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Dense Plasma focus experimentation in the "COVID-19" environment

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Abstract

In today's world of the "COVID-19 endemic", movement control order has been enforced in a majority of countries all over the world. This severely restricts access to universities and research facilities. In this paper, Lee's model code which was developed by one of the coauthors, is shown to simulate Tsinghua University Plasma Focus machine of Beijing China. Such numerical experiments are a good stop-gap measure until we can access our laboratories again. Our code requires only a measured current waveform from the actual machine. The computed current waveform is fitted to the measured current waveform by fine-tuning the model parameters. Once fitted, realistic dynamics is generated giving a good understanding to the plasma conditions in the machine. Importantly, we demonstrate that the neutron yield computed from this code agrees reasonably well with the published measurements.

Keywords

Dense plasma focus, neutron yield, current waveform

Introduction

The movement control orders due to the recent pandemics have interrupted conventional face to face education, with nationwide schools and institutions of higher learning closures in most countries including Malaysia.

Educational institutions including INTI International University have made concerted efforts to maintain learning continuity during this period by replacing face-to-face lectures and laboratory experiments remotely with lectures through online learning. Research labs such as the Centre of Plasma Research (CPR) on the university premises are also under limited access, thus the need for a suitable and reliable dense plasma focus simulation is of outmost important.

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In this paper, to appreciate the value of the ability of the Lee's code, a brief summary of other similar simulation work (such as Lim et.al., 2016) working in deuterium gas is stated.

Firstly, looking at Potter's (Potter, 1971) papers, his magnetohydrodynamics simulation computes qualitatively reasonable neutron yield but the disagreement of his results with the "neutron yield anisotropy measured in plasma focus discharges" suggests that his assumption of thermonuclear origin of the fusion neutrons was incorrect and that his computed flow velocities were unrealistically high. Analysing Moreno (Moreno et.al., 2000) and Gonzalez (González et.al., 2009) papers, their computed neutron yields were adjusted to agree with the measured neutron yield using a thermonuclear model but in that process they had to over-estimate the radial shock speed, temperature and thermalized fusion cross-sections by a factors of 2, 4 and 1000 respectively (Lee et.al.,2009). Schmidt (Schmidt et.al., 2014), used a fully kinetic simulation for the plasma dynamics and obtained good agreement of neutron yield with the Gemini plasma focus. Even using immense world-class computing power at their disposal, they could follow the plasma evolution for only 26 nanoseconds and had to patch up their kinetic computation using magnetohydrodynamics methods. The authors were not able to find any other reliable computations of neutron yield or ion beams in the literature. Hence the Lee code is a unique tool that computes reliable neutron yields requiring only a laptop computing power. It should be also noted, that this code has also been widely used in designing and analyzing several machines all over the world, of which one is the UNU/ICTP PFF (Lee, 2014).

Methodology

In this paper, Tsinghua Plasma Focus machine which is a 2.2 kJ, Mather type desktop device working in deuterium gas is simulated using the Lee's code. The computed results are compared to the published experimental results (Wang et.al., 1999). It should be noted that the Lee codes uses the current waveform as the current waveform reveals all the information about the plasma properties that occur in the all the phases of the device" (Lee and Saw[(a)], 2010).

To simulate the device, firstly, the current derivative waveform from the published article (shown as Figure 2(a) in the journal paper "A compact plasma focus device and its neutron emission" published 1999) was digitalised using a free software available on the internet called "engauge".

The digitalised current derivative data was then integrated with respect to time to obtain the measured current waveform.

This experimental current waveform was than uploaded into the Lee code and was used as a reference as shown in Figure 1.

The device parameters for this machine such as its capacitance bank, static inductance, anode radius and length, cathode radius, operating pressure gas and working voltages which were directly obtained from the reference paper were then inputted into the code. The current waveform flowing in the discharge circuit calculated from the code was than fitted to the measured waveform (reference waveform) by adjusting the model parameters, these being the mass factor of the axial

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phase f_m, the corresponding current factor f_c, and the appropriate factors for the radial phases f_{mr} and f_{cr}. This fitting procedure was performed systematically, one phase at a time until the waveform produced in the computation matches the measured waveform. It should be noted that these factors are of outmost important because the "mass factors account for the effects on increasing or reducing the amount of mass in the moving structure whereas the current factors account for the fraction of current effectively flowing in the moving structure in the dense plasma focus machine" (Lee and Saw [b] ,2010). The fitted current waveform is shown in Figure 1.

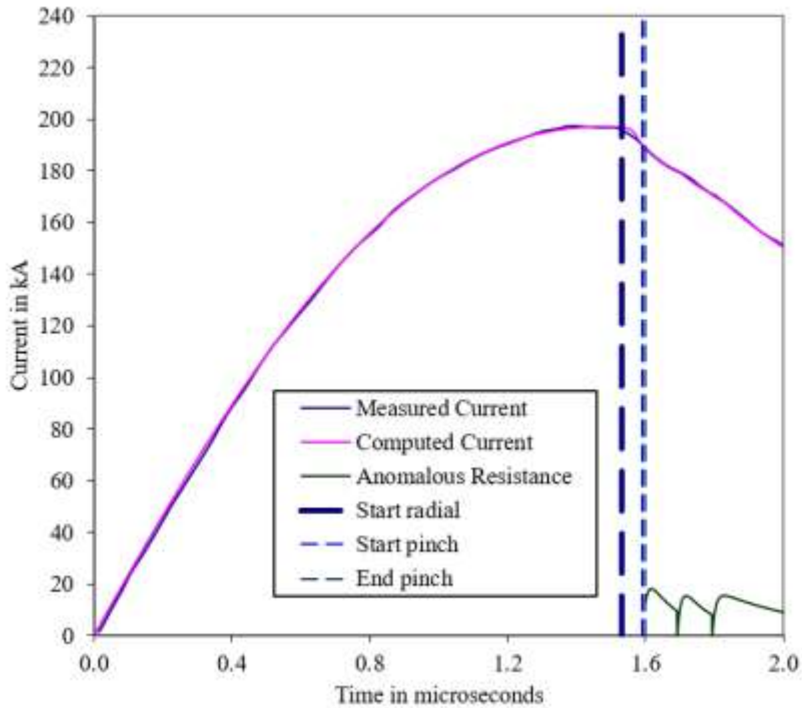

Figure 1. Measured current waveform of Tsinghua University Plasma Focus machine at 18 kV, 11.25 Torr deuterium gas compared with Lee Model 6-phase code computed current waveform.

Results and Discussion

During the current fitting process, it was found that the static inductance of the capacitor bank was 76nH instead of the 67nH as stated in the Journal (Wang et.al.,1999) demonstrating a unique capability of the code. The peak current computed is 197 kA with a computed neutron yield of 2.07×10^7 neutron/shot.

Using the model parameters obtained from the current fitting, the Lee codes were simulated to run from 1 Torr to 19 Torr since this code reveal all the plasma dynamics occurring in the dense plasma machine. A few of the results obtained from the code will be discuss here.

Figure 2 show the speed of the axial current(cm/µs), radial piston(cm/µs) and radial shock (cm/µs) drops at a rate of $P_o^{-0.341}$, $P_o^{-0.396}$ and $P_o^{-0.397}$ respectively, where P_o is the pressure in Torr. The speed of the axial current is affected by the voltage of the capacitor discharge, pressure and the back emf due to the greater mass loading. The radial shock speed is effected by the magnetic

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pressure whereas the speed of the piston affected by the first law of thermodynamics applied to the effective increase in the volume between the shock front and the current sheet which was created due to the incremental motion of the shock front.

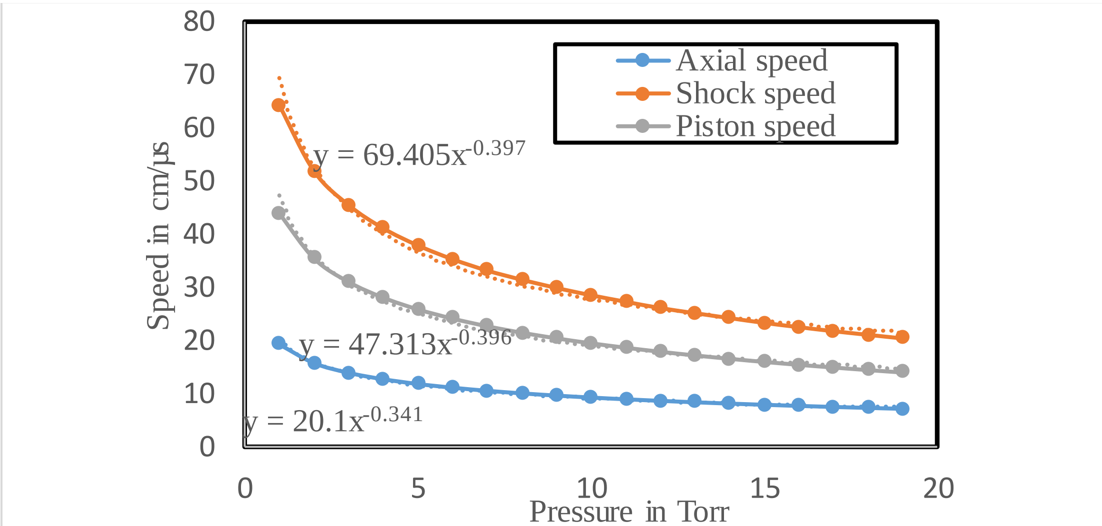

Figure 2. Computed Plasma speed versus pressure.

As the pressure increases, the axial speed decreases, thus the shock speed and magnetic piston speed will also decrease as well. The decrease in shock speed will cause a decrease in the temperature of the radial inward shock as the temperature depends on shock speed to power of 2.

This causes the decrease in pinch temperature as pressure increases, as shown in Figure 3.

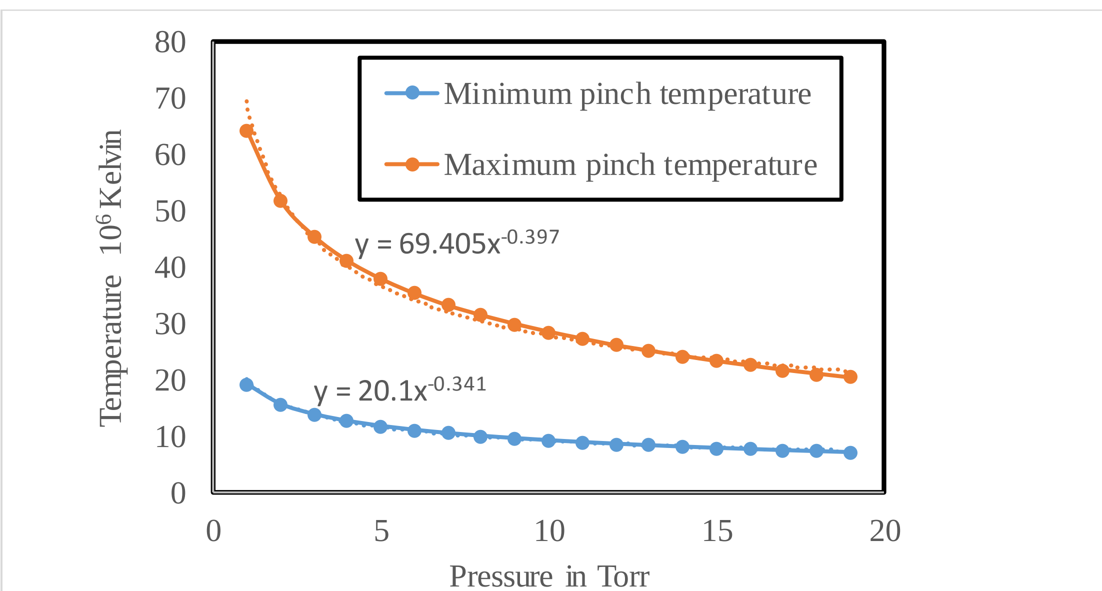

Figure 3. Computed Plasma pinch temperature versus pressure.

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As the radial speed decreases, the time required for the radial reflected shock increases and also pinch duration increases.

During the pinch, a dense plasma is formed and fusion neutrons and energy are emitted. The computed neutron yield from the code and the measured neutron yield are plotted versus pressure as shown in Figure 4. The figure shows the simulation to be reasonably accurate. The unique capability of the code to provide insights into the dynamics of the plasma and the neutron yield is thus demonstrated in Figures 2-4.

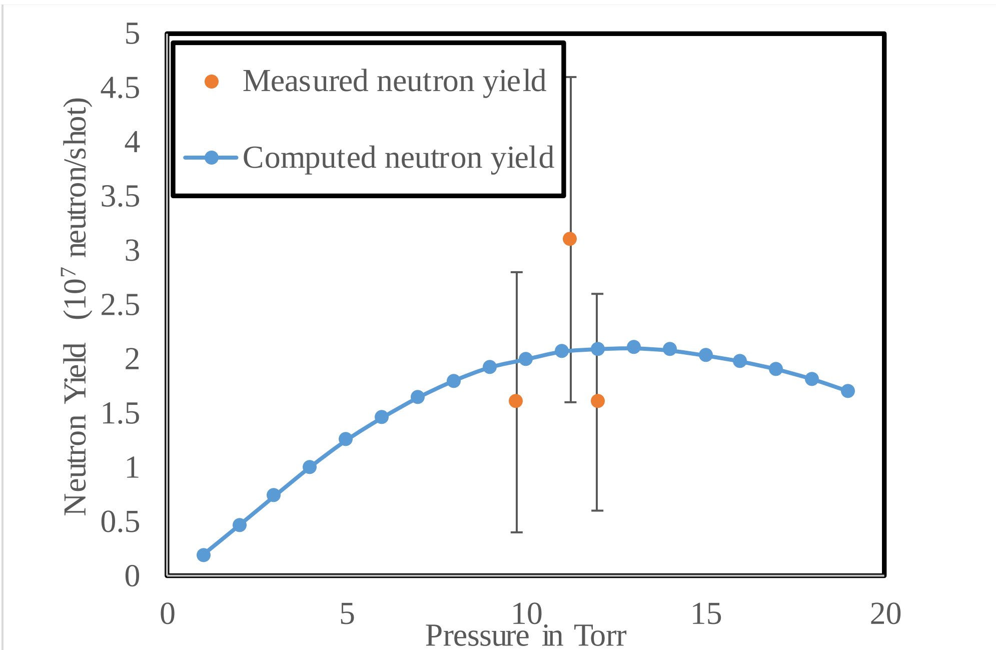

Figure 4. Computed and measured neutron yield versus pressure.

Conclusion

This paper shows that the Lee Code successfully models the dynamics and the neutron yield of Tsinghua University Plasma focus machine which is thousands of miles away from Malaysia, just using data of published measured current derivative waveform obtained from an actual experiment conducted years ago. Thus this code is a good tool to enable researchers to conduct remote experiments anywhere and then verify the results with the actual machine to increase the confidence level of the data results obtained once the Research Centre is again accessible to the researchers. Further topics that could be investigated by such numerical experiments include radiation and beams from the focused plasma and some practical effects on materials including hardening of exposed samples.

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