# Study of Green Energy Production in INTI's 3 kJ Plasma Focus Device

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**Abstract:** Green and sustainable energy production has recently become a topic of great interest due to limited natural resources such as oil and gas, the increasing political turmoil and environmental concerns over temperature increase due to greenhouse effect. In INTI, a basic study of the creation of green energy or plasma energy was carried out. Plasma can be understood as the highest energy state of matter. When matter is heated to a high enough temperature, it is ionized into positive and negative charged particles with potential of energy production. To study such energy production, INTI's 3 kJ Mather- type plasma focus machine is charged to 13.5 kV and discharged into 3 Torr deuterium gas. This machine produces a current sheet that travels at extremely high speeds which will heat and compress (pinch) the plasma above the anode to produce extremely high temperature. This pinch undergoes instabilities and breaks up releasing intense electromagnetic radiation (including fusion energy). To make fusion energy more reliable and commercially viable, continuous fusion reaction is needed and plasma should be sustained over a long period of time. The leading candidate for a fusion reactor is a different plasma machine call a tokamak, but the plasma focus is emerging as a more compact contender.

**Keywords:** Green Energy, Plasma, Deuterium Gas, Fusion Energy, Neutron Yield.

## 1. Introduction

Green and sustainable energy production has recently become a topic of great interest due to limited natural resources such as oil, gas, and coal. Increasing political turmoil such as the Russian-Ukraine conflict and sanctioning of fuel imports by some countries as well as environmental concern increase interest in searching for alternative sources of energy. The fusion of nuclei in a controlled way to release energy is now one of the top contenders (Pouzo & Milanese, 2003; Soto et al., 2017; Lee, 2022a; Lee, 2022b). This is because the gases used is either deuterium or tritium. These are isotopes of hydrogen, and deuterium is readily available in abundant quantity since it is present in sea water. It should also be noted that nuclear fusion produces more energy than nuclear fission and it also produce less radioactive waste (Fetter et al., 1988; Sandri et al., 2020).

To help understand the creation of this form of green energy, INTI International University has a dedicated fully equipped Plasma Research Laboratory in which fusion energy is studied with the INTI Dense Plasma Focus (INTI PF) machine operating in deuterium gas. It should be noted that INTI PF is a 3-kJ machine whereas other research groups use machines of different energies; from the Chilean Nano Focus (Soto et al., 2008) to much larger machines such as the 1 MJ machine operated by the International Centre for Dense Magnetised Plasmas (ICDMP) in Warsaw, Poland (Scholz et al., 2001). It should be noted that the dense plasma focus machines uses pulsed inertial confinement, whereas tokomak (Wesson & Campbell, 2001) and stellarator (Boozer, 1998) are specially designed for steady-state plasma confinement.

## 2. Methodology

To produce fusion energy in the laboratory, the INTI plasma focus machine is used. The INTI PF is part of a network of 3 kJ Mather type (Mather,1965) plasma machine known as the UNU/ICTP PFF (United Nations University/International Centre for Theoretical Physics Plasma Fusion Facility) (Lee el al 1988, Lee, 2014; Singh et al., 2018). It has a capacitance of 30 μF, static inductance of 110 nH; a circuit resistance of 12 mΩ. This machine has an anode length of 16 cm with a radius of 0.95 cm. The anode is surrounded by a cathode made up of an array of rods arranged in a circle having a radius of 3.2 cm measured from its center.

The current waveform of this machine is downloaded from from an internet site called plasmafocus.net which is run by some of the co-authors (Lee, 2020). The downloaded waveform is then digitalised. This downloaded waveform in then compared to computed current waveform calculated from the Lee Model Code.

The procedure to fit the computed current waveform to the measured current waveform is shown in Figure 1.

To use this code, firstly, the parameters of the machine and operation parameters for that shot are placed into the Lee codes followed by a set of trial fitting parameters, namely the mass and current factors. The mass ($f_m$, and $f_{mr}$) and current factors ($f_c$ and $f_{cr}$) are adjusted one by one until the computer and measured waveform agrees. These factors are important because the mass factors ($f_m$, and $f_{mr}$) account for the effects equivalent to increasing or reducing the amount of mass in the moving structure, during the axial phase as well as account all mechanisms which increase or reduce the amount of mass in the moving plasma slug, during the radial phase.

The current factors ($f_c$ and $f_{cr}$) account for the fraction of current effectively flowing in the moving structure during the axial phase as well as the fraction of current effectively driving the radial plasma slug. The 5 phase Lee model stop here if the pinch has a normal dip. If the pinch has an extended dip, then the anomalous resistances values, rise time and fall time are inputted (Lee et al., 2010; Singh et al.,2017).

The fitting procedure is completed for one current waveform at one pressure. The output data from the code is recorded. The procedure is then repeated for another shot at another pressure for which an actual discharge had been performed in the laboratory. In this way actual experiments are run over a range of pressures, and the current waveform of each shot is used to fit the Lee Code. The collected data for a range of pressure is used to find the optimum neutron yield from the experiments and from the code (Singh et al., 2017). It should be noted that the Lee codes automatically generate all the required information at any pressure of interest.

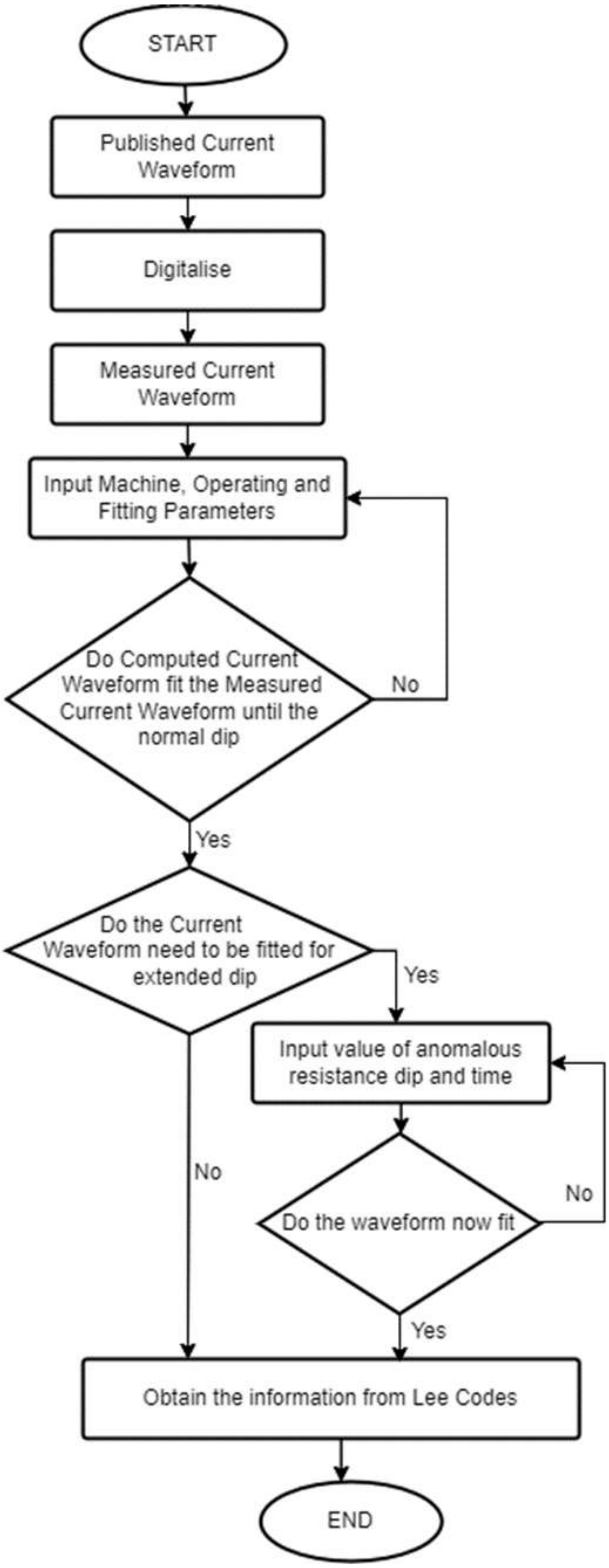


**Figure 1**. Flow chart showing the fitting of the Lee Codes

## 3. Result and Discussion

Table 1 shows the values of the parameters and anomalous resistance values needed to be typed into the Lee codes for the current fitting to match as shown in Figure 2.

Table 1: Input parameters and the anomalous resistance value used in the fitting for Lee code for the fitting of the INTI Plasma Focus Machine

| | | | | |
|---|---|---|---|---|
| Fill pressure $P_0$ (Torr) | 3 | Axial phase mass factor, $f_m$ | | 0.09 |
| Fill gas (molecular weight) | 4 | Axial phase current factor, $f_c$ | | 0.7 |
| Fill gas (atomic number) | 1 | Radial phase mass factor, $f_{mr}$ | | 0.14 |
| Fill gas (molecule) | 2 | Radial phase current factor, $f_{cr}$ | | 0.7 |
| | | Dip1 | Dip 2 | Dip3 |
| Ro(Ω) | | 0.2 | 0.1 | 0.05 |
| Fall time in nanoseconds | | 100 | 100 | 100 |
| Rise time in nano seconds | | 10 | 10 | 10 |
| End fraction | | 1 | 1 | 1 |

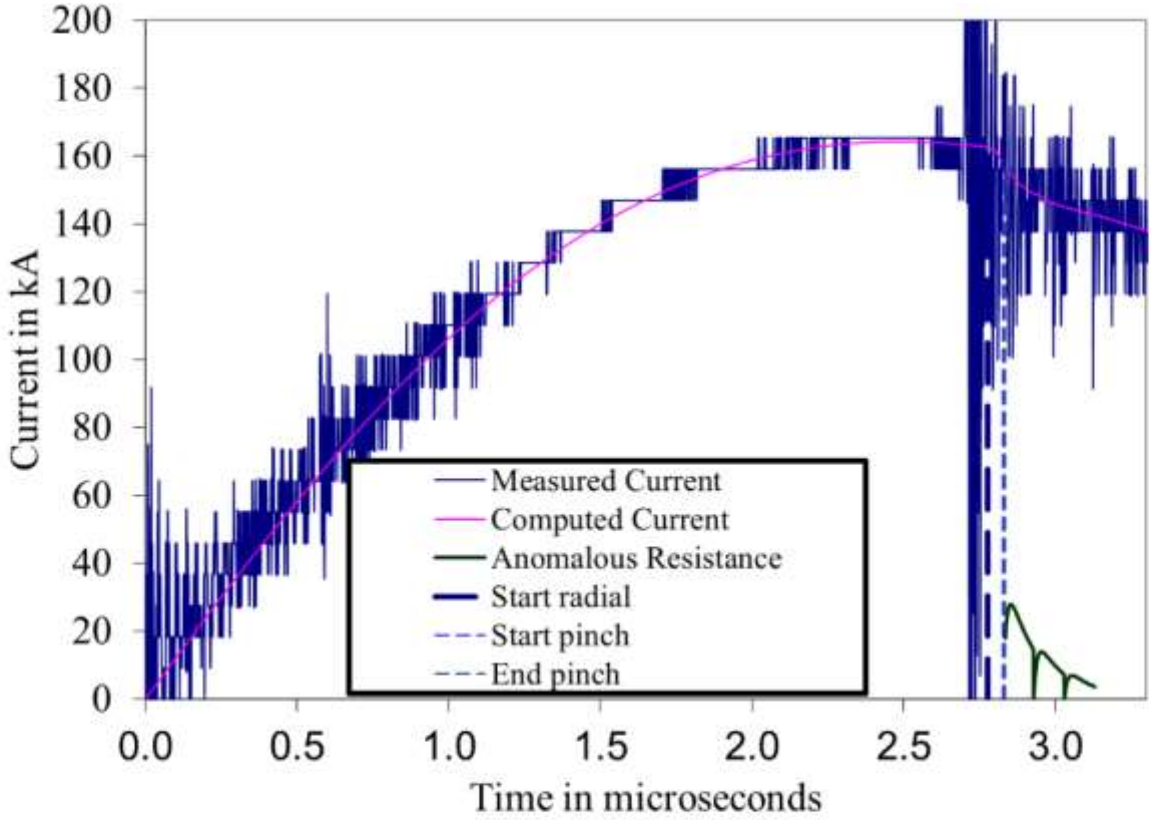


**Figure 2.** The measured and computed current waveform when the capacitor was charged to 13.5kV

The Lee code when simulated for the fitting shown in Figure 2, reveal information on the dynamic, electrodynamic, thermodynamic and radiation processes in the plasma focus. Part of this information is shown in Table 3.

**Table 3.** Part of detailed information obtained from Lee code after fitting of computed with measured current waveforms-INTI Plasma Focus Machine

| | |
|---|---|
| Peak current (kA) | 164 |
| Pinch start current (kA) | 110 |
| Pinch minimum temperature ($10^6$ K) | 7.73 |
| Pinch maximum temperature ($10^6$ K) | 7.85 |
| Peak axial speed (cm/μs) | 8.9 |
| Peak radial shock speed (cm/μs) | 37.7 |
| Peak radial piston speed (cm/μs) | 26 |
| Final pinch radius $r_{min}$ (cm) | 0.13 |
| Pinch length $z_{max}$ (cm) | 1.4 |
| Pinch duration (ns) | 7.3 |
| Peak induced voltage (kV) | 23.6 |
| Neutron yield ($\times 10^6$ n/shot) | 6.22 |
| Energy Inflow into Plasma (%) | 9.1 |
| Speed Factor ((kA/cm)/$Torr^{0.5}$) | 100 |
| Current per cm anode radius (kA/cm) | 173 |

Table 3 reveals that the current sheet that travels at extremely high speeds will then pinch to produce very high temperature of nearly 8 million kelvins. This pinch undergoes instabilities and breaks up releasing intense electromagnetic radiation, neutron and Helium-3 gas as shown in Figure 3.

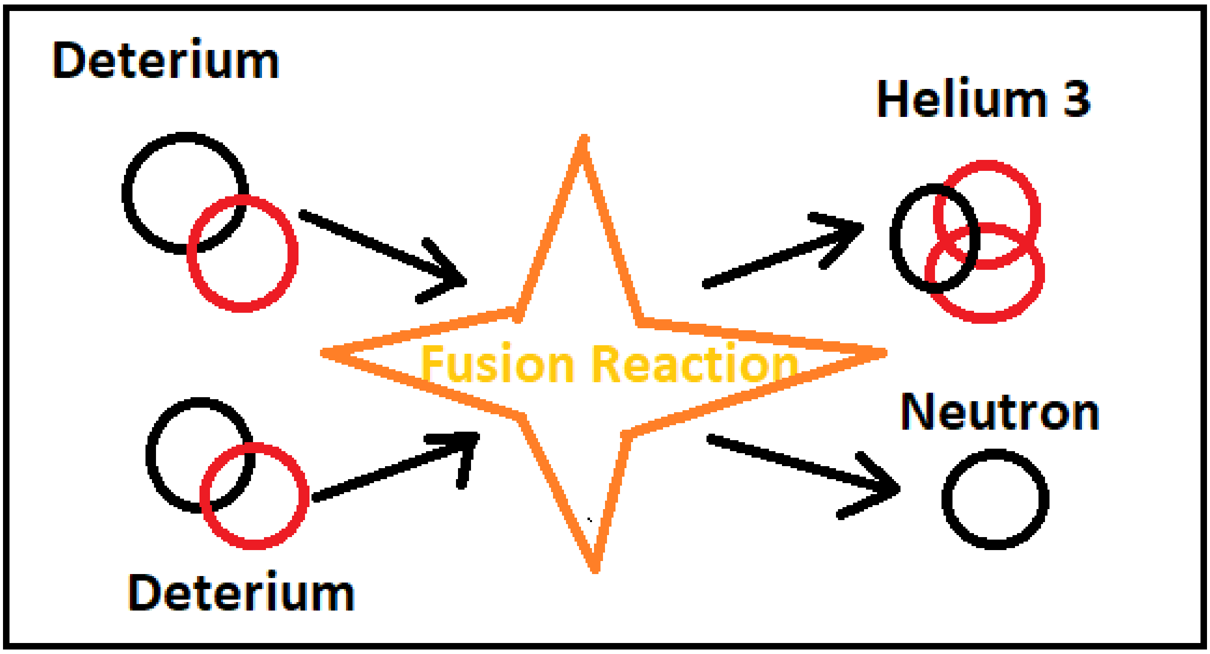


**Figure 3**. The deuterium-deuterium fusion (He-3 branch)

## 4. Conclusions

The Lee code reveals that INTI's plasma focus machine for this shot produces a neutron yield of $6.2\times10^{6}$ n for a pinch duration of 7 nanoseconds. This regime of fusion yield is useful for basic and scaling studies but is too short in duration for energy production. Thus, to make fusion energy more reliable and commercially viable, continuous fusion reaction is needed and plasma should be sustained over a long period of time. The leading candidate for a fusion reactor is a different plasma machine call a tokamak. But tokamaks are huge machines. The dense plasma focus is much more suitable for studies in an academic setting and there is increasing world-wide interest to develop and scale (Lee 2022a, Lee 2022b) such focus pinch machines into alternative concepts of a fusion reactor.

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