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Research Article

Development of 2.2 kJ Plasma Focus Device and its Operation in various gases

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Abstract: A design of 2.2 kJ plasma focus (PF) device has been constructed using a set of four capacitors which are connected in parallel and has capacity of (30.84µf) and charged with voltage (12kV). This device was operated in various gases; Helium, Argon and Nitrogen in the range of pressure from 0.2 to 3.6 torr. Exchanging the Teflon flat insulator with the Pyrex glass tubular insulator between the two coaxial electrodes surrounding the inner electrode IE with a thickness 3mm and 3cm in length (effective length 25 mm from the surface of outer electrode (OE) back plate) for beam dense. Another modification was made to the discharge circuit connections to minimize the inductance of the circuit across the length of the coaxial cables has length of 2 meter and a number 0f 20 cables which are connected in parallel compared to the previous set up of the device. The optimum operating pressures have been established for each gas type under consideration in this work. We get a good focusing from this device with best spike voltage of 4.5 kV for nitrogen gas at the time of the first peak of current (T_{Imax}) with pressure of 0.35 torr, 2 kV for argon at time (T_{Imax}) with pressure of 0.3 torr and 1kV for helium at time (T_{Imax}) with pressure ranged between (o.3 torr). The discharge current has a maximum value of 180 kA at pressure of 1.2 torr, 170 kA at pressure of 0.5 torr and 120 kA at pressure of 0.2 torr for helium, argon and nitrogen gas respectively.

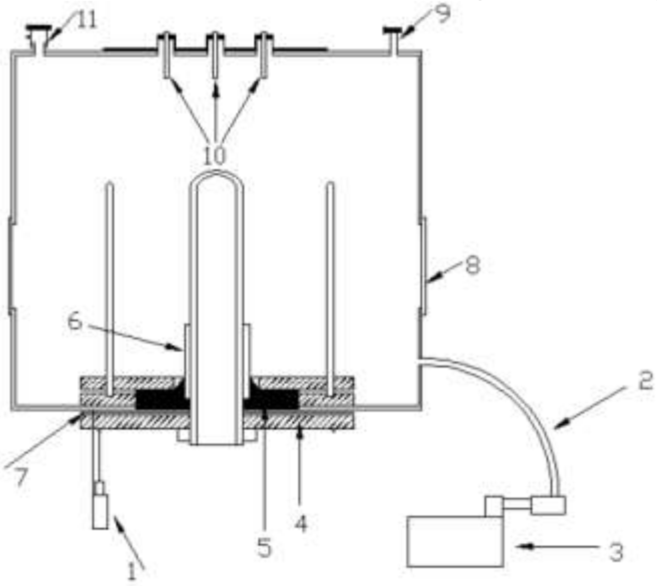
Keywords: Plasma/Focus/Voltage spike/Focusing time/Max. current time

INTRODUCTION

Plasma focus is a device which produces high density ($n \geq 10^{19}$ cm^{-3}) and high temperature (few kev)plasma with short live time nearly about100nsec [1-2]. The plasma focus [3,4] is a phenomenon that occurs when a fast electrical discharge (at least tens of kilovolts and in general, some kilojoules or more) is generated between a pair of cylindrical coaxial electrodes. These are immersed into a low pressure (some milibars) atmosphere [5]. The length of the coaxial electrodes is longer compared with electrodes radii for Mather configuration shape [6]. The dynamics of the plasma focus machine includes three phases distinct [7,8,9]. Finally once gas breakdown is achieved at the insulator surface between the coaxial electrodes breech. The current front motion is best described as an un-pinch or inverse process i.e the $(J \times B)_r$ body force is exerted out ward between the central electrode surface and the plasma current sheath, PCS. During this inverse phase, the sheath remains stables as expected, of the stability of inverse pinch process (the B_θ lines are concave). The initial current-front shape is prescribed by the Pyrex insulator. Secondly during the coaxial acceleration phase, the PCS is the forwad phase Z-direction by the coaxial electrodes muzzle. Thirdly when the PCS reaches the muzzle resulting plasma focus. Several studies were made in the past [10] to detect the correlation between the best plasma focus action and the operation discharge condition of focus devices. The study of the present paper is connected with the effects of various gases with different pressures upon the formation of the best focus action. Numerical experiments have been investigated systematically using S.Lee Model to characterize various plasma focus parameters which are operated with different gases (nitrogen, argon and helium) [11].

EXPERIMENTAL SET UP

A plasma focus device of a Mather-type was used in this experiment [1]. It was improved to get a good focusing. Our plasma focus device consisted of a coaxial electrodes system open at one end and closed separated by an insulator. The coaxial electrodes were enclosed in stain steel discharge chamber has length of40 cm and diameter of 40cm. It consists of (IE) inner electrode made of brass which has diameter 4cm length 11.5cm and (OE) outer electrode consists of eight brass rods each of them has radius 8mm and diameter 11 cm, length 13cm which are fixed around the inner electrode. A Pyrex glass insulator was surrounded the inner electrode which has a thickness of 3mm and a length of 41mm and was inserted to rubber insulator between the two electrodes instead of Teflon plate between the inner and outer electrodes. A capacitor bank consists of four capacitor which are connected in parallel and has a total capacitance of C = 30.84 µf and it charged to 12KV giving a peak discharge current until ≈ 180 kA. A resistive voltage divider consisting of ten resistance of 550 (division ratio A of 100) was connected across the anode and cathode headers at the back of the focus device. It recorded the HV transients in this device. A Rogowski coil around the (IE) at the back of the header was used to record the discharge current. It was a tours of major radius 12.5cm and minor radius 1.25cm with turns number of 165 turns. A shunt resistance .02Ω was connected between the two terminals of it. A schematic diagram of the plasma focus device with a new insulator design is shown in fig.(1).



1-Coaxial cables(20 cables). 2-Rubber tube. 3-Rotary pump. 4-Copper flange. 5-Rubber ring. 6-Glass. 7-Insultation. 8-Glass slits. 9-Vacuum Gauge. 10-Diagnostic tools. 11-Gas inle t

Fig-1: A schematic diagram of the plasma focus device

RESULTS AND DISCUSSION

For the operation of the improved plasma focus device of 2.2KJ. Helium, argon and nitrogen gases are used with pressures in the range from 0.2-3Torr. Figures (2,3and4) show a good focus position time, where the time of spike voltage is approximately coincident with the time of a peak value of total discharge current for helium, argon and nitrogen gases respectively for different gases pressures.

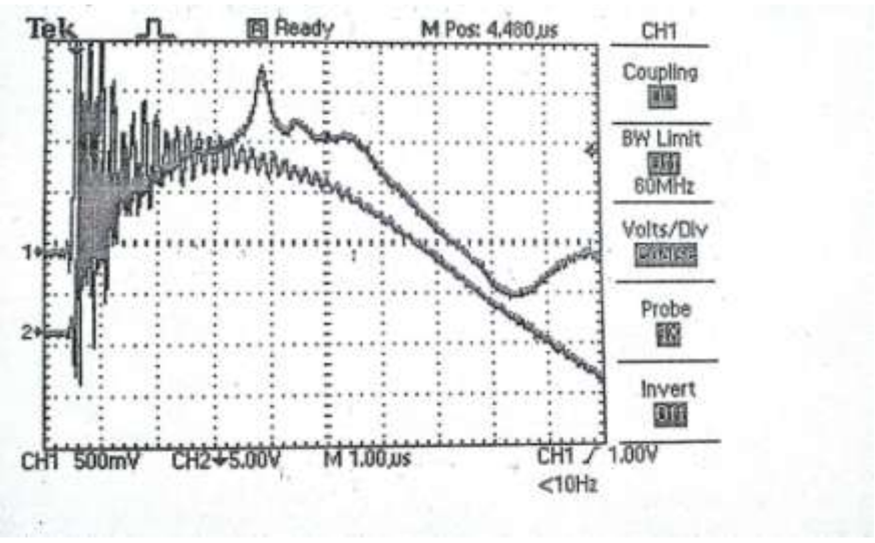


Fig-2:Oscillogram of discharge voltage and current for Helium at charging voltage 12KV and pressure 0.3torr

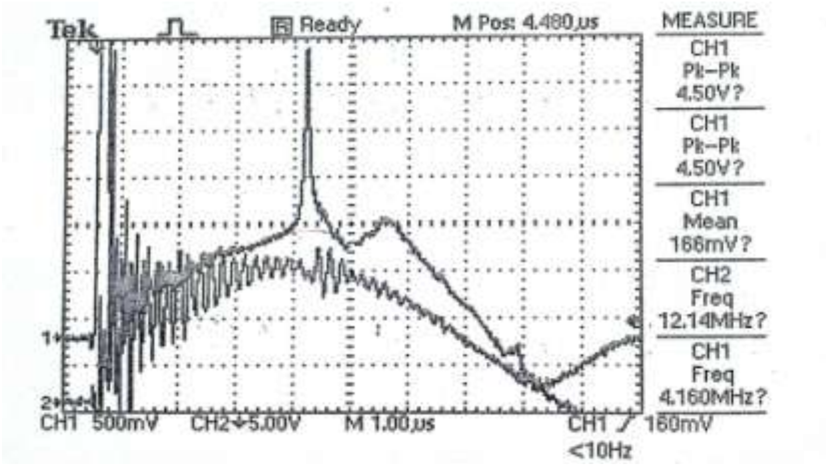


Fig-3:Oscillogram of discharge voltage and current for Argon at charging voltage 12kV and pressure .3torr

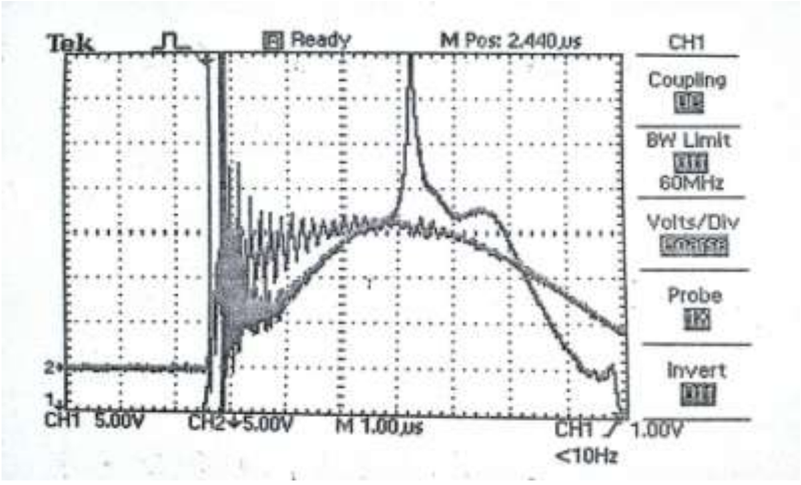


Fig-4: Oscillogram of discharge voltage and current for Nitrogen at charging voltage 12KV and pressure 0.35 torr

The above figures clear that, the optimum gas pressures is detected at 0.3torr for helium, argon gas and at 0.35torr for nitrogen gas. The relation between the spike voltage amplitude and gas pressure is shown in figure (5) for different types of gases.

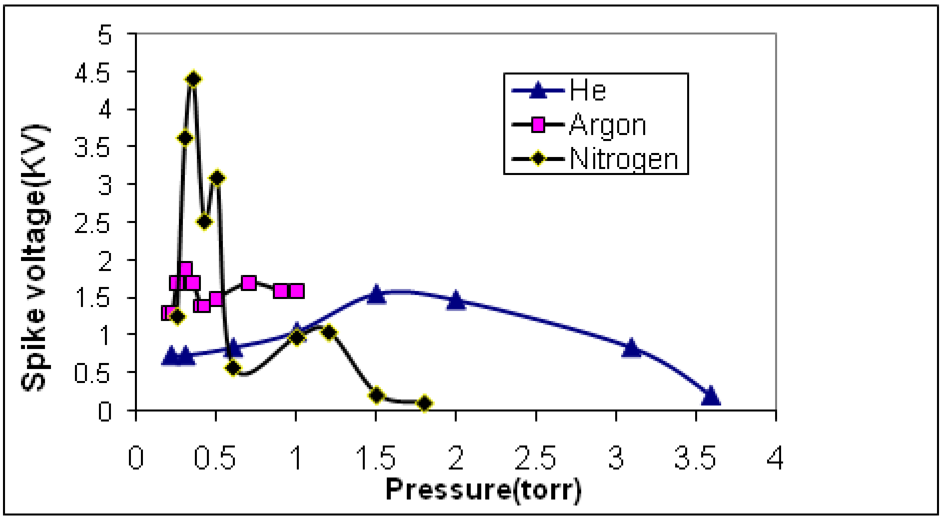


Fig-5: Relation between gas pressure and spike voltage

We notice that the maximum value of voltage 4.5 kV at time 4 µsec (T_{Imax}) and at pressure 0.3torr is obtained with Nitrogen gas and the maximum value 2KV at time 4 µsec (T_{Imax}) with pressure 0.35torr for Argon gas and the maximum value 1KV at time 3.8 µsec (T_{Imax}) with pressure 0.3torr for the helium gas. These values indicate that the nitrogen gas has maximum value for spike voltage compared to argon and helium gases.

Another notice we indicate that the relation between the focusing time and the time of maximum discharge current with gas pressure is shown in Figures (6,7and 8) for helium, argon and nitrogen respectively

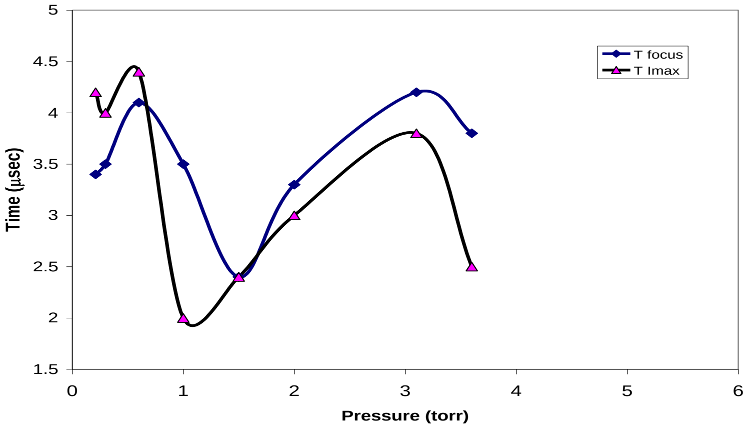


Fig-6:The relation between T_{focus} ,T_{Imax} and Helium gas pressure at chargingvoltage12KV

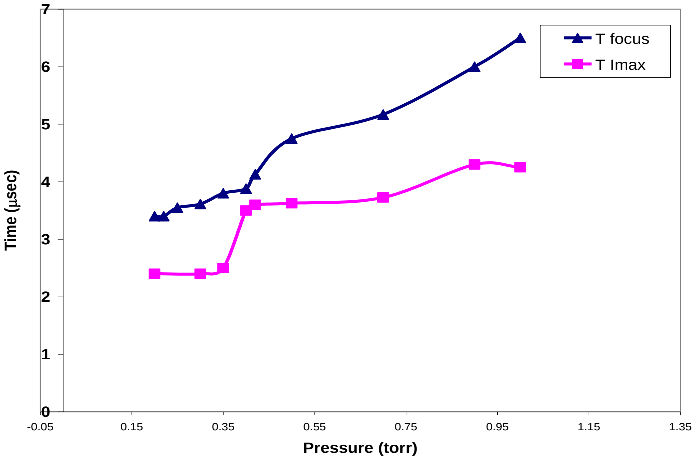


Fig-7:The relation between T_{focus} ,T_{Imax} andArgon gas pressure at charging voltage 12KV.

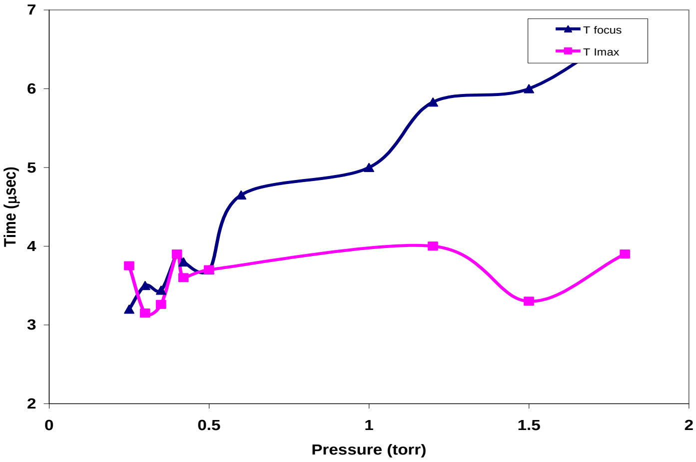


Fig-8: The relation between T_{focus} ,T_{Imax} for Nitrogen gas and pressure at charging voltage 12KV.

Figure (6) (for helium gas) shows that the T_{focus} is equal to T_{Imax} at pressure approximately 0.3torr. Figure (7) (for argon gas) shows that the T_{focus} is equal to T_{Imax} at pressure 0.35torr. Figure (8) (for nitrogen gas) shows that the T_{focus} is equal to T_{Imax} at pressure 0.35torr.

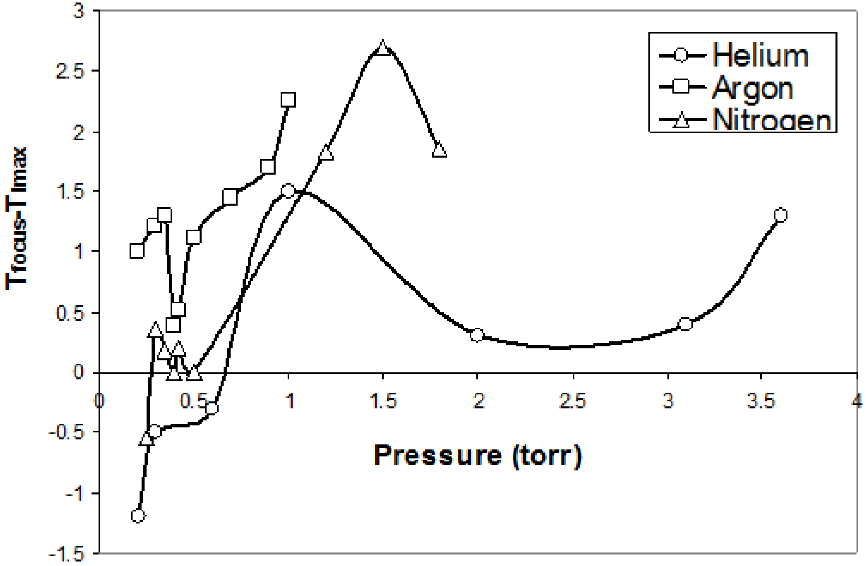


Fig-9:The relation between T_{focus}- T_{Imax} with pressure for gases helium,argon and nitrogen at charging voltage 12kV.

Figure (9) shows the relation between the value of T_{focus}- T_{Imax} and the pressures of helium, argon and nitrogen gases. We show from figure (9) that for helium T_{focus} coincident with T_{Imax} at pressure 0.3, for argon T_{focus} coincident approximately with T_{Imax} at pressure 0.3torr and for nitrogen T_{focus} coincident with T_{Imax} at pressure of 0.35torr. These results clear that a good focusing are obtained.

Numerical modeling of plasma focus using Lee Model

In the present work, the numerical simulation of the plasma focus is performed. The computational results are compared with the extensive measurements of the plasma focus with different gases at different pressures and at charging voltage of 12 KV. In 1985, a simple 2 phase (axial and radial) model was developed by S.Lee as a component of a 3 KJ plasma focus experimental package which became known as the UNU/ICTP PFF (United Nations University/ International Center for Theoretical physics plasma focus facility [12,13]. Later on, the model is written as a 3 phase (non-radiative) model for an experimental program at the 1991 Spring College in plasma physics at the international center for theoretical physics (ICTP). And finally, the present 5-phase package (axial, radial inward shock, radial reflected shock, slow compression radiative and expanded large column phase) is re-written in Microsoft EXCEL VISUAL BASIC in order to make it available for wider usage [14].

The model may be adapted to any conventional Mather-type [15] plasma focus by inputting machine parameters such as, inductance, capacitance, voltage, electrode radii and length. The main model parameters are the tube current flow factor CURRF and the mass swept-up factor MASSF. These have been pre-selected in the model.

In this experiment, the Lee Model code has been adapted as a branch version RADPF6.1b to gases of special interest to us, namely, nitrogen, helium and argon. Numerical experiments have been investigated systematically using S.Lee Model to characterize various plasma focus parameters which are operated with two gases (nitrogen and argon).

To start the numerical experiments, we select the operation parameters of the UNU/ICTP PFF which are used and collected in (table 1) and (table 2) including the input values required for operating the simulation model program [16].

Table-1: the S. lee model parameters and operational conditions of the argon gas used in our experiment

Lo nH	Co uF	b cm	a cm	zo cm	ro mOhm
237.6	30.84	5.5	2	11.5	50.24
massf	Curff	massfr	currfr	Model Parameters	
0.003	0.25	0.18	0.25		
Vo kV	Po Torr	MW	A	At-1 mol-2	Operational
12	0.3	40	18	1	Parameters

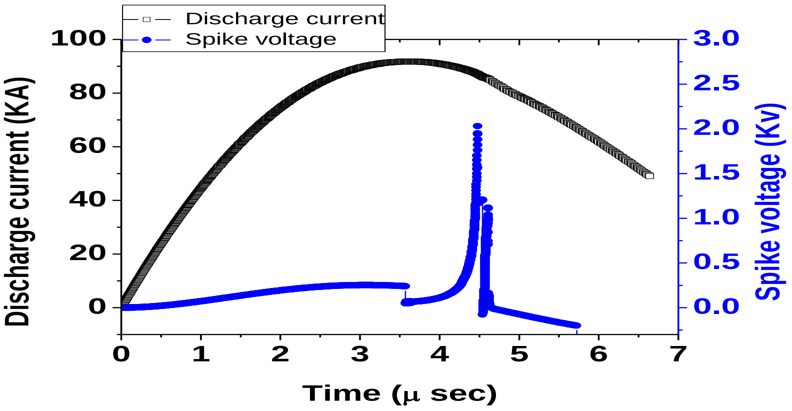


Fig-10: Theoretical relation between (the discharge current, spike voltage) and the time by using Lee Model for the argon gas.

Table-2: the S.lee model parameters and operational conditions of the nitrogen gas used in our experiment

Lo nH	Co uF	b cm	a cm	zo cm	ro mOhm
237.6	30.84	5.5	2	11.5	50.24
massf	Curff	massfr	currfr	Model Parameters	
0.01	0.3	0.05	0.3		
Vo kV	Po Torr	MW	A	At-1 mol-2	Operational
12	0.35	28	7	1	Parameters

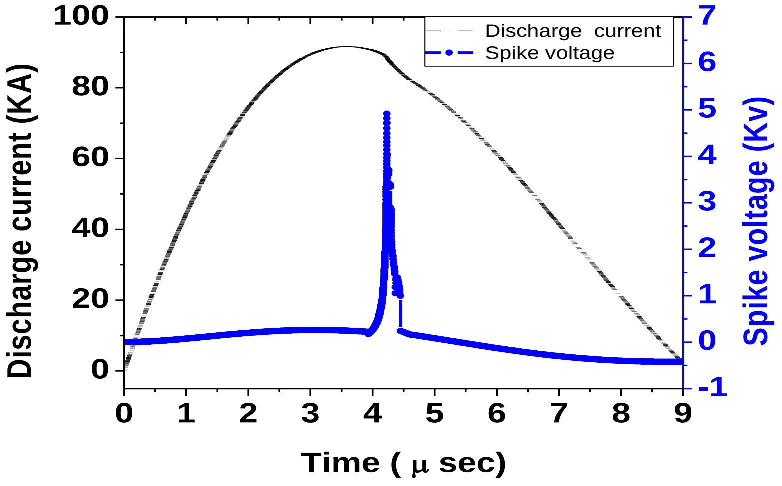


Fig-11: Theoretical relation between (the discharge current, spike voltage) and the time by using S.Lee Model for the nitrogen gas.

CONCLUSION

2.2kJ plasma focus device design is developed by exchanging the Teflon flat insulator with the Pyrex glass tubular insulator between the two coaxial electrodes surrounding the inner electrode IE with 3mm thickness and 3cm length (effective length 25 mm from the surface of OE back plate). Another modification was made to the discharge circuit connections to minimize the inductance of the circuit across the length of the coaxial cables has length of 2 meter and number 20 cables which are connected in parallel. Instead of length 2.5 meter which were used previously [1]. This device has been operated in various gases including helium, argon and nitrogen. The optimum operating pressures have been established in this work. These were 0.3torr for helium, 0.3torr for argon and 0.35torr for nitrogen. We get a good focusing from this device with best spike voltage 4kV at time of maximum discharge current pressure 0.3torr for nitrogen gas, 2kV at time of maximum discharge current pressure 0.3torr and 1kV at time of maximum discharge current pressure from o.3torr for helium gas. The discharge current has maximum value 180kA at pressure 0.3torr, 170kA at pressure at 0.3torr and 120kA at pressure 0.2 torr for helium, argon and nitrogen gas respectively. Also there were for helium T_{focus} coincident with T_{Imax} at pressure 0.31torr, for argon T_{focus} coincident with T_{Imax} at pressure 0.3torr and for nitrogen T_{focus} coincident with T_{Imax} at pressure 0.35torr. By using S.Lee model, a comparison between experimental and theoretical results was invstgated and theoretical results are reagreements with the experimental results.

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