Numerical Calculation of a 2.8 kJ Plasma Focus Characteristics Using a Five Phase Model

Sh. Al-Hawat & M. Akel

Physics Department, Atomic Energy Commission, P O Box 6091 Damascus, Syria

Fax: (+963 -11) 6112289

Abstract

•A radiative five-phase model for plasma focus (S. Lee model) (axial phase, inward radial phase, reflected shock phase, pinch phase and expanded phase) was applied to a 2.8 kJ plasma focus device to find the plasma parameters and the SXR radiation emitted from the plasma pinch at different gas pressures.

- Fitting the model parameters, the calculated and measured current waveforms at 0.75 Torr of Argon were obtained and compared.

- The results were tabulated for the optimal operating conditions and compared with the same features of other different PF devices (NX2, PF1000, PF400, and DPF78).

Introduction

- As known, the plasma focus is generated by applying a high-pulse voltage to a low-pressure gas between two coaxial electrodes, with a high energy density, intense beams of charged particles and radiation emission including SXR radiation, which could be used in radiography and microelectronics lithography.

- In the early stage of Mather type - PF devices, a simple three phase model was developed to characterize their work, using a snow plow model in the axial phase and a slug model in the radial phase. Then, the model was modified to get a five phase model, in which the radial phase is divided into three radial sub-phases in addition to two essential phases (axial, and expanded). The sub-phases are a radial inward shock phase, a radial reflected shock phase and a slow compression (radiative) phase.

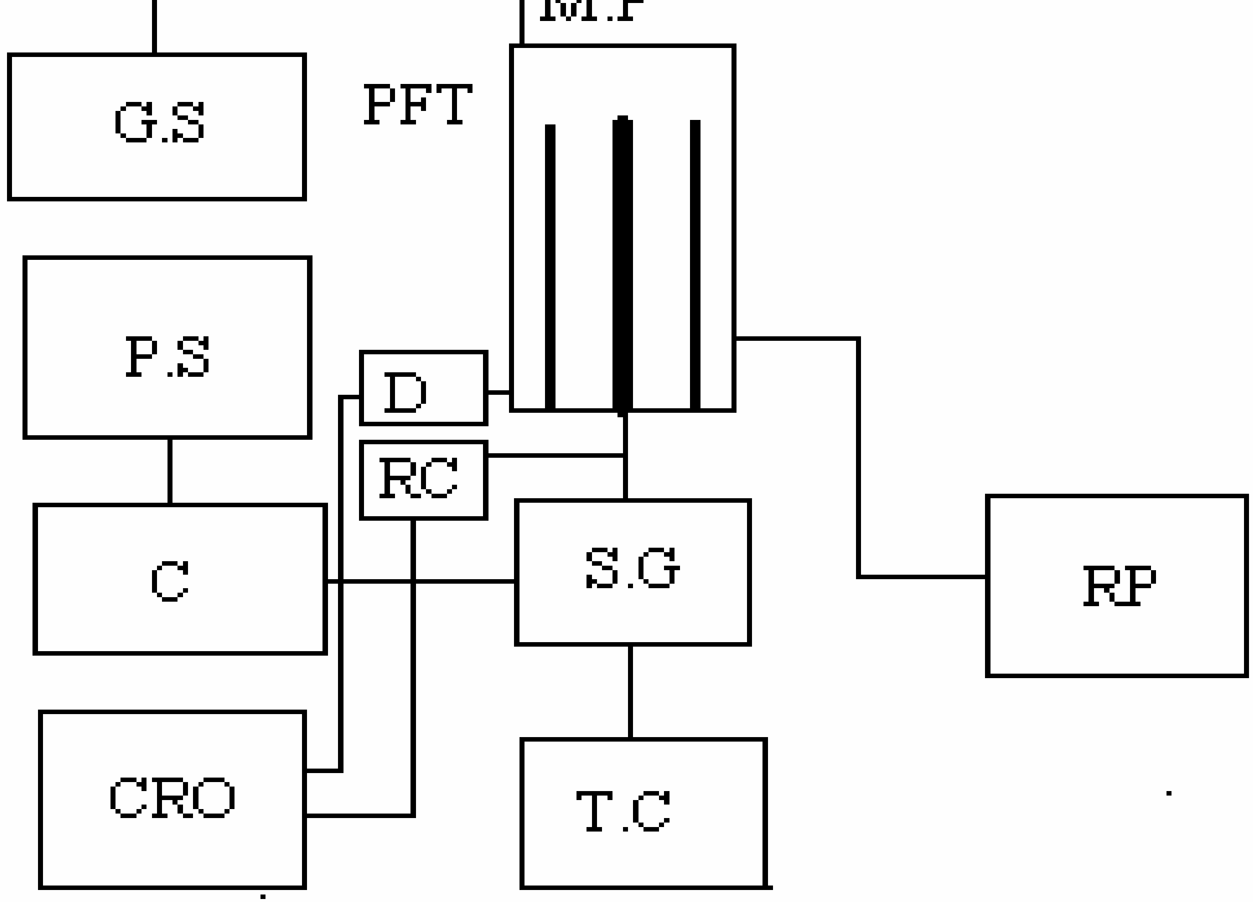
- This model is valid for many applications such as: the design of a cascading plasma focus; for estimating soft x-ray yield and for the purpose of developing a soft x-ray source (SXR) for microelectronics lithography.

- **The aim of this work** is to use the visual basic program written on the base of S Lee five phase radiative model distributed during the last **internet workshop on numerical plasma focus experiments to characterise our plasma focus device**, in comparison with other PF devices.

Experimental setup

- **Energy from the charger with specifications of 0-20 kV and 0-100 mA is stored in a 25uF, 20kV capacitor which is charged to 15 kV and switched by means of a spark gap which is in turn switched by a high voltage negative pulse getting from TV transformer of a triggering unit.**

- **The system is pumped down to a base pressure of 0.25 mbar and operated at pressures up to 5 mbar. The focus action is characterized by a distinctive dip in the current signal and a spike in the voltage signal, which indicate a rapid magnetic compression. an Ohmic voltage divider 1:100 and Rogowski coil were used to determine the voltage and current signals vs. the time during the plasma focus process using a storage oscilloscope with 1:10 attenuator.**



PF-Sy1 device: PFT plasma focus tube, GS gas supplier, PS power supply, C bank capacitors, SG spark gap, TC triggering circuit, CRO storage oscilloscope, RP rotary pump, D voltage divider, RC Rogowski coil.

On the base of measured or calculated current waveform in the case of a short circuit , the parameters such: period T , inductance L_0, resistance r_0 and the maximum current I_0 after the determining factor f could be found using the following formulae:

$$f = \frac{1}{n} \sum_{n} I_{n+1} / I_{n}$$

$$L_0 = T^2 / (4\pi^2 C_0)$$

$$I_0 = \pi C_0 V_0 (1 + f) / T$$

$$r_0 = -\frac{2}{\pi} \ln(f)(L_0 / C_0)^{1/2}$$

Results and discussion

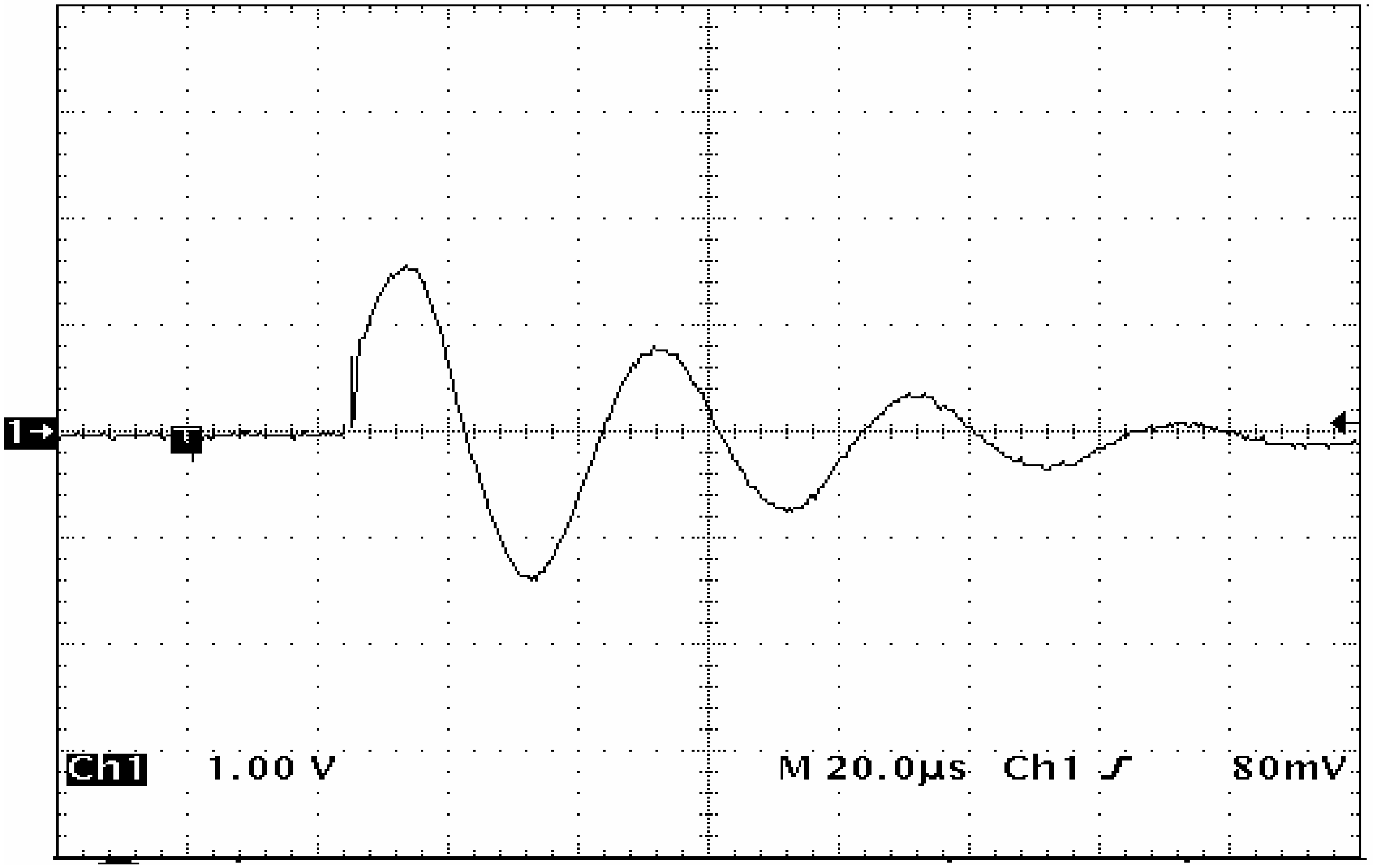


Fig. 2a The measured and calculated current waveform in the case of L-C-R circuit of device.

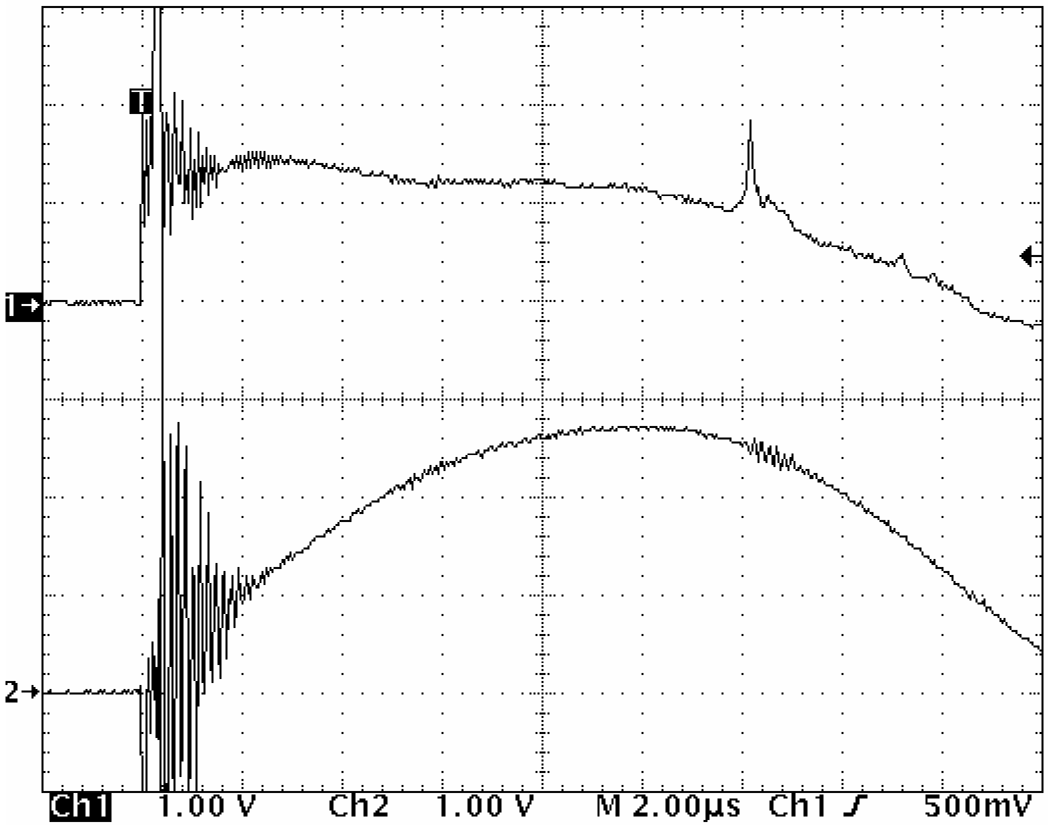


Fig. 2b The measured current (down) (**1V=21.2 kA**) and voltage (up) (**1V=1kV**) waveforms for **15 kV**, and 0.75 Torr of Ar.

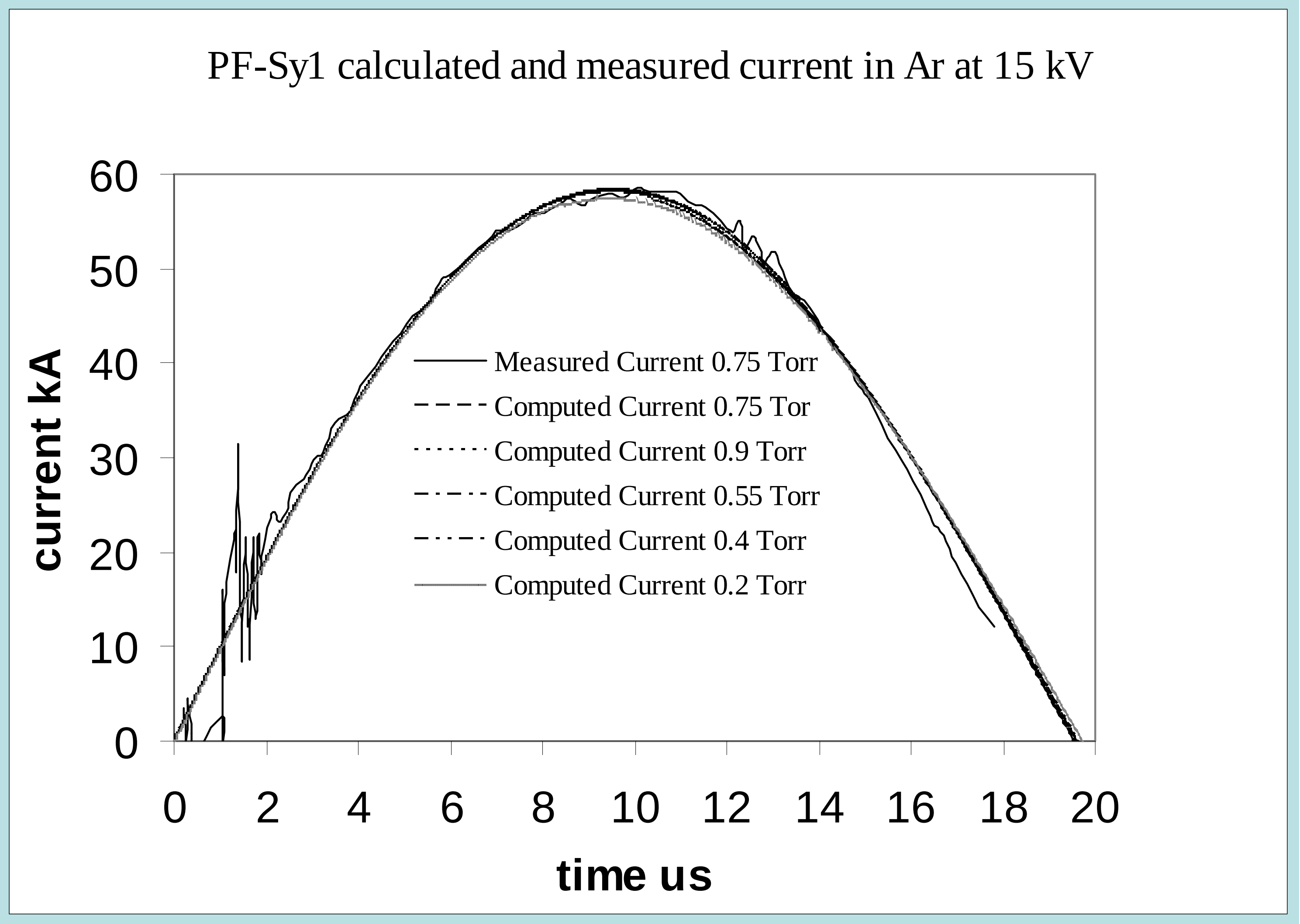


Fig. 3a The calculated and measured current – waveforms in Ar at 15 kV for diferent pressures.

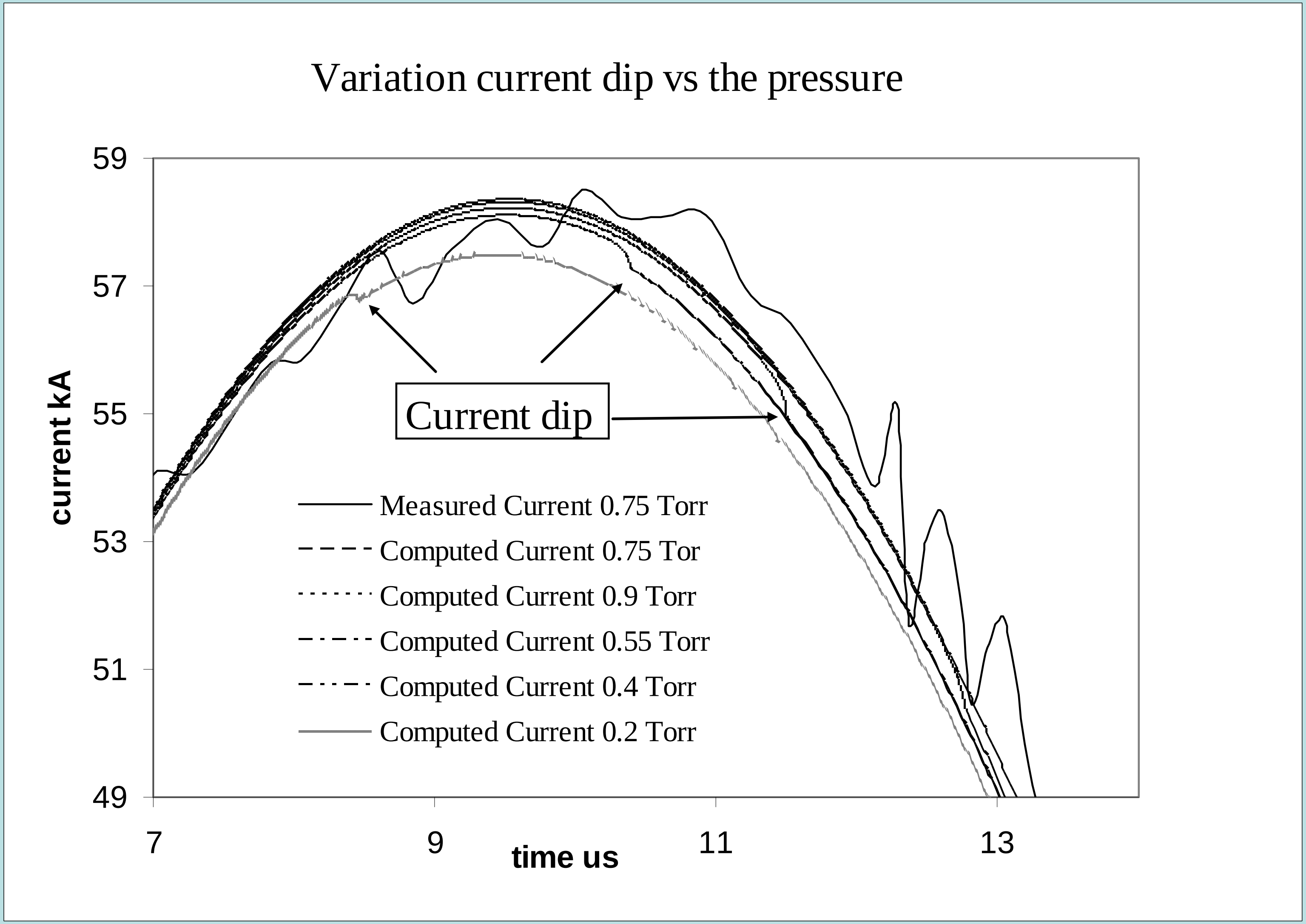


Fig. 3b Variation of the current dip on the current – waveforms vs the pressure (enlargement).

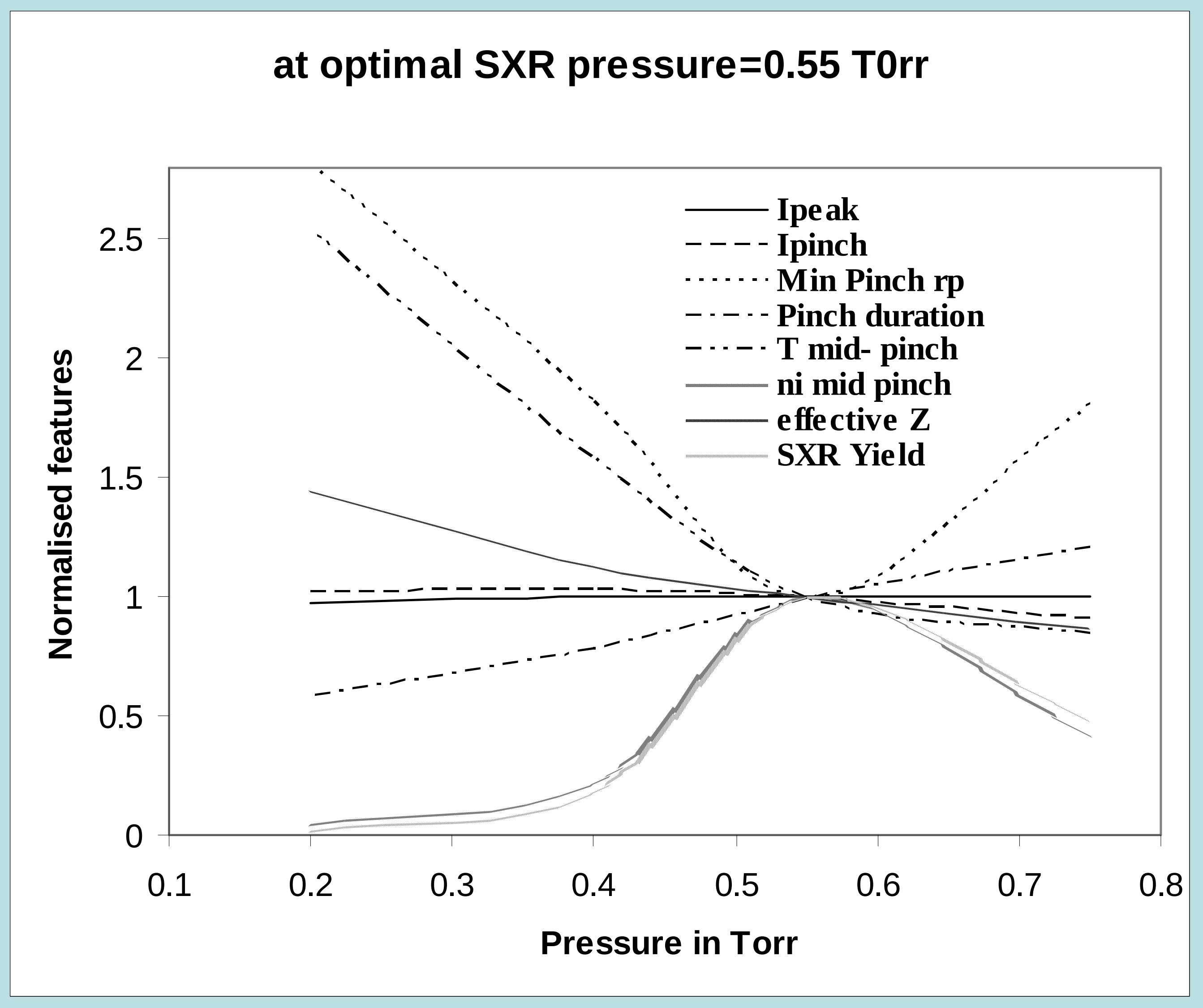


Fig. 4 Normalized characteristic features of PF-Sy1 at optimal case for SXR radiation (p=0.55 Torr).

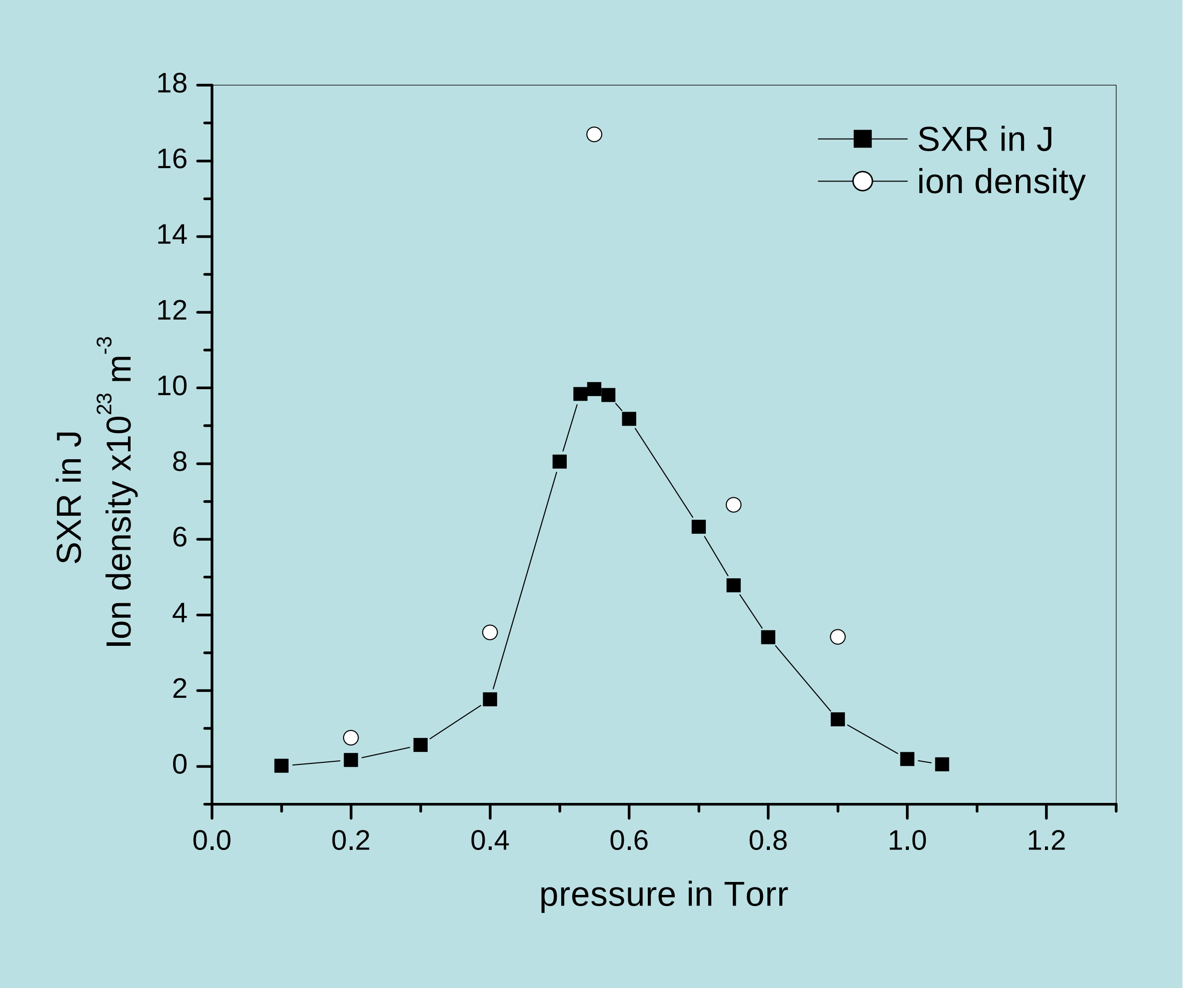


Fig. 5 Variation of SXR energy as line radiation and ion density vs. the pressure.

L_0, nH	C_0, uF	a, cm	b, cm	Z_0, cm	$r_{0,mOhm}$
1525	25	0.95	3.2	16	10
massf	currf	massfr	currfr		
0.1	0.7	0.15	0.7		
V_0, kV	P_0, Torr	MW	A	At-1 mol-2	
15	0.75	40	18	1	

Tab. I Given bank , tube, operating parameters and model parameters at 0.75 Torr and applied voltage of 15 kV in Argon (at the best fitting).

C_0 uF	V_0 kV	C_0*V_0	3*T us	T	L_0 nH		f	I_0 kA	r_0 mOhm
25	15	0.375	117.85	39.28	1565		0.938	85.1	10
	I_1	I_2	I_3	I_4	I_5	I_6			
	57.4	54.8	49.3	47.5	44.12	41.68			
	f_1	f_2	f_3	f_4	f_5				
	0.955	0.899	0.963	0.929	0.945				

Tab. IIa Calculated characteristic features: period **T**, inductance **L_0**, resistance **r_0**, maximum current **I_0** and reversal ratio **f** in the case of L-C-R short circuit of device.

C_0 uF	V_0 kV	C_0*V_0	3*T us	T	L_0 nH		f	I_0 kA	r_0 mOhm
25	15	0.375	123.75	41.25	1726		0.813	51.75	34.6
	I_1	I_2	I_3	I_4	I_5	I_6			
	53.85	46.92	25.62	26.93	11.54	13.48			
	f_1	f_2	f_3	f_4	f_5				
	0.871	0.546	1.051	0.429	1.168				

Tab. IIb Measured characteristic features: period T , inductance L_0, resistance r_0, maximum current I_0 and reversal ratio f in the case of L-C-R circuit (Ar, 3.75 Torr, 15 kV).

Tab. III Comparison of PF-Sy1 characteristics with others PF devices like NX2 (Singapore), PF1000 (Poland), PF400 (Chile) and DPF78 (Germany).

Plasma focus device	PF-SY1	PF-Sy2	NX2	PF1000	PF400	DPF78
Stored Energy E_0 in kJ	2.81	1.5	1.7	486	0.37	30.96
Pressure in Torr, P_0	0.55	0.54	2.9	3.5	6.6	7.5
Anode radius a in cm	0.95	0.95	1.9	11.55	0.6	2.5
c=b/a	3.37	3.37	2.16	1.39	2.6	2
anode length z_o in cm	16	16	5	60	1.7	13.7
final pinch radius r_{min} in cm	0.023	0.0235	0.172	2.3	0.086	0.372
pinch length z_{max} in cm	1.74	1.71	2.79	18.9	0.85	3.66
pinch duration in ns	14.532	14.709	30.6	282	5.3	21.276
r_{min}/a	0.024	0.025	0.091	0.2	0.143	0.1488
z_{max}/a	1.83	1.8	1.47	1.64	1.42	1.464
I_{peak} in kA	58.2	82.5	369.4	1845	126	867.6

I_{peak}/a in kA/cm	61.26	86.84	194.42	160	210	347.04
$S=(I_{peak}/a)/(P_o^{1/2})$(kA/cm)/Torr$^{1/2}$	82.61	118.177	114	85.6	81.7	126.7
I_{pinch} in kA	38.6	38.9	142	784	81.3	437.4
I_{pinch}/I_{peak}	0.66	0.47	0.38	0.425	0.65	0.504
Peak induced voltage in kV	33.4	32.3	20.3	40.1	16.7	79.2
peak axial speed in cm/us	2.19	3.37	5.8	11.2	9	15.7
peak radial shock speed cm/us	13	13.4	20.6	16.4	34.3	-36.2
peak radial piston speed cm/us	6.91	11.3	14.5	10.9	22.9	-24.2
peak temperature in 10^6K	1. 59	1.79	1.52	1.14	6.1	6.58
SXY yield in J	9.97	9.31	20.8	-	-	-

Conclusion

In this work we have applied RADV5.13.9b program to fit a computed current trace with a measured waveform varying the model parameters, given all bank, tube and operating parameters, in addition to that the current waveform was calculated at different pressures.

The parameters such as L_0 , I_0 and r_0 were determined from the measured and calculated current waveform and compared between them.

- **It was shown also the variation of normalized main properties of the plasma like Ipeak, I pinch, temperature and SXR yield and others vs. the pressure in related to the case of optimal SXR and the variation of SXR and ion density according to the pressure.**
- **The calculations have allowed comparing our PF device characteristics with other small and big PF devices.**

References

[1] S. Lee; “Spring College on Plasma Physics, Experiments with the ICTP-UM 3.3kJ Plasma Fusion Facility”; (17 May-11 June 1993).

[2] B. Paosawatyanyong et al., “Proceedings of the Regional Conference on Plasma Research in 21th Century”; Bangkok, Thailand, May 7-12, 80 (2000).

[3] Sharif Al-Hawat, "Axial Velocity Measurement of Current Sheath in a Plasma Focus Device Using a Magnetic Probe", IEEE Transactions on Plasma Science, Vol. 32, No. 2, April 2004.

[4] S. Lee, Institute for Plasma Focus Studies, Internet Workshop on Numerical Plasma Focus Experiments, 14/4/2008-14/5/2008

[5] S. Lee, Plasma Focus Model (radiative mofel), School of Science, Nanyang Technological University, report, 2000.

Thank You