Effects of atomic number and pressure of different filling gases on soft X-ray yield from PF1000 plasma focus device

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Abstract

The effects of atomic number (Z_n) and operating pressure (P_0) of different filling gases on soft X-ray yield (Y_{sxr}) from PF1000 are studied through numerical experiments using the modified version of the Lee model code (RADPFV5.015b). In these numerical experiments, Hydrogen (H_2), Deuterium (D_2), Deuterium-Tritium (*D-T*), Helium (*He*), Nitrogen (N_2), Oxygen (O_2) and Argon (*Ar*) are used over the range of 4.0 – 0.1 Torr of P_0 as the filling gases. Optimum P_0 at which Y_{sxr} becomes maximum is obtained through numerical experiments for each gas. The number density (n_i), percentage of input energy into the pinch (*EINP*), speed factor (*SF*), maximum tube voltage (V_{max}), pinch temperature (T_{pinch}), minimum pinch radius (r_{min}) and pinch column length (z_{max}) are computed at the optimum P_0 of each gas to realize the corresponding plasma behavior of the PF1000 device.

1. Introduction

A Dens plasma focus (DPF) device produces short-lived plasma by electromagnetic acceleration and compression which is super-hot (1 keV) and super-dense (10^{16}-10^{19} cm^{-3}) enough to cause nuclear fusion along with pulsed neutron yield (2.45 and 14 MeV), soft X-ray (0.1-10 keV) and hard X-ray (10-1000 keV), electromagnetic waves, high-energy electrons (0.01-1 MeV) and ion beams (0.01-100 MeV) [1]. The pulsed X-ray emitted from a DPF has the highest intensity among all other existing devices of equivalent operating energy [2]. Many efforts have been taking through numerical and experimental research for enhancing X-ray yields from a DPF by changing bank, tube and operating parameters of the device, such as energy of the bank, discharge current, electrode shape and material, insulator material and dimensions, operating gas and filling gas pressure [3]. For large energy devices like PF1000, the X-ray yield investigations are not very frequent since their main target is to achieve fast neutron yields for different applications [4]. Recently, we carried out numerical experiment to optimize the soft X-ray yield for Neon gas with pressure variation from PF1000 and the results of the study was published [5].

In this present work, extended numerical experiments are conducted using the modified version of the Lee model code to study the effect of Z_n and P_0 on Y_{sxr} from the standard configuration of PF1000. Relevant plasma focus parameters are computed at the optimum P_0 for different gases to understand the correlation of Y_{sxr} with the plasma properties of the PF1000 device. The consequent effects of operating pressure and atomic number on soft X-ray emission are then discussed in this paper.

2. Lee Model Code

For conducting numerical studies the Lee model code has been developed which is applicable for all Mather type and Filippov type of DPF devices [6]. This code is used to analyze all of the gross properties of a DPF machine along with soft X-ray emission by only fitting the computed and measured current waveform. In NX2 machine, this code has been successfully used showing a reasonable good agreement between the computed and measured values of neon Y_{sxr} yield as a function of pressure [7]. In the code, the line radiation is calculated as follows [8]:

$$\frac{dQ_L}{dt} = -4.6\times 10^{-31} n_i^2 Z_{eff} Z_n^4 \left(\pi r_p^2\right) \frac{z_{max}}{T} \text{ ………(1)}$$

Where, Q_L= line radiation depends on, Number density (n_i),

2. Lee Model Code (Cont.)

effective charge number (Z_{eff}), pinch radius (r_p), pinch length (z_{max}),atomic number(Z_n) and average pinch plasma temperature (T). In this code we take the soft X-ray yield (H-like and He-like ions) from neon, argon, oxygen and nitrogen to be equivalent to line radiation yield i. e. Y_{sxr} = Q_L at a suitable different temperature windows for each gas as follows: 200 – 500 eV for neon, 1.4 – 5 keV for argon, 74 – 173 eV for nitrogen and 119 – 260 eV for oxygen [8].

3. Method of Numerical Experiment

The code is configured with the following machine parameters which are taken from a published papers on PF1000 [4]:

Bank parameters: Static inductance (L_0) = 33.5 nH (slightly modified), Capacitance (C_0) = 1332 μF, Stray circuit resistance (r_0) = 6.3 mΩ (it is changed later slightly for a better fitting, r_0 = 6.1 mΩ).

Tube parameters: Cathode radius (b) = 16 cm, Anode radius (a) = 11.55 cm, Anode length (z_0) = 60 cm.

Operating parameters: Charging voltage (V_0) = 27 kV, Gas pressure (P_0) = 3.5 Torr Deuterium. The values of best fitted model parameters: f_m = 0.13, f_c = 0.7, f_{mr} = 0.35, f_{cr} = 0.65 [16]. These fitted values of the model parameters are kept constant throughout our numerical experiments for the computation of all the discharges of various gases [1, 9, 10].

4. Results

Table: At each P_0, computed Y_{sxr} yields for H, D, D-T (1:1), He, O_2, N_2, Ne and Ar gases with fixed f_m = 0.13, f_c = 0.7, f_{mr} = 0.35, f_{cr} = 0.65 in PF1000.

P_0 (Torr)	Y_{sxr} Yields (J)							
	H_2	D_2	D-T	He	N_2	O_2	Ne	Ar
4.0	0.09	0.18	1.56	10.16	4.69	3.71	17.18	10.29
3.5	0.12	0.26	**1.71**	14.93	12.96	10.55	29.21	12.32
3.0	0.17	0.39	1.32	**22.86**	37.91	31.11	65.65	61.53
2.5	**0.26**	**0.61**	0.81	20.48	119.68	96.18	111.23	242.79
2.0	0.23	0.48	0.41	16.08	403.76	320.56	269.17	1148.87
1.5	0.24	0.29	0.17	7.53	1411.87	1188.34	846.75	4352.35
1.0	0.09	0.09	0.01	2.24	**3755.92**	**4388.18**	3160.36	10702.21
0.5	0.01	0.01	0.00	0.28	729.01	2015.96	**9266.23**	23340.10
0.4	0.01	0.01	0.00	0.15	341.85	896.63	2403.50	26344.67
0.3	0.00	0.00	0.00	0.06	133.75	342.51	887.91	**28555.12**
0.2	0.00	0.00	0.00	0.02	36.72	94.43	263.3	28336.85
0.1	0.00	0.00	0.00	0.00	3.55	11.23	38.38	2243.15

It is found that the P_0 and Z_n have significant effects on Y_{sxr}. The results confirm that the heavier gas produces maximum Y_{sxr} at low P_0, where T_{pinch} becomes high compared to those for lighter gases. It is observed that for heavier gas *Ar*, Y_{sxr} = 28555.12 J is found at P_0 = 0.3 Torr with T_{pinch} = 3.2 ×10^6 K, whereas for lighter gas H_2, Y_{sxr} = 0.26 J at P_0 = 2.5 Torr with T_{pinch} = 1.15 ×10^6 K.

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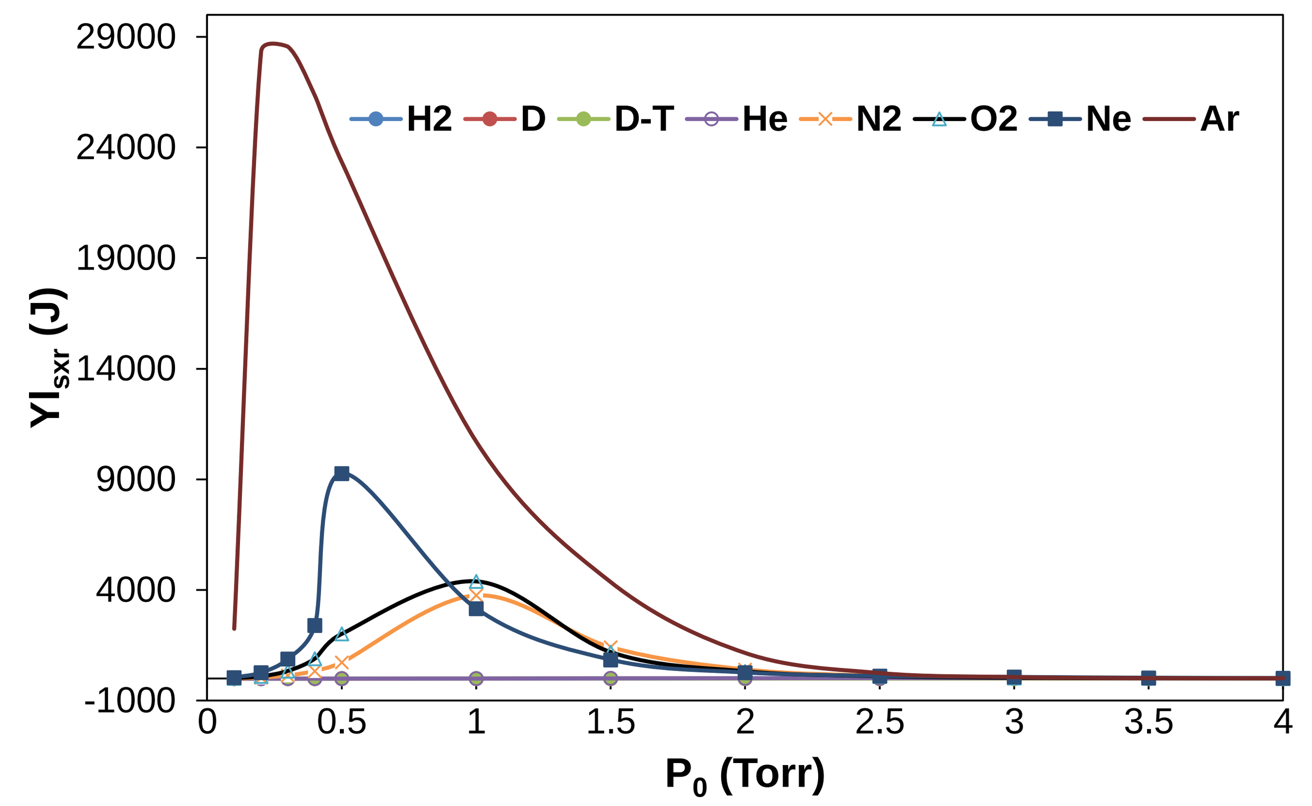

Fig. 1: Computed soft X-ray yields for different gases with respect to pressure variation in PF1000.

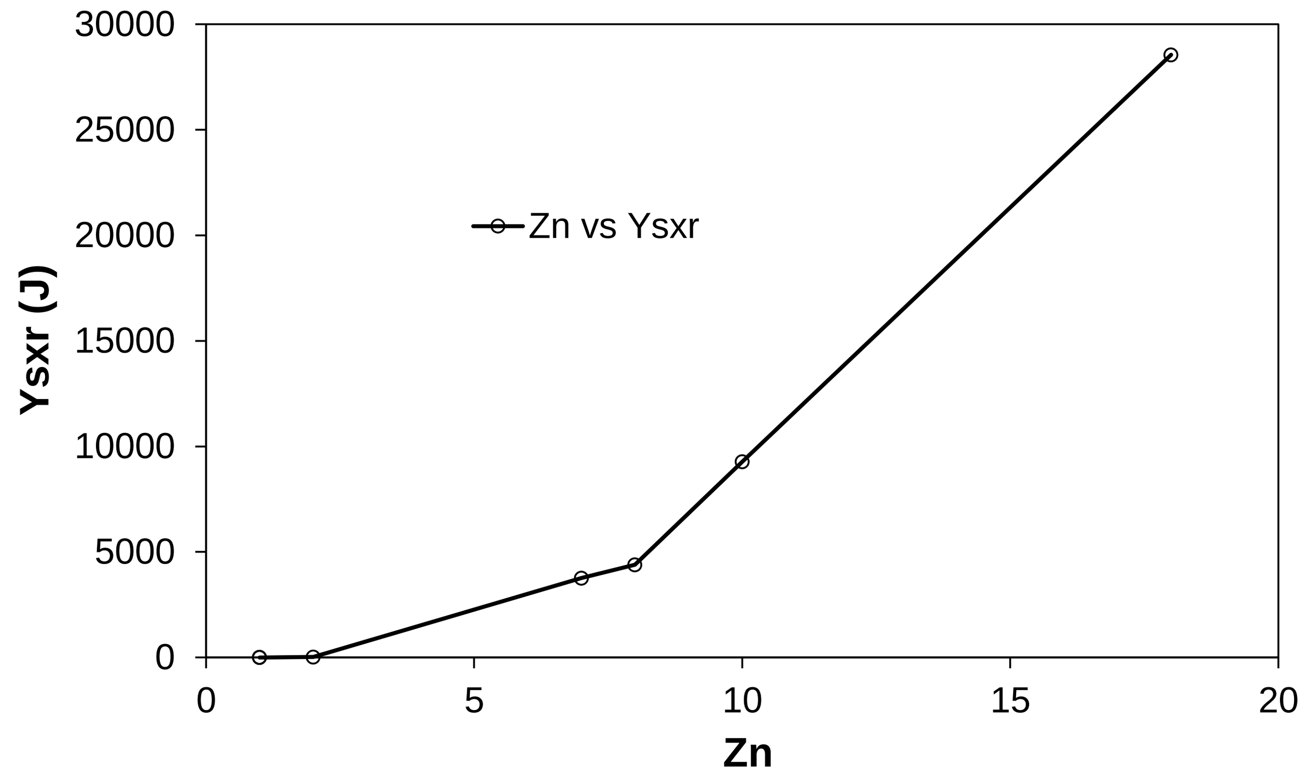

Fig. 2: Computed optimum value of Y_{sxr} yield of a gas with its corresponding atomic number pinch plasma in PF1000.

5. Discussions

The computed Y_{sxr} are plotted with respect to P_0 in Fig. 1. It shows that Y_{sxr} yield for each gas increases with decreasing P_0. But after a particular value of P_0 , Y_{sxr} yield reduce with further decreasing of P_0. This particular value of P_0 at which Y_{sxr} yield is maximum for each gas called the optimum pressure of the corresponding gas. The results confirm that the heavier gas produces maximum Y_{sxr} at low P_0 as shown in the table. The computed optimum Y_{sxr} yields for different gases are plotted as function of their corresponding Z_n as shown in Fig. 2. It is found that the optimum value of Y_{sxr} yield increases with the increase of Z_n value. This is because X-ray yield is directly proportional to the atomic number as mentioned in Eq. 1. In the study, we found that using low Z_n gas like Hydrogen or Helium it is easier to form plasma and generate Y_{sxr} but the intensity is small. These results, incorporating thermodynamics and radiative aspects, indicate a major difference between H_2 and Ar gases. The interactions of all the natures of E^{INP}, n_i, z_{max}, r_{min}, T_{pinch}, *SF* and V_{max} all contribute to the peak in Y_{sxr} as a function of atomic number and operating pressure.

6. Conclusions

Conclusion of the present numerical study is that in the case of soft X-ray production from PF1000, operating pressure for a particular gas would be adjusted carefully so that the maximum emission of soft X-ray is obtained.

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