Numerical Experiments on PF400 Neutron Yield

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Abstract

Numerical experiments are carried out, using the Lee model code to compute the neutron yield of PF400 as a function of pressure. Results are compared with published laboratory measurements, showing agreement between the numerical and the laboratory experiments.

1. Introduction

The Lee Model couples the electrical circuit with plasma focus dynamics, thermodynamics and radiation, enabling realistic simulation of all gross focus properties. The basic model, described in 1984 [1], was successfully used to assist several experiments [2-5]. An improved 5-phase model and code incorporating small disturbance speed [6], and radiation coupling with dynamics assisted other research projects [7-9], and was web-published in 2000 [10] and 2005 [11]. Plasma self-absorption was included in 2007 [10] improving soft x-ray yield simulation. The code has been used extensively in several machines including UNU/ICTP PFF [2,5,7,8,12], NX2 [8,9], NX1 [8], and adapted for the Filippov-type plasma focus DENA [13]. A recent development is the inclusion of neutron yield, Y_n, using a beam–target mechanism [2], incorporated in the present version [14] of the code RADPFV5.13, resulting in realistic Y_n scaling with I_{pinch} [15]. The versatility and utility of the Lee Model is demonstrated in its clear distinction of I_{pinch} from I_{peak} [16] and the recent uncovering of a plasma focus pinch current limitation effect [17,18]. The description, theory, code and a broad range of results of this 'Universal Plasma Focus Laboratory Facility' is available for download from [19].

2. Procedures for the numerical experiments

The Lee Model code is configured to work as any plasma focus by inputting the bank parameters, L_0, C_0 and stray circuit resistance r_0; the tube parameters b, a and z_0 and operational parameters V_0 and P_0 and the fill gas. The standard practice is to fit the computed total current waveform to an experimentally measured total current waveform [11,15-19] using four model parameters representing the mass swept-up factor f_m, the plasma current factor f_c for the axial phase and factors f_{mr} and f_{cr} for the radial phases.
From experience, it is known that the current trace of the focus is one of the best indicator of gross performance. The axial and radial phase dynamics and the crucial energy transfer into the focus pinch are among the important information that is quickly apparent from the 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. It also depends 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 detailed profile of the discharge current during the pinch phase also reflects the Joule heating and radiative yields. At the end of the pinch phase the total current profile also reflects the sudden transition of the current flow from a constricted pinch to a large column flow. Thus the discharge current powers all dynamic, electrodynamic, thermodynamic and radiation processes in the various phases of the plasma focus. Conversely all the dynamic, electrodynamic, thermodynamic and radiation processes in the various phases of the plasma focus affect the discharge current. It is then no exaggeration to say that the discharge current waveform contains information on all the dynamic, electrodynamic, thermodynamic and radiation processes that occurs in the various phases of the plasma focus. This explains the importance attached to matching the computed current trace to the measured current trace in the procedure adopted by the Lee Model code.

3. The numerical experiments - fitting the computed current trace to obtain the model parameters

Silva, Moreno and Soto et al had published a paper [20] with laboratory measurements from the PF400, including a typical current waveform and a graph on neutron yield vs pressure. We first fit the computed current waveform to the published measured waveform in the following manner.

We then configure the Lee model code (version RADPF05.13.9b) to operate as the PF400 starting with the following published [20] bank and tube parameters:

Bank parameters:	L_0=38nH, C_0=0.88μF, r_0=not given
Tube parameters:	b=1.55 cm, a=0.6 cm, z_0=2.8 cm
Operating parameters:	V_0=28 kV, P_0= 6.6 Torr deuterium

where L_0=static inductance (nominal) , C_0= storage capacitance (nominal), b=tube outer radius, a=inner radius, z_0=tube axial length, V_0=operating voltage, P_0= operating initial pressure.

To obtain a reasonably good fit the following bank and tube parameters (L_0, C_0 and z_0 refitted and r_0 fitted) are used:

Bank parameters:	L_0=40 nH, C_0=0.95 μF, r_0=10 mΩ
Tube parameters:	b=1.55 cm, a=0.6 cm, z_0=1.7 cm
Operating parameters:	V_0=28 kV, P_0= 6.6 Torr deuterium

together with the following fitted model parameters:

f_m=0.08, f_c=0.7, f_{mr}=0.11 and f_{cr}=0.7.

The fitted computed current waveform is compared with published waveform in Fig.1.

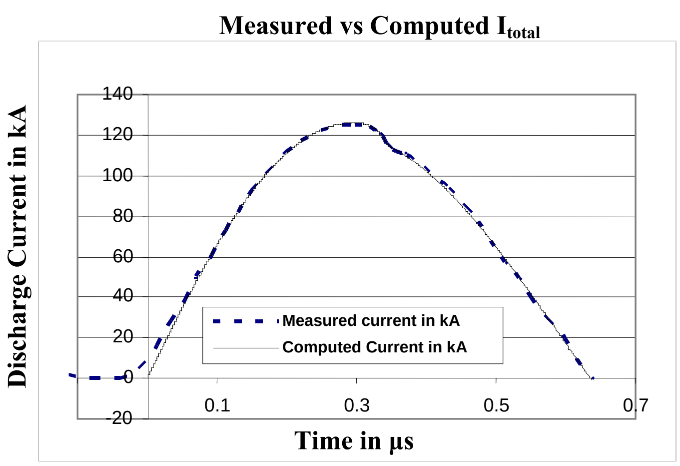

Fig 1. Computed discharge current compared to published current for PF400.

4. The numerical Experiments- computing the neutron yield as a function of operating pressure

Using the fitted model parameters, numerical experiments are then carried out at various initial pressures in deuterium. The neutron yields Y_n are then tabulated in Table 1 and compared with the published values [20] in Fig. 2.

Table 1: Computed Y_n compared with published Y_n for PF400 as a function of pressure

	Measured	Computed
P_0 (mbar)	**Y_n (10^6)**	**Y_n (10^6)**
1		0.25
2		0.55
3		0.81
4		0.99
5		1.11
6	0.2	1.16
7	0.53	1.15
8	0.7	1.10
9	1.06	1.01
10	0.78	0.90
11	0.74	0.77
12	0.2	0.63
13		0.50
14		0.38
15		0.27

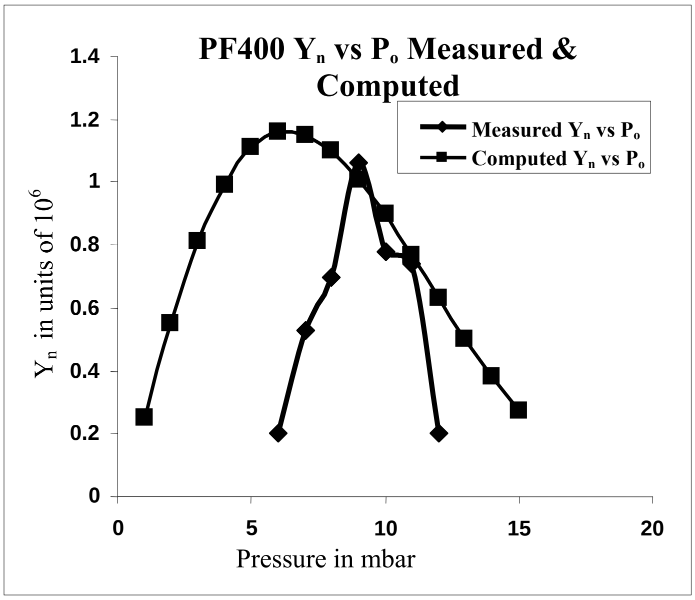

Fig. 2. Computed and measured neutron yield as functions of pressure.

Figure 2 shows that the computed neutron yield versus pressure curve agrees reasonably with the published curve. The agreement is even more remarkable when we note that the same model code (version RADPF05.13.9b) also shows reasonable agreement in neutron yield when compared with the published results of the PF1000 [15]; noting that the PF400 is a small plasma focus of 400 J whilst the PF1000 is one of the biggest plasma focus in the world at 1 MJ. Despite all the discussions in the literature about neutron production mechanisms such as beam-target [14], gyrating ions, moving boiler and others, the state of the art is not able to do better than make order of magnitude estimates [21]. Figure 2 is the first time, to our knowledge, that computed neutron yield versus pressure data has been quantitatively compared with measured data; moreover with several important features of agreement.

5. Conclusion

The Lee Model code is used to compute the neutron yield versus pressure curve of the Chilean PF400. The computed results agree reasonably well with the published curve.

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