-I

A discharge of DPF can be considered as a discharge of RLC circuit (figure 3). So, RLC discharge equations was used to find inductance form this device which shown in equation (1) and equation (2). So, we can determine the inductance the inductance from the period of discharge.

\[ f = \frac{1}{2\pi \sqrt{LC}} \]  
\[ L = \frac{T^2}{4\pi^2 C} \]  

The Lee model code [9] is a well-known code and can be used as a benchmark for simulating a current waveform of any conventional Mather-type plasma focus. Lee model code requires input parameters such as inductance, capacitance, electrode radii and length, and operating parameters; charging voltage and fill gas pressure. In this work, after we determine total inductance, we will use it to simulate in Lee model code and verify the finding.

3.1 Finding the total inductance from the period

To find the total inductance we use the Rogowski coil capture the discharge signal from one of the six cables connected to cathode inside the chamber. The experiment with two different operating voltages, at 12kV and 10kV, are applied. Half of the periods is determined from several points of these signals as indicated the figure 4. The values of half period are shown in table 2, also their corresponding the total inductance. The average inductance is found to be 216±12 nH.
Table 2. The computation of the inductance from signal period. In this table, T = period, f = frequency and L = inductance.

| No. (i) | 0.5T_1(µs) | T_1(µs) | L_1(nH) | No. (i) | 0.5T_1(µs) | T_1(µs) | L_1(nH) |
|---------|-------------|---------|---------|---------|-------------|---------|---------|
| 1       | 7.82        | 15.64   | 207     | 9       | 8.00        | 16.00   | 216     |
| 2       | 7.80        | 15.50   | 205     | 10      | 8.20        | 16.40   | 227     |
| 3       | 8.40        | 16.80   | 238     | 11      | 8.00        | 16.00   | 216     |
| 4       | 8.00        | 16.00   | 216     | 12      | 8.00        | 16.00   | 216     |
| 5       | 7.50        | 15.20   | 195     | 13      | 7.80        | 15.60   | 205     |
| 6       | 7.80        | 15.50   | 205     | 14      | 8.20        | 16.40   | 227     |
| 7       | 8.40        | 16.80   | 238     | 15      | 8.20        | 16.40   | 227     |
| 8       | 7.80        | 15.50   | 205     | 16      | 8.00        | 16.00   | 216     |

Average Inductance = 216
Standard deviation = 12
Range of Inductance = Average ± Standard deviation

3.2. Confirming inductance with Lee model code

The Lee model is used to predict the plasma behaviors in TPF-I. In this part, we use the obtained lower and upper limit of inductance, which are 204 nH and 228 nH respectively, from part 3.1 to simulate the current waveform and compare with experimental waveform. The other parameters used in simulation are given in table 2. The results of the experimental signal and the simulation signal are shown in figure 5. We simulate at two operating voltage; 10 kV and 12 kV. Note that the peak experimental signal is normalized to the peak of simulation signal using average inductance from the graph, it can be seen that the experimental signal are generally within the upper and lower limits of simulation signals. Some of discrepancies could be due to parameters, massf currf massfr and currfr, which are assumed to be similar to those in UNU/ICTP [10].
Table 2. Model parameters of Lee model code.

| Lee Model parameter | Description               | Value   |
|---------------------|---------------------------|---------|
| Lo                  | Inductance                | Vary    |
| Co                  | Capacitance               | 30 µF   |
| b                   | Cathode radius            | 1.85 cm.|
| a                   | Anode radius              | 0.95 cm.|
| ro mohm             | System resistance         | 9       |
| zo                  | Anode length              | 13.5 cm.|
| Vo                  | Voltage                   | 12 kV, 10 kV|
| Po                  | Pressure                  | 0.75 torr|
| MW                  | Mass weight of gas (Argon)| 40      |
| A                   | Atomic number of gas (Argon)| 18     |
| At-l mol-           | Operational parameter     | 1       |
| massf               | Axial mass swept-up factor| 0.0635  |
| currf               | Axial Current flow factor | 0.7     |
| massfr              | Radial mass swept-up factor| 0.16   |
| currfr              | Radial Current flow factor| 0.7     |

Figure 5. Comparison the result between simulation(dotted line) and experiment(solid line). (Voltage: Left 10 kV, Right 12 kV).

4. Conclusion
TPF-I or Thailand Plasma Focus I device has been completely constructed. We captured the discharge signal of the TPF-I using Rogowski coil. The signals were then used to determine the total inductance of TPF-I, which is found to be $216\pm12$ nH. This result of total inductance generally agrees with Lee model simulation. The disagreement could be because the parameterization of the massf, currf, massfr, and currfr variables has not been investigated. The study of these variables is planned for the future work.

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