Suitability of Lee Codes to fit Mather, Fillipov and Hybrid Dense Plasma Focus Machines Current Waveform.

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There are several types of Dense Plasma Focus (DPF) machines with different anode geometry. It is a real advantage if the various types of machines could be simulated using one code. This is of particular importance from the comparative point of view. This paper examines the use of the Lee Code to model a Mather type Plasma Focus(PF), a Filippov type PF and a hybrid type PF. The test for model fit is to check if the computed current trace could be fitted to the experimentally measured trace of current. It is found that the Mather type PF is modelled well and that the hybrid PF is also fitted well. The Filippov type PF could be fitted only for the lift-off and the first part of the radial sub-phase using the standard Lee Code, although it has been reported that a different code called the ML (Modified Lee) has been developed and is used to fit Filippov typed PF's. The conclusion is that the Lee Code in its current form can be used to model Mather type PF and hybrids, but needs extensive modification such as to Siahpoush's ML version in order to accurately portray all phases of the Filippov type PF.

1. Introduction

In today's industrialized world, the usage of electrical power has increased at a tremendous rate. Our planet earth with its limited resources would not be able to sustain this increasing demand in the long term. Thus the need to find a substitute source of power is of great importance [1]. Controlled nuclear fusion is seen as one of the possible replacements as it is does not cause contamination or greenhouse effect and is practically limitless. This fusion reaction occurs in nature as it is a similar phenomenon to that which occurs on the surface of our sun.

To understand the working principle of fusion reaction on high energy density nuclear fusion in plasmas, various countries such as the United States, Russia, India, Pakistan, China, and Malaysia have built Dense Plasma Focus (DPF) devices to carry out the study of its effect as well as its applications from high density plasmas in various gases.

Most of the Dense Plasma Focus devices can be classified according to their distinct anode geometries (size of anode radius to anode length). For those having a ratio of typically 0.25 or below, it is classified by a Mather type Plasma focus [2], whereas those whose ratio is typically greater than 5 it is classified as a Filippov version of the focus [3]. A Hybrid version has a ratio between 0.25 and 5. These machines are shown in Figure 1.

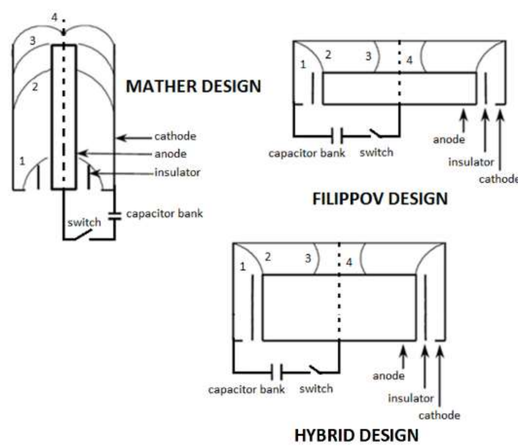

Fig. 1. Mather, Filippov and Hybrid Type Dense Plasma Focus devices schematic drawing.

These machines are quite expensive to build. Thus, each new machine should be designed for its most efficient performance and must operate efficiently. This can be done through numerical experiments using for example the Lee code.

The Plasma Focus works as follows: the capacitor bank rapidly discharges its stored electrical energy via a fast switch to coaxial electrodes. In all the three types of configuration (Mather, Filippov and the Hybrid type devices), the electric current starts along the insulator surface (shown as '1' in Fig. 1). The electric and magnetic forces combine (Lorentz force) accelerate the plasma current sheath quickly starting at position 1 through position 2 to position 3. In position 4, the shock front of the sheath coalesces symmetrically at the axis of the electrodes. A super-heated and dense plasma forms in a thin filament at position 4 on the face of the anode. The plasma pinch then breaks up because of instabilities and rapidly decays [4-6].

2. Objectives

With an increasing numbers and types of dense plasma focus machines and anode geometry all over the world, the performance of these machines comes into question. Will the numerical experimental codes, in particular the Lee code, be able to model the current waveforms of all these machines so that the designer or user of this machine is able to understand its plasma dynamics? The answer to this question is important to understand the limitations of the code. Most reports using the code have tended to discuss how the code is applicable to specific machines. This report intends to look also at the limitations, for example, in the attempts to use the code on Filippov machines.

This is because according to a research paper published by Lee and Saw [7, 8], the output current waveform of the code, when correctly fitted to the measured current signal, will reveal all the information about the "dynamics, electrodynamics, thermodynamics and radiation processes that occur in various phases of the plasma focus" of the actual machine [7, 9-17].

3. Methodology Used

In this paper, the Lee 5 and 6 phase code will be used to fit a Mather, a Fillipov and a Hybrid machine. This model was first introduced by S Lee as a 2-phase (axial and radial) model [9,18] in 1983, which was later modified over time into a 5 and 6 phase radiative plasma focus model now widely known as the Lee Model code [19]. Moreover, a model based on the Lee model, the so-called ML (modified Lee) has also been developed by Siahposh [20] and is used to successfully model Filippov type PF's, using the current fit method pioneered by the Lee code.

The physical basis, the structure of the model, the result and extensive scope of the code is shown in Fig. 2 [8,19].

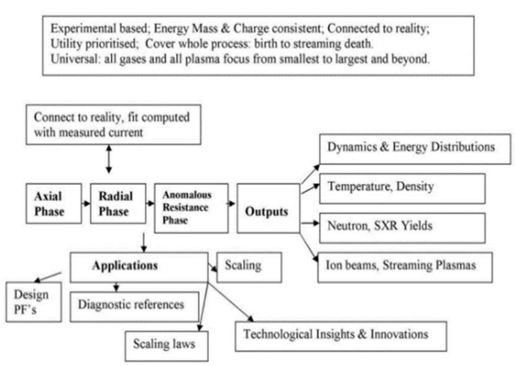

Fig. 2. The physical basis, structure, results and the extensive scope of the Lee Model code.

4. Results and Discussion

We first present case 1. The Lee code was applied to generate the current waveform of the INTI Plasma Focus (INTI PF), a Mather type machine working in neon gas at 2.0 Torr pressure. The current waveform computed from the code is fitted to the corresponding waveform measured in an actual discharge. The fitting done by overlaying the two current waveforms, computed and measured. The axial model mass and current parameters in the code are varied, repetitively, until the sections of the computed current trace between points 1, 2 and 3 (see Fig. 3) agree closely with the corresponding measured sections. Next, the radial mass and current parameters varied repetitively until the sections between points 4 and 5 of the computed waveform also agree with the corresponding sections of the measured waveform.

Fig. 3 below shows the fitting that uses the Lee Model 5-phase code to fit the measured waveform. The figure reveals that the waveform generated by the code is fitted very well up to the measured current dip corresponding to the start of pinch indicated by the lighter dashed vertical line. Beyond that point there is a divergence between the computed and measured waveform that cannot be fitted however much the mass and current factors are varied. This part of the current dip that cannot be fitted is attributed to anomalous resistivity and the large amount of remnant inductive energy that is transferred to instabilities after the pinch [21]. To account for this, the Lee 6-phase code is used. The 6-phase model code adds anomalous resistance terms into the circuit equation. The improved fitting is shown in Fig. 4.

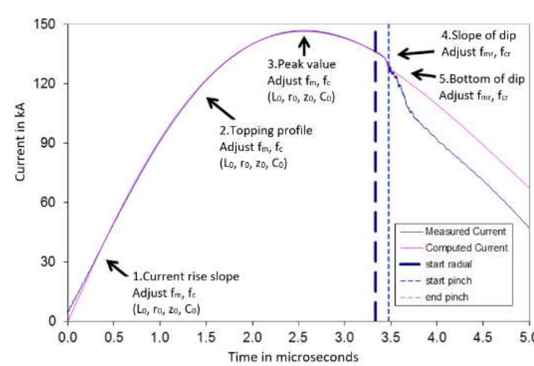

Fig. 3. The 5 phase computed current waveform compared to the corresponding waveform measured from INTI PF operated at 2.0 Torr neon.

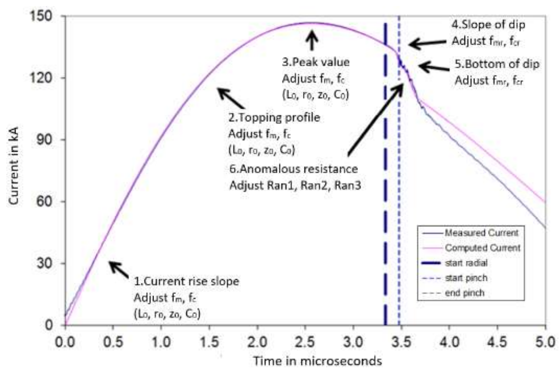

Fig. 4. The 6 phase computed current waveform fitted to the current waveform measured from INTI PF fired at 2.0 Torr in neon.

The Lee 5 and 6 phase codes are thus proven to describe the Mather Plasma Focus very well. The codes take into account the various physical mechanisms of the actual machine not accounted for in the equations of motion coupled to the circuit equation by the fitted mass sweeping (f_m and f_{mr}) fractions and effective current fractions (f_c and f_{cr}). Upon successful fitting of the corresponding waveforms, the configured code is deemed to represent the actual Mather type Plasma Focus in the gross mass-consistent, energy-consistent and charge-consistent sense.

In the second case, Lee code was used to a fit the current waveform of a Filippov-type machine having a capacitance of 9.2 mF, namely PF3 machine [22] working at 1.5 Torr in neon gas. It was found that the Lee Model codes could not fit this Fillippov Focus as shown in Fig. 5, although important information about the radial dynamics of this Filippov Focus was obtained in the process.

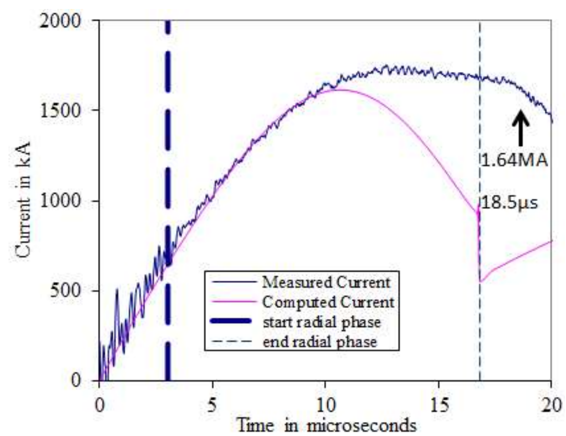

Fig.5. Measured current trace of Filippov PF3 Plasma Focus at 9 kV, 1.5 Torr neon gas compared with Lee Model 5-phase code computed current waveform. Note that the digital waveform for shot 4102 obtained on 3/5/2011 from Mitrofanov Konstantin and Krause Slava authors of [22]).

From Figure 5, it is noticed that the Lee code easily manages to fit the 'axial' phase reasonably well. The radial phase could be fitted up to 9.6 μs. Beyond that no good fit could be obtained however much of the model 4 parameters are adjusted.

Looking at the corresponding plasma trajectories from the code as shown in Fig. 6, the positions of the plasma sheath during the fitting period is identified as its very short 'axial' phase (lift-off phase) and part of the radial phase from 50 cm to 36 cm. As the radial implosion proceeds beyond radial positions less than 36 cm, the computed curve diverges. It is postulated that this is because the code assumes a well-defined slug motion (of shock front and magnetic piston), which is not the case for Filippov- type machines during the final run-down of the plasma slug towards the axis.

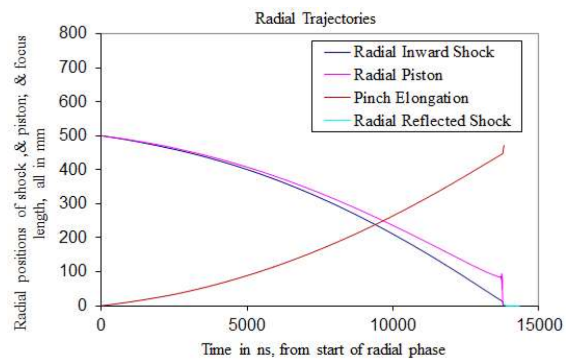

Fig. 6. Radial trajectory of Filippov PF3 according to the Lee Model 5-phase code taken from the same numerical shot as Fig. 5.

In the third case, the hybrid type plasma focus machine namely the Nano focus will be simulated with the Lee code (Current fitting shown in Fig. 7).

The Nano Focus is a very small (0.1-0.2 J) hybrid machine (ratio of anode radius (0.08cm) to anode length (0.04 cm) is 2) constructed at the Nuclear Energy Commission of Chile. It has capacitance of 0.0049 μF charged to 6.5 kV for operation in 2.25 Torr hydrogen gas [23]. Because of the small physical size of the machine (anode length of only 0.04 cm and anode radius of 0.08 cm) the step size of the computation had to be made 10 times smaller. Moreover, in order to achieve a satisfactory fit, the effective anode length was fitted to be 0.025 cm and its static inductor was fitted as 4 nH (instead of 4.8 nH as stated in reference [23]). The codes also reveal that the peak current was 5.4 kA as compared to the measured value of 4.5 kA stated in the reference.

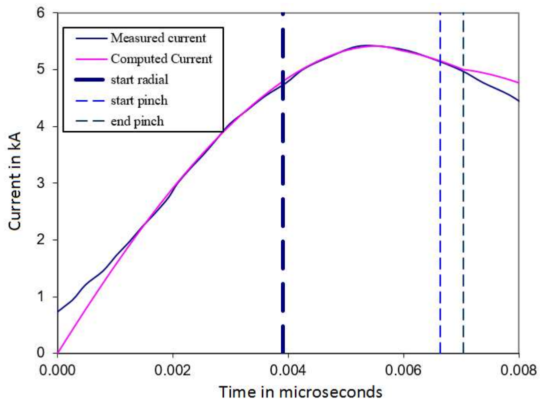

Fig. 7. Measured current waveform of the Nano Focus at 6.5 kV, 2.25 Torr hydrogen gas compared with the fitted current from Lee Model 5-phase code. Note the measured current was obtained from Fig. 4, page 3 of [23].

Thus, this experiment shows that the Lee Model 5-phase code can be used to fit even the smallest hybrid type machine.

5. Conclusion

From the fittings obtained above, it can be noted that the Lee code, fits the conventional Mather type machine very well. It should be noted that some of the Mather types machines used in various laboratories might use different anode configuration [24] or use transformer in its configuration such as the AASC machine and this is not discussed in this paper.

The codes need to be modified if it is to be fitted to a Filippov machine as stated by V Siahpoush et al, whereas for a hybrid machine, the code still fits well. Whenever the current waveform simulated by the code is correctly fitted to the corresponding measured waveform, the Lee model code computes the plasma dynamics as well as the temperature, densities, yields, ion beam, and characteristics of the streaming plasma.

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