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Numerical experimentation on focusing time and neutron yield in GN1 plasma focus machine

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In this paper, we have shown how we have fitted Lee's six phase model code to analyze the current waveform of the GN1 plasma focus machine working in deuterium gas. The Lee's 6-phase model codes was later configured to work between 0.5 to 6 Torr and the results of both focusing time and neutron yield was than compared with the published experimental results.

The final results indicate that Lee's code, gives realistic plasma dynamics and focus properties together with a realistic neutron yield for GN1 plasma focus, without the need of any adjustable parameters, needing only to fit the computed current trace to a measured current trace.

Keywords: Lee's six phase model code; current waveform; neutron yield; focusing time.

1. Introduction

According to S. Lee and SH Saw[1] the current trace of the plasma focus is one of the best indicators of gross performance of the plasma focus machine. The axial and radial phase dynamics and the crucial energy transfer into the focus pinch are among the most important information that is quickly apparent from these current trace.

The exact time profile of the total current trace is governed by the bank parameters, by the focus tube geometry and the operational parameters. The current trace is also dependent on the fraction of mass swept-up and the fraction of sheath current and the variation of these fractions through the axial and radial phases. These parameters determine the axial and radial dynamics, specifically the axial and radial speeds which in turn affect the profile and magnitudes of the discharge current.

The discharge current waveform contains information on all the dynamic, electrodynamic, thermodynamic and radiation processes that occur in the various phases of the plasma focus. Thus, this explains the importance attached to matching the computed total current trace to the measured total current trace in the procedure adopted by the Lee model code.[2-16]

Once matched, the fitted model parameters assure that the computation proceeds with all physical mechanisms accounted for, at least in the gross energy and mass balance sense. One of the most important procedures therefore is to tie the numerical experiment to the reality of the actual machine by fitting the computed current trace to a measured current trace.

In this paper, the Lee's model code will be configured for the Argentina GN1 Plasma Focus Machine and important readings especially the neutron yield and focusing time will be extracted and compared to the experimental neutron yield and focusing time taken from the publish article "Industrial Application of Plasma Focus Radiation" which was published in Brazilian Journal of Physics[17].

2. Methodology Used

From the published article[17] the information of GN1 extracted is as follows. The GN1 consisted of three discharging modules, each of them composed of five Maxwell type 31161 condensers making a total capacitance of 10.5 µF. The anode consisted of a copper cylinder, 38 mm diameter, 1.5 mm thick, 87 mm long, and an outer cathode formed of 12 bronze bars, 3 mm diameter, 100 mm long, cylindrically placed, and welded at the end to a bronze ring of 72 mm diameter. The insulator was a Pyrex glass cylinder 35 mm long and 4 mm thick. The value of the inductor was estimated at 52 nH based on the information that the quarter time period was ~ 1.1 µs. Operational voltage was 30 kV at a pressure of 4 mbar deuterium.

We digitized their published current waveform using an open access source digitizing program, Engauge [18]. The Lee's model code is configured as the GN1 Plasma Focus Machine as shown in Table 1.

Table 1: Machine parameters for GN1 Plasma focus machine that were extracted and placed into Lee's 6 phase model code.

Capacitance C_0 (µF)	10.5
External or static inductance L0 (nH)	52
Circuit resistance r0 (mΩ)	7
Electrode radii, outer 'b'(cm)	3.6
Inner anode 'a'(cm)	1.9
Anode length 'z_0'(cm)	8.7
Charging voltage V_0 (kV)	30
Fill pressure P_0 (Torr)	3
Fill gas(molecular weight)	4
Fill gas(atomic number)	1
Fill gas(atom(1) or molecule(2))	2

To match with the published current trace until the end of the radial dip, the fraction of mass swept-up and the fraction of sheath current and the variation of these fractions through the axial and radial phases were done and its final values are shown in Table 2.

Table 2: Final value of the fraction of mass swept-up and sheath current through the axial and radial phases fitted by the Lee' model code.

Axial phase mass factor, f_m	0.13
Axial phase current factor, f_c	0.7
Radial phase mass factor, f_{mr}	0.15
Radial phase current factor, f_{cr}	0.85

To match the current waveform beyond the computed radial dip into a longer and deeper extended dip the post-pinch phase[16] of anomalous resistances were fitted and final values are shown in Table 3.

Table 3: Final value of the Anomalous resistances used in Lee' model code.

	$R_0(\Omega)$	Characteristic of fall time τ_2 (ns)	Characteristic of rise time τ_1 (ns)	End fraction time
Dip 1	0.13	100	10	1
Dip 2	0.02	50	10	1
Dip 3	0.01	50	10	1

3. Results

The computed and measured current waveform is shown in Fig. 1.

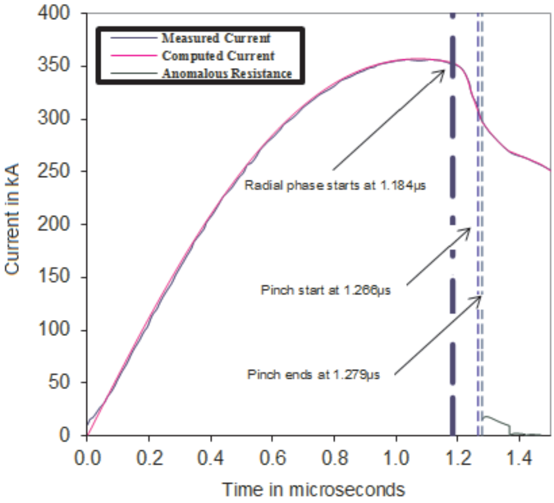

Fig. 1. Measured current waveform compared with Lee's six phase computed current waveform for GN1 at 3 Torr deuterium gas at 30 kV. The 3 vertical dashed lines show the time positions of start of radial phase, start of pinch and end of pinch respectively.

The computed and measured waveform show a good fit when Lee's 6 phase model was used.

The maximum computed current was 357 kA (The experimental peak value is 350 kA[17]) and exhibits a radial phase start time of 1.184 µs and end time of 1.266 µs with neutron yield of 2.1×10^8. (The maximum experimental neutron yield is 3×10^8n[17]). The other detail information is attached in Table 4.

Table 4: Information obtained from Lee's model code configured for GN1 plasma focus machine at 3 Torr deuterium gas and 30 kV.

Peak current(kA)	357
Pinch start current(kA)	261
Peak axial speed(cm/µs)	11.6
Peak radial shock speed(cm/µs)	45.6
Peak radial piston speed(cm/µs)	32.1
Final pinch radius r_{min}, (cm)	0.29
Pinch length z_{max}(cm)	2.8
Pinch duration(ns)	13.1
Peak induced voltage(kV)	58.1
Yields (Neutron yield)n	$2.1\text{x}10^8$
Energy Inflow in Plasma (in % E_0)	16.6
Speed Factor ((kA/cm)$\text{Torr}^{0.5}$)	108
Current per cm anode radius (kA/cm)	188

4. Discussion

To check the focusing time and the amount of neutron yield obtained from the codes and compare with the experimental values, Lee's model code was configured for pressures from 0.5 Torr to 6 Torr at 30 kV and the results were compared.

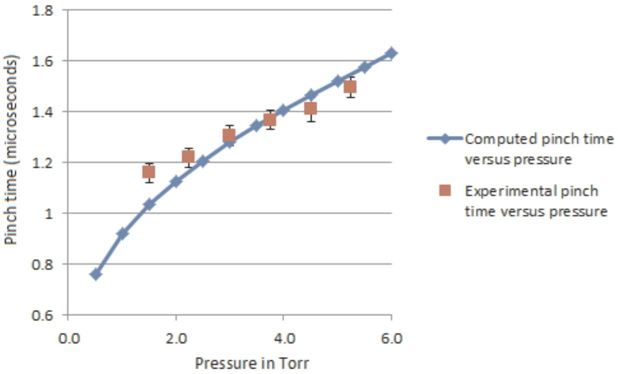

Fig. 2. Computed pinch time versus pressure compared to experimental focusing timing (pinch time) versus pressure[17] from 0.5 Torr and 6 Torr working at 30 kV.

Fig. 2 and Fig. 3 show that the computed focusing time and the computed neutron yield versus pressure curve agrees reasonably with the published curve [17]. From Fig. 2, the experimental focusing time values rises at a slightly lower gradient compared to the computed values but they both agree that at 3.8 Torr the focusing time is 1.38 µs.

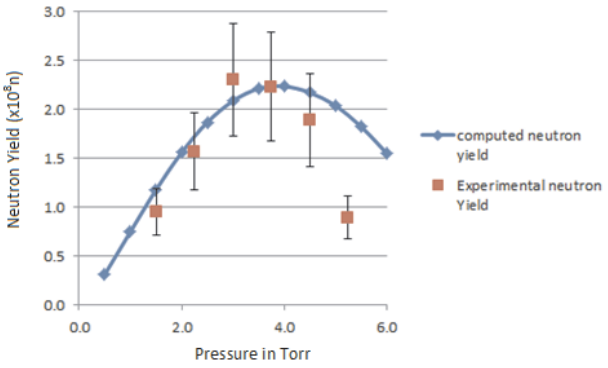

Figure 3. Computed neutron yield versus pressure compared to experimental neutron yield versus pressure[17] from 0.5 Torr and 6 Torr working at 30 kV.

In Fig. 3, the computed values shows that the optimum yield occurs at 4 Torr and produces a neutron yield of 2.24×10^8 n, the energy input into plasma at this instant is 16.2% whereas the experimental optimum neutron yield occurs at slight a lower value of 3 Torr (4 mbar) with an average neutron yield of 2.3×10^8 n (maximum is about 3×10^8 n as stated in the publish results) [17], while the drop off of both the experimental and computed neutron yield are gradual.

5. Conclusion

The Lee model code is used to compute the focusing time and neutron yield versus pressure curve of the Argentina GN1 Plasma Focus Machine. The computed results agree reasonably well with the published curves[17] and give confidence that the Lee model code computes not just optimum neutron yields and focusing time but also the behavior of neutron yield and focusing time with pressure. The results indicate that Lee code gives realistic plasma dynamics and focus properties together with a realistic neutron yield for the GN1 plasma focus.

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