INTI JOURNAL | eISSN:2600-7320
Vol.2020:02

Numerical Experimentation to Obtain the Scaling Laws of Mather type Dense Plasma Focus Machines Working in Argon gas

Arwinder Singh[1*], Saw Sor Heoh [2,3] and Lee Sing[1,3,4]

[1] Faculty of Engineering and Quantity Surveying, INTI International University, Persiaran Perdana BBN, Putra Nilai,71800 Nilai, Negeri Sembilan, Malaysia
[2] First City University College, No.1, Persiaran Bukit Utama, Bandar Utama, 47800 Petaling Jaya, Malaysia
[3]Institute for Plasma Focus Studies, Chadstone, VIC3148, Australia
[4]University of Malaya, Kuala Lumpur, Malaysia

[*]**Email:** arwinders.jigiris@newinti.edu.my

Abstract

In this paper, a total of 5 Dense Plasma Focus (DPF) machines, working in argon gas which uses Mather type anode (7 energy range), were analysed using numerical experimentation (Lee Codes). Three important scaling laws relating the all line yield to the peak current, pinch current and energy input into the plasma were obtained. The scaling laws act as guidelines in scaling the DPF for applications such as medical radiation.

Keywords

Numerical experiment, dense plasma focus, Lee model code, scaling laws in argon gas

Introduction

Dense plasma focus (DPF) devices are pulsed power devices capable of producing short-lived, hot and dense plasmas through a fast compression of plasma sheath. A DPF device provides intense bursts of electrons and ion beams and etc. when working in various gases. In this research paper, only Mather type anodes (the ratio of the anode radius/anode length of typically 0.25 or below) working in argon gas will be discuss and its scaling law relating the all line yield to the peak current, pinch current and energy input into plasma will be obtained using numerical experiment (Lee codes).

Dense Plasma Focus devices work as follows: the electrical energy which is stored in the capacitor bank is rapidly discharged to the electrodes by means of a fast switch. The discharge current starts along the surface of the insulator and moves along the axial phase by the Lorentz force action. In the radial phase the shock wave preceding the sheath reaches the axis of symmetry of the electrodes. Following this a filament of hot and dense plasma is formed in front of the anode. After a very short time duration, the plasma column breaks up and decays due to its instabilities (Krishnan, 2012)

International Conference on Innovation and Technopreneurship 2020
Submission: 26 June 2020; Acceptance: 3 August 2020

Methodology

According to a research paper "The Plasma Focus- Scaling Properties to Scaling Laws" (Lee and Saw, 2010), it is important to fit the numerical experiment (Lee codes) computed current trace to the measured current trace as it will reveal all the information about the dynamic, electrodynamic, thermodynamic and radiation processes that occur in the various phases of the plasma focus. This current fitting technique in terms of a flow chart is shown in Figure 1.

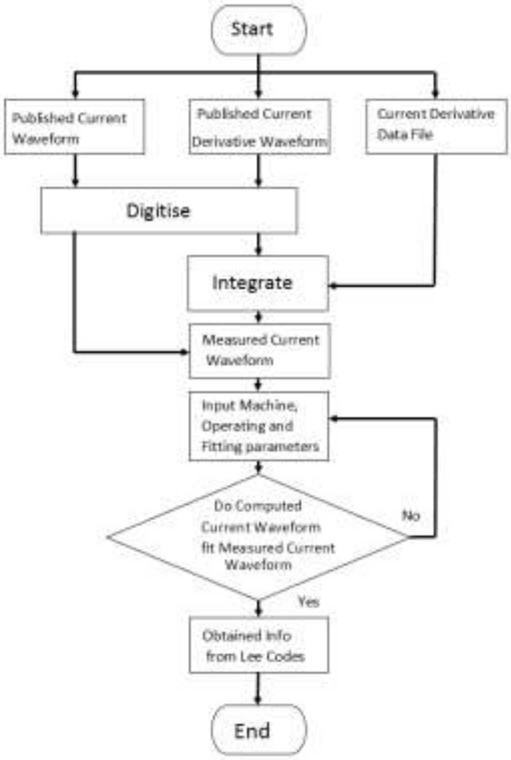

Figure 1. Flow chart showing the fitting procedure using the Lee Model codes

An example is shown below on how step-by-step procedure is used to configure the Lee's 6 phase model code (RADPFV6.1) (Lee, 2014) for a plasma focus device studied, namely the Plasma Physics Research Center (PPRC) Plasma Focus machine (Davari, 2011) from Azad University, Iran.

Firstly, the machine and operation parameters from the actual machine are placed into the Lee codes as shown in Table 1.

Table 1. The machine and operation parameters for PPRC Plasma Focus machine operating in Argon

Operating Parameters	Values	Operating Parameters	Values
Capacitance C_0 (μF)	10	Anode length 'z_0' (cm)	13.2
Static inductance L_0 (nH)	158	Voltage	14.2
Circuit resistance r_0 (mΩ)	12.5	Pressure	0.3
Cathode radius 'b' (cm)	3	Fill gas (molecular weight)	40
Anode radius 'a' (cm)	1	Fill gas (atomic number)	18
		Fill gas (atom)	1

Only then can the fitting parameters, namely the mass and current parameters be inputted to fit the computed to the measured current waveform as shown in Table 2.

Table 2. The fitting parameters for PPRC Plasma Focus machine operating in Argon

Fitting parameters	Values	Fitting parameters	Values
Axial phase mass factor, f_m	0.007	Radial phase mass factor, f_{mr}	0.1
Axial phase current factor, f_c	0.75	Radial phase current factor, f_{cr}	0.75

The mass (f_m, and f_{mr}) and current factors (f_c and f_{cr}) are adjusted one by one until the computer and measured waveform agrees as shown in Figure 2. These factors are important because the mass factors (f_m, and f_{mr}) account for the effects equivalent to increasing or reducing the amount of mass in the moving structure, during the axial phase as well as account all mechanisms which increase or reduce the amount of mass in the moving slug, during the radial phase.

The current factors (f_c and f_{cr}) account for the fraction of current effectively flowing in the moving structure during the axial phase as well as the fraction of current effectively driving the radial slug.

And lastly, the anomalous resistances values, rise time and fall time are inputted. Figure 2 shows the fitting of the measured and computed current waveforms.

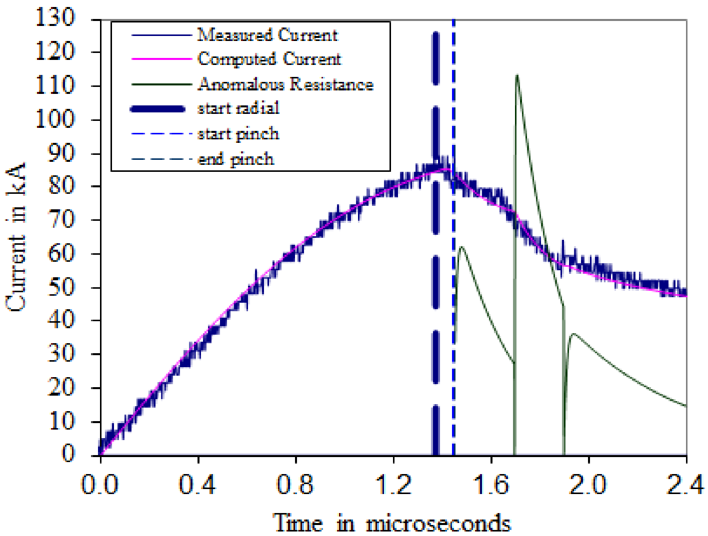

Figure 2. Measured current waveform of PPRC Plasma Focus machine at 14.2 kV, 0.3 Torr argon gas compared with Lee Model 6-phase code computed current waveform

Once all this information has been inputted, the Lee codes will automatically generate the required information (Data not displayed here).

Discussion

The Lee code computed current curve was fitted for all the 5 machines (7 different energy) using measured current waveform for each shot. Lee Model 6-phase code was used to simulate that particular focus machine for a range of pressure at the given voltage the capacitor was charged to. The optimum all-line yield and other important parameters obtained are shown in Table 3. It should be noted that the computed argon all-line yield is different from the measured argon characteristic line yield (wavelength of 3-4 Å). (Note: 1 ångström is a metric unit of length equal to 10^{-10} m)

Table 3. Parameters obtained from the Lee codes corresponding to machines named below

Machine Name	PPRC (Davari, 2011)	PPRC (Davari, 2011)	PPRC (Davari, 2011)	Tehran (Behbahani, 2011)	UNU (Lee et al, 1998)	AECS PF-1 (Al-Hawat, 2004)	AECS PF-2 (Akel and Lee, 2011)
Energy (kJ)	1	1.7	1.8	2	2.7	2.8	2.8
Peak current (kA)	96	127	131	152	171	58	108
Pinch current (kA)	66	81	76	77	101	36	68
Plasma column (cm)	0.02	0.02	0.02	0.02	0.02	0.03	0.02
Pinch duration (ns)	12.9	11.7	12.3	12.5	10.9	15.5	11.5
Pinch Voltage (kV)	69.7	112.8	93.5	90.3	134.4	27.4	87.3
EINP (%)	9.5	9.6	9.0	10.0	12.5	1.2	4.5
EINP (J)	96	164	162	199	342	34	127
All-line yield (J)	25.3	36.1	32.6	34.0	58.0	8.3	28.5

When optimum computed all-line yield was plotted to the energy input into plasma as shown in Figure 3, the equation $Y_{All-line} \sim EINP^{0.82}$ is obtained.

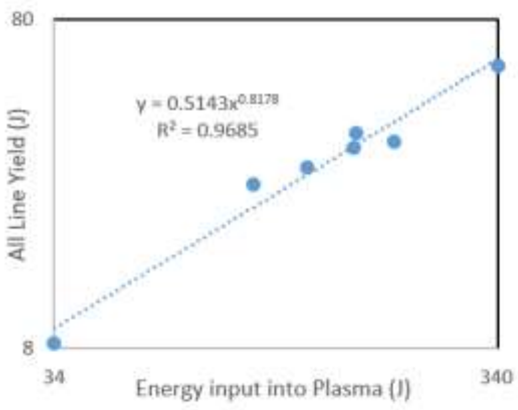

Figure 3. Computed all-line yield versus energy input into plasma

When the optimum computed all-line yield was plotted against the peak current and pinch current as shown in Figure 4. The equation of $Y_{All-line} \sim I_{peak}^{1.61}$ and $Y_{All-line} \sim I_{pinch}^{1.86}$ is obtained

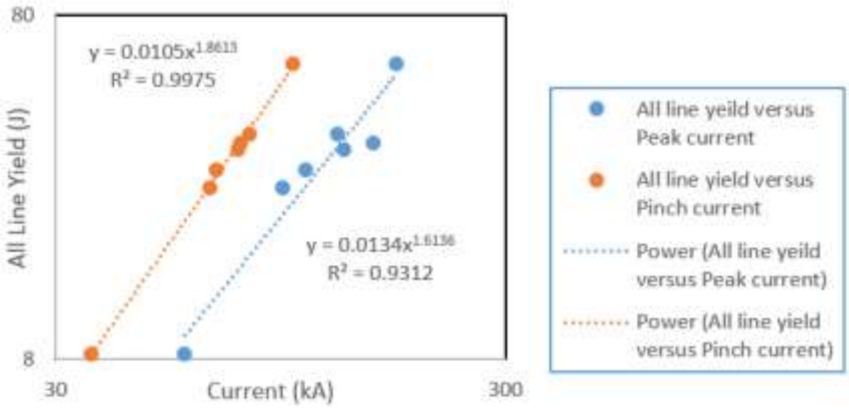

Figure 4. Computed all-line yield versus peak current and pinch current respectively

These 3 equations are the Argon all-line yield $Y_{All-line}$ scaling laws. The equations show that the Argon all-line yield depends importantly on I_{peak} and I_{pinch} and also the necessity to keep the energy going into the plasma EINP at a high level. For practical scaling purposes, the scaling equation for peak current I_{peak}, being readily controllable for example through charging voltage, is likely the most useful equation.

Conclusion

Numerical experimentation using Lee codes has helped scientists and researchers design, simulate and optimise new and existing Mather type plasma focus machine all over the world. These codes are used in this research paper to derive three scaling laws relating the all line yield to the peak current, pinch current and energy input into the plasma in argon gas. Argon plasma and its radiation are commonly used as part of medical treatment for superficial treatments of skin tissue, hence the scaling laws of argon radiation in plasma focus may be of use in designing treatment protocols. The scaling equations show that controlling the peak discharge current is the practical way to control the delivery of Argon radiation dose. The peak discharge current will affect the value of the pinch current in such a way that the two currents act together to increase/decrease the yield as the currents increase/decrease accordingly, provided the energy into the plasma quantity is kept at a high level by time-matching the discharge peak to the pinch. Thus although controlling the peak discharge current is the practical way to control the Argon all-line yield, the interaction of the three equations have also to be controlled.

References

Akel, M., & Lee. S. (2011). Practical Optimization of AECS PF-2 Plasma Focus Device for Argon Soft X-ray Operation, J Fusion Energy, pp.1-8, DOI:10.1007/s10894-011-9444-x.

Al-Hawat Sharif. (2004). Axial Velocity Measurement of Current Sheath in a Plasma Focus Device Using a Magnetic Probe, IEEE Trans Plasma Science, 32, 2, pp 764-769.

Behbahani, R. A. (2011). Private Communication, 24th July 2011.

Bing, S. (2000), Plasma dynamics and X-ray emission of the plasma focus, Ph.D. dissertation, NIE, Nanyang Technological Univ., Singapore.

Davari, T. (2011). Private Communication, 24th July 2011.

Krishnan, M. (2012). The Dense Plasma Focus: A Versatile Dense Pinch for Diverse Applications. IEEE Transactions on Plasma Science, Vol. 40, No. 12, December 2012, 3189-3221. DOI: 10.1109/TPS.2012.222267.

Lee, S. (2014). Radiative Dense Plasma Focus Computation Package: RADPF, 2014 http://www.plasmafocus.net
http://www.plasmafocus.net/IPFS/modelpackage/File1RADPF.htm
http://www.plasmafocus.net/IPFS/modelpackage/File2Theory.pdf
http://www.plasmafocus.net/IPFS/modelpackage/UPF.htm;

Lee, S., & Saw, S. H. (2010). The Plasma Focus- Scaling Properties to Scaling Laws. Joint ICTP-IAEA Workshop on Dense Magnetized Plasma and Plasma Diagnostics, 15 - 26 November 2010.

Lee, S., Tou, T. Y., Moo, S. P., Eissa, M. A., Gholap, A. V., Kwek, K. H., Mulyodrono. S., Smith. A. J., Suryadi, U. W., & Zakaullah, M. (1998). A simple facility for the teaching of plasma dynamics and plasma nuclear fusion, Am. J. Phys, 56, no. 1, pp 62–68, DOI:10.1119/1.15433