Variation of the X-Ray Emission with Argon Gas Pressure in a UNU/ICTP PFF Plasma Focus

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Abstract

Theoretical calculations are achieved to study the effect of different Argon pressures on various parameters for UNU/ICTP PFF, a 3.3 kJ plasma focus using Lee code. Without changing the geometry and electrical parameters of this machine which build originally to work with deuterium we compute theoretically the X – ray emission energy using argon as working gas in the machine. However, some of parameters variations in this machine are studied with changing working gas pressure.

Key words: Dense Plasma Focus, Soft X – Ray Source, Argon Plasma, Lee Code

Introduction

A plasma focus device is a high power pulsed discharge which is able to produce a compressed dense plasma at the end of its coaxial electrodes. This device has been found to be an intense source of neutrons, X – ray, ion and electron beams [1]. DPF devices belong to the family of dynamic Z-pinches which are self – constricted plasma configurations. They were originally developed in the early 1960s independently in the former Soviet Union (Filippov type) and the USA (Mather type) [2]. In this device the plasma is pinched in very short time (ns), however it is hot and dense enough to enhance nuclear fusion reactions, making the DPF to be multi – radiation source. When PDF operated with argon or xenon it produces large quantities of soft X – ray whilst with deuterium it produces a fusion plasma

[3]. The plasma focus is divided into two sections. The first is a pre – pinch (axial) section. The function of this section is primarily to delay the pinch until the capacitor discharge approaches its maximum current. This is done by driving a current sheet down an axial section until the capacitor current approaches its peak. Then the current sheet is allowed to undergo transition into a radial compression phase. Thus the pinch starts and occurs at the top of the current pulse [4].

The Lee model code couples the electrical circuit with plasma focus dynamics, thermodynamics and radiation, enabling realistic simulation of all gross focus properties. The code was successfully used to assist several projects [5]. We use Lee model code (version RADPFV6.1b.xls) which executes in Microsoft Excel Visual Basic that is converted from original old version written in GWBASIC. We choose a UNU/ICTP PFF machine to execute in our numerical experiment. The UNU/ICTP PFF (United Nations University/ International Centre for Theoretical Physics Plasma Focus Facility) machine was originally designed for operation in deuterium. It is the only plasma focus machine operating in nine research laboratories in seven countries. The UNU/ICTP PFF is a $3.3\ \mathrm{kJ}$ Mather-type plasma focus system powered by a single $15\ \mathrm{kV}, 30\ \mu\mathrm{F}$ Maxwell capacitor switched on by a simple parallel-plate swinging cascade air gap [6]. However, the device can work to produce soft X-rays (SXR) with Neon and Argon. The experimental current waveform of Argon as gas fuel is taken from [7]. Then we proceed fitting to match time of the experimental and computed current data.

We use Bank parameters: the static inductance $L_0 = 110\ \mathrm{nH}$, the storage capacitance $C_0 = 30\ \mu\mathrm{F}$, and stray circuit resistance $r_0 = 12\ \mathrm{m\Omega}$. Tube parameters: the tube outer radius $b = 3.2\ \mathrm{cm},$ the inner radius $a = 0.95\ \mathrm{cm}$, and the anode length $z_0 = 16\ \mathrm{cm}$. Operational parameters: are operating voltage $V_0 = 13.5\ \mathrm{kV}$ and operating initial pressure of deuterium gas $P_0 = \cdots\ \mathrm{Torr}$. The computed total current waveform is fitted to the measured waveform by putting model parameters: the axial mass swept – up factor $f_m = 0.05,$ the tube current flow factor $f_c = 0.7,$ the radial mass swept – up factor $f_{mr} = 0.2$ and the radial current factor $f_{cr} = 0.7$ so that the computed waveform matches with the measured waveform (Fig. 1).

Since the current trace of the focus is one of the best indicators of gross performance such that the information is rapidly apparent from the current trace [8]. The computed properties are all realistic, once the two traces of measured and computed waveform are practically inseparable. The numerical experiments are then carried out at an operating voltage of $(13.5\ \mathrm{kV})$ and at various initial argon fuel pressures. A brief description of the code is given in [9] and a detailed description of the model is already available on the internet [10].

X-Ray Emissions in Plasma Focus

The calculation of the power emitted by processes within the plasma depends on assumptions made about the state of the plasma. In the code in pinch phase, line radiation Q_L is calculated using the relation

$$Q_L = -4.6 \times 10^{-31} N_i^2 Z_{eff} Z_n^4 (\pi a_{min}^2) Z_{max}/T$$

after being integrated over the pinch duration. Hence the soft X – ray energy generated within the plasma pinch depends on the properties: number density N_i, effective charge number Z_{eff}, atomic number of gas Z_n, pinch radius a_{min}, pinch length Z_{max}, plasma temperature T and the pinch duration. This generated energy is then reduced by the plasma self-absorption which depends primarily on density and temperature; the reduced quantity of energy is then emitted as the soft X – ray yield. [11]

Results and calculations

Figure (1) shows the variation of measured and computed current trace vs. time. When plasma focus loaded the current waveform distorts from damped sinusoid due to electrodynamical effects of plasma motion. The spikes of measured current waveform indicate that the pinch phase starts while the computed current waveform has a dip in pinch phase. The value of peak pinch current is (116.13 kA) occurs at time (3.721 μs) for a pressure (1.5 Toor).

Figure (2) displays the distinction of I_{peak} from I_{pinch} as pressure varied. The behavior of the plasma pinch current at start of pinch I_{pinch} with pressure is quite different from that of I_{peak}. The I_{peak} represents the maximum of current waveform at certain pressure in figure (1) while I_{pinch} represents the corresponding peak pinch current that flowing through the pinch at start of the slow compression phase. The peak value of total discharge I_{peak} increases as the pressure increased. The reason of this increasing is attributed to decreasing dynamic resistance or decreasing the rate of change of plasma inductance due to decreasing current piston when the pressure increased. The pinch current I_{pinch} that flows through the pinched plasma column increases with increasing pressure due to the pinch time that occurs before current peak time. Then I_{pinch} peaks at pressure (0.5 Torr) and starts to decrease due to the shifting of the pinch time toward the time of peak current. The main factor of decreasing I_{pinch} although I_{peak} increased, is the shift of pinch time from very late in the discharge to earlier in the discharge. The radial phase at low pressure occurs early such that it is forcing the current down early and this lowers both currents.

Figure (3) displays the computed minimum and maximum average pinch temperature vs. pressure. The T_{pinch} , a measure of energy per unit mass, is the temperature at the middle of the pinch, keeps decreasing as pressure is increased. We note that the minimum and maximum pinch temperatures have same temperature at lower and higher pressures used. They separate in the range between them. The temperature is one of factor that affects emission of x – ray energy.

Figure (4) shows the variation of axial peak in rundown stage v_a (typically end axial speed), radial shock v_s , and the radial piston v_p speeds vs. pressure. The whole speeds decrease as pressure increased in same manner. However, the figure indicates lower values of plasma speed at axial phase and the higher at radial piston (current sheath).

Figure (5) displays the minimum radius of the pinch r_{min} and pinch length at time of maximum compression z_{max} vs. pressure. Obviously there is a minimum of radius of pinch at a pressure lower than (1.5 Torr). This corresponds to peak of pinch length curve. The latter increases with pressure, peaking at mentioned pressure and then decreases as pressure increased.

Figure (6) shows the variation of pinch duration vs. pressure. It is clear that duration of the pinch increases as pressure increased. The pinch duration is another factor which affects the x – ray emission.

Figure (7) shows the variation of maximum induced voltage V_{max} vs. pressure. As pressure decreases the maximum voltage increased and has a peak at pressure (1 Torr) . It has sharp drop as pressure decreased.

Figure (8) shows the variation of ion number density at the middle of pinch duration vs. pressures. It increases as pressure decreases peaking around (1 Torr) and then dropping at lower pressures. The behavior of n_i pinch maximum is similar to maximum induced voltage.

Figure (9) displays the variation of radial phase piston work EINP (%) vs. pressures. The radial EINP computes the cumulative work done by the current sheath in the radial phases or the work done by the dynamic resistance during radial phase expressed as % of E_0. The EINP increased as the pressure increased, has a peak at pressure of 1 Torr and then decreases with increased pressure.

Figure (10) displays the variation of axial end time vs. pressures. As pressure increases the axial end time increased.

Figure (11) shows the variation of speed factor SF $(I_{peak}/a)/p_0^{1/2}$ vs. pressures. Obviously as pressure increases the SF decreased. The range of SF is 317 to 112 kAcm $^{1}/\mathrm{Toor}^{1/2}$ for argon gas.

Figure (12) shows the variation of current per cm of anode radius I_{peak}/a versus pressures. The variation extends in a narrow range from 158 to 186 kA/cm .

Figure (13) shows the variation of soft X – ray (SXR) energy vs. pressures. This energy is generated within the pinch. It is clear that higher energy generated at pressure 1 Toor which is the optimum pressure for working argon in this device. The SXR energy affects by several properties such as pinch radius, pinch length, effective charge number, temperature, number density and pinch duration.

Conclusion

The UNU/ICTP PFF is a 3.3 kJ Mather-type plasma focus system. Despite the device is originally design to work with deuterium, we without changing the geometry and electrical parameters, examine it working with argon as a source of X – ray energy. We use Lee code to simulate it operating with argon for use as an intense soft X – ray (SXR) source for lithography.

We change the fuel argon gas pressure and look to the production of X – ray energy. The optimum working pressure is 1.5 Toor since at this pressure yield higher X – ray energy.

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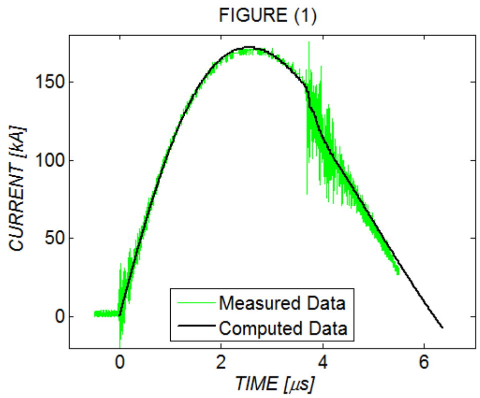

Figure (1): the variation of tube current vs. time.

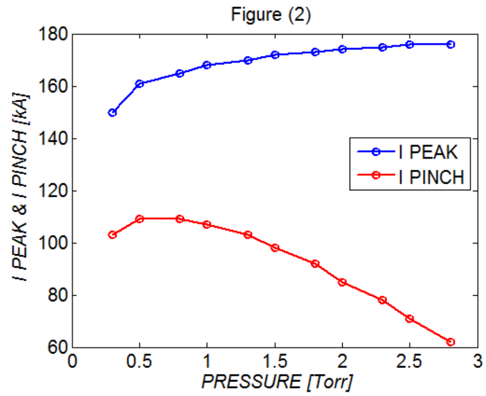

Figure (2): the variation of peak and pinch current vs.

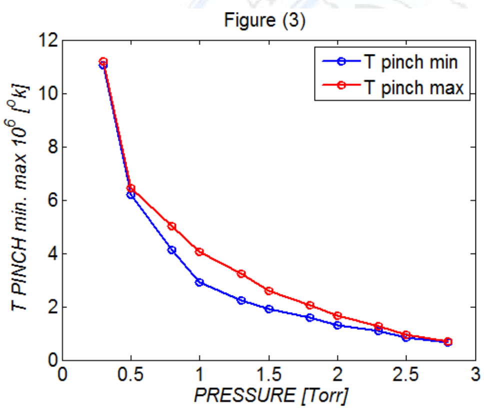

Figure (3): the variation of minimum & maximum pinch time vs. ressures.

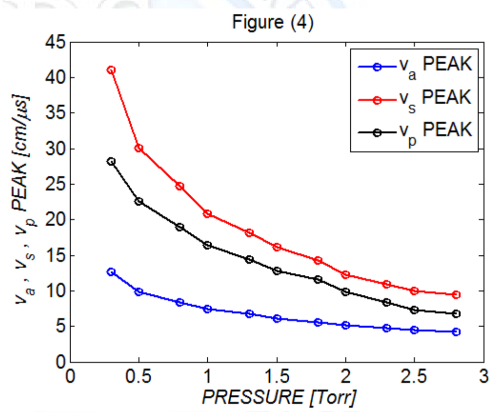

Figure (4): the variation of speeds vs. pressures.

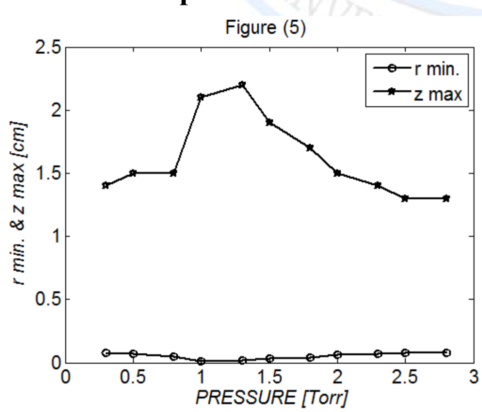

Figure (5): the variation of pinch duration vs. pressures.

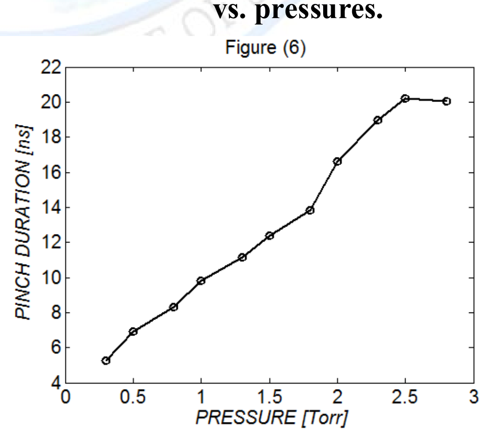

Figure (6): the variation of pinch duration vs. pressures.

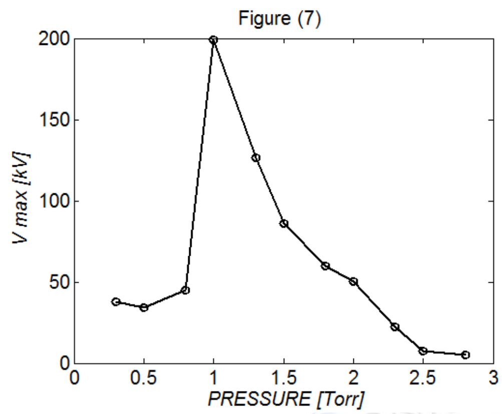

Figure (7): the variation of maximum voltage vs. pressures.

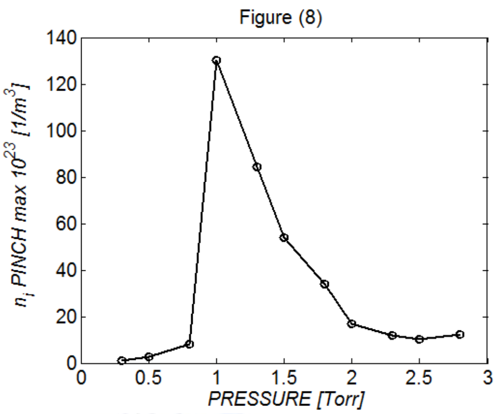

Figure (8): the variation of ion density vs. pressures.

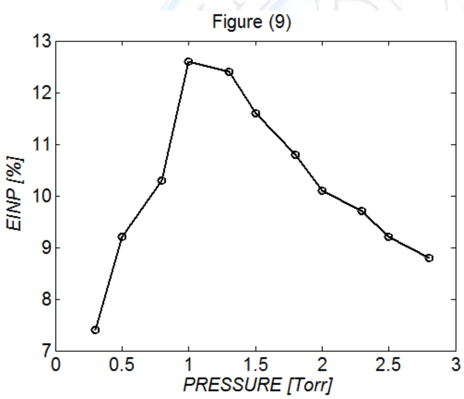

Figure (9): the variation of EINP (%) vs. pressures.

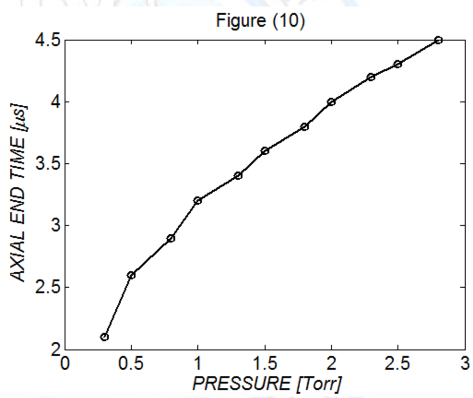

Figure (10): the variation of axial end time vs.

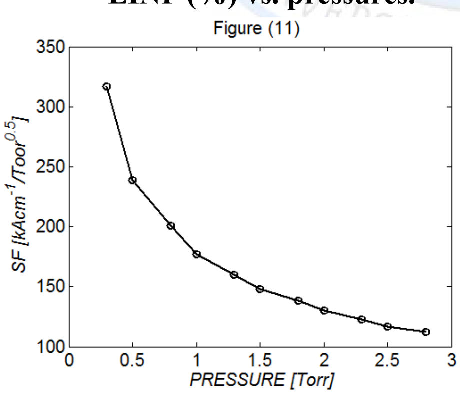

Figure (11): the variation of SF vs. pressures.

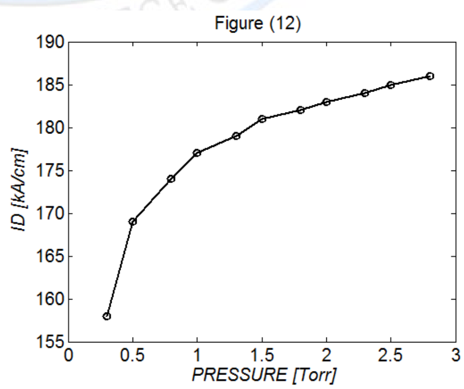

Figure (12): the variation of ID vs. pressures.

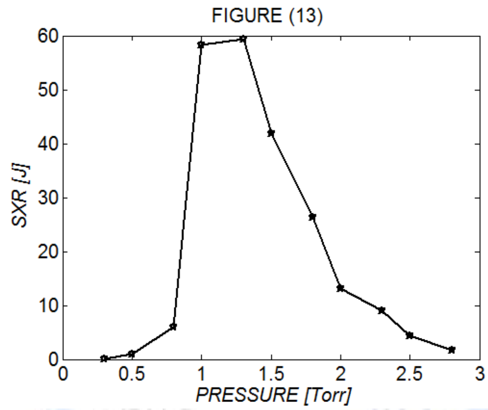

Figure (13): the variation of SXR vs. pressures.

تغيرات انبعاث الاشعة السينية مع ضغط غاز الاركـون في ماكنة بؤرة البلازما UNU/ICTP PFF

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الخلاصة

أنجزت حسابات نظرية لدراسة تأثير ضغوط مختلفة على مختلف معلمات جهاز بؤرة البلازما ,UNU/ICTP PFF 3.3 kJ باستعمال برنامج لـــي. فعند عدم تغيير هندسة هذه الماكنة ومعلماتها الكهربائية التي بنيت بالاصل للعمل بالديتروويوم حسبنا نظريا طاقة انبعاث اشعة السينية باستعمال غاز الاركـون بدلا من الديتروويوم. وقد درست تغيرات بعض المعلمات في هذه الماكنة مع تغيرات ضغط الغاز العامل.

الكلمات المفتاحية: ماكنة بؤرة البلازما ، مصدر الاشعة السينية – بلازما الاركــون – برنامج لـــي