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Investigation of AISI Steel Vickers Hardness and Nitrogen Ion Beam Energy of a 3 kJ Plasma Focus

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Abstract

INTI 3kJ Plasma Focus which produces dense hot plasmas with intense multi-radiations including x-rays, beam ions, relativistic electrons and powerful plasma streams is discussed in this paper. This device is a table top sized nuclear fusion machine producing fusion neutrons when operated in deuterium. It has many applications including energy, medical and materials. Current work on materials hardening conducted at the INTI plasma focus laboratory using nitrogen gas is briefly discussed. The methodology of the research is briefly presented as is our unique advantageous approach in integrating the laboratory measurements with analysis using the Lee code, which INTI Centre of Plasma Research plays a big role in its continuing development. An example is discussed. The beam energy obtained from the Lee codes is plotted against the average hardness obtained from the Vickers Hardness test and reveals the correlation between the energy released by the plasma beam and the hardness of the material.

Keywords

INTI dense plasma focus; Nitriding; Lee model code; Machine performance

Introduction

INTI is one of the universities in Malaysia and around the world that actively carries out research in Plasma studies. To carry out this research INTI has one 3 kJ dense plasma focus machine (DPF) and is presently constructing another machine. This dense plasma focus machine uses electromagnetic acceleration and compression to produce short-lived plasma that is so hot and dense that it emits intense multi-radiations including x-rays, high energy ions, relativistic electrons and powerful plasma streams, as it undergoes nuclear fusion when operating in deuterium gas. This research is important because it is potentially an alternative method for providing environmentally friendly and practically inexhaustible energy production (S Lee and S H Saw, 2011).

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When this DPF machine works in other gases such as neon, argon, nitrogen etc., its output can be used in various applications such as microelectronics, lithography, medical applications, material modifications and etc. (P Lee, 2012).

Methodology

To understand the working dynamics of INTI DPF, the Lee model code will be used in concurrence with the actual machine. This is because this code uses the wave form of the discharge current and actual machine parameters to compute the behavior and properties of the plasma. According to a research article (S Lee and S H Saw, 2010) the current waveform of the plasma focus is one of the best gauges of gross performance of the plasma focus machine. The axial and radial phase dynamics and the critical energy transfer into the focus pinch are revealed by studying these discharge current waveforms. To operate the INTI plasma Focus machine. The following steps are carried out.

Firstly, a Franklin vacuum pump is used to evacuate the 6 litre chamber INTI plasma focus machine to a base pressure of 0.01 Torr. It is then filled with the required gas to a higher pressure than required before been evacuated until the desired pressure is reached.

The capacitor bank is then charged up to the required voltage before its energy is discharged into the gas.

A Digital Phosphor Oscilloscope (Tektronix-TDS3034C) is used to observe the current derivative waveform. This waveform is numerically integrated to obtain the waveform of the discharge current. The voltage waveform is also monitored. The presence of an intense voltage spike indicates the strong focusing (plasma pinch) action.

The current derivative data is input into the Lee code. Figure 1 shows the flow chart on how the current derivative data is used in the Lee code (S Lee, 2014).

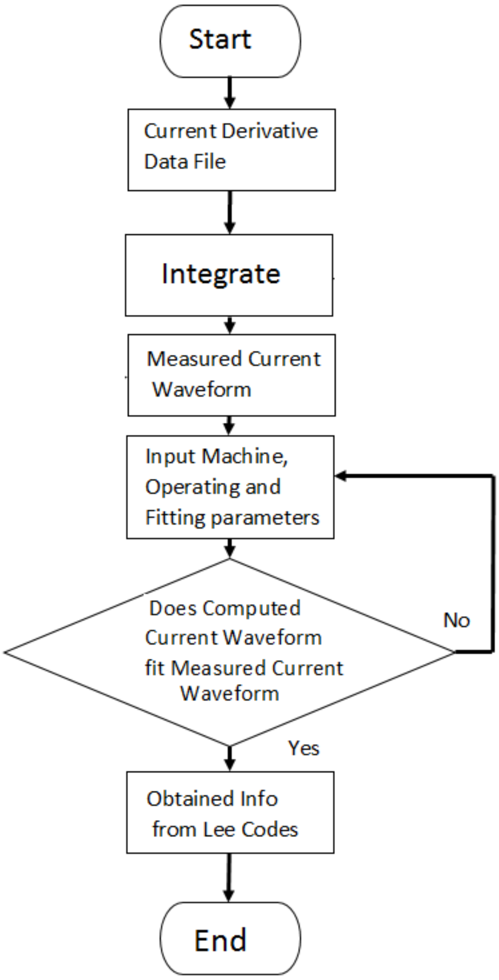

Figure 1. The flow chart showing how current and current derivative are used in the Lee codes.

Results and Discussion

To use the codes, the bank, tube and operational parameters need to be input. The bank parameters consist of the values for the capacitance, inductance and unavoidable stray resistance. The length and radius of the anode as well as the radius of the cathode are also input into the code.

For the operational parameters, the voltage to which the capacitor is charged, the type of gas and pressure of operation are also recorded in the input.

Finally, the model parameters (mass and current factor in both axial and radial phase) are obtained by fitting the computed current waveform to the measured current waveform.

Figure 2 shows an example of the fitting of the computed current to the measured current when the machine is operating in Nitrogen gas.

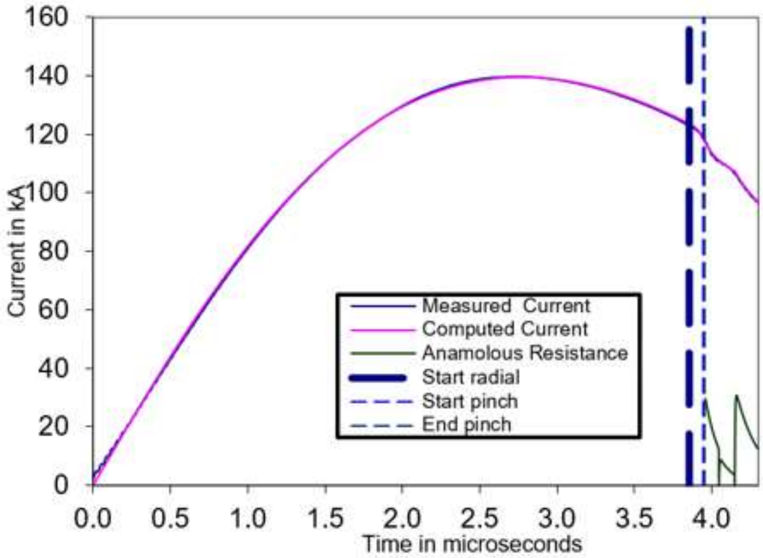

Figure 2. Computed current waveform of INTI (UNU/ ICTP PFF) machine at 12 kV, 1.5 Torr nitrogen gas fitted to the measured current waveform.

Once the current waveform has been fitted, the plasma dynamics of the focus for this particular shot is automatically computed within the code. This includes the axial and radial speeds, temperature of pinch, its duration, length and well as its radius. The ions produced, the beam energy, yield produced (all line yield etc.) are also computed.

Using Lee model code in concurrence with the actual machine, research on hardening of material (Low carbon steel bars (AISI1020) (Teh Thiam Oun, 2019) and alloy steel bar (AISI 304) (Manmeshpal Singh, 2019) using nitrogen gas (nitrating) is currently been carried out. The results on the surface condition of the alloy steel bar are shown in Figure 3.

Figure 3. Surface condition of AISI 304 alloy steel after nitriding.

Nitriding is important as it increases the surface hardness. The fitted Lee codes to the current waveform reveals the energy produced in each shot, whereas the result of the alloy steel reveals the harness of the material. When the beam energy and average hardness are plotted together as shown in Figure 4, it shows that the hardness and maximum beam energy occurs at the same optimum pressure of 1.5 Torr. It can be stated that the more the energy released by the shot, the harder the material will become.

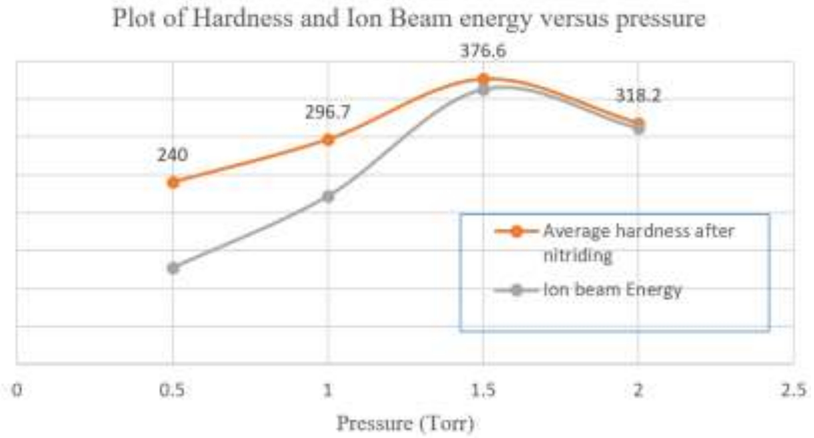

Figure 4. Plot of beam energy and hardness after nitriding versus pressure
(Note: Magnitude not using same scale)

To appreciate the value of this methodology (Lee codes used in conjunction with actual machine results), a summary has been made of what has been achieved in similar work. These summaries reviewed the work starting from Potter's studies (1971) which demonstrated qualitative agreement of his numerical experimentation with experimentally measured neutron yield although his thermonuclear mechanism was at odds with the neutron yield anisotropy measured in plasma focus discharges. Moreno et al (2000) and Gonzalez et al (2009) achieved agreement of their numerical methodology by adjusting their axial and radial mass swept-up factors until the computed neutron yield agree with the measured neutron yield. This methodology could not predict the yields for any other machine even for neutron yield. Schmidt et al. (2014) used a fully kinetic self-consistent simulation to obtain detail distributions of dynamics, electric fields, and plasma properties to estimate the ion beam and neutron yield. Kinetic simulation needs immense computing power required to follow the plasma evolution for even a few nanoseconds. Hence our method is unique as it required only a laptop computing power to complement any plasma focus laboratory.

Conclusions

The study conducted in INTI Plasma focus lab working in various gases is of outmost importance since it reveals the physics and the working principle of plasma such as its energy production (nuclear fusion byproduct such as neutrons) when working in deuterium gas, soft X ray yield when working in neon gas (useful for microelectronics, lithography, surface micromachining) all line yield when it works in argon gas (useful for medical applications) and concepts of material modification (nitrating) when working in nitrogen gas. The experimental results in nitrogen gas reveals that the amount of energy released during plasma pinching directly affected the material hardness.

Knowledge gained from INTI plasma focus experiments for material modification is quite unique showing that the process hardens material at only one spot. Further studies need to be carried out on the possibilities of using this information on hardening textured material such as knife blades, edges of screw drivers etc for commercial purposes.

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