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EFFECT OF INNER ELECTRODE LENGTH OF 2.2 KJ MATHER TYPE PLASMA FOCUS ON FOCUS ACTION

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ABSTRACT

This paper presents results of experimental studies carried out with a Mather type plasma focus device of 2.2 kJ energy. A critical effect of plasma focus inner electrode, IE length on the plasma focus action is detected for IE length has been changed to 9.5, 10.5 and 11.5 cm respectively; also for different Argon gas pressure ranging from 0.2 to 1.8 Torr. To verify this effect, it is important to investigate the plasma focus characteristics such as, a focusing time, voltage spike amplitude, focus action intensity, focus duration time, plasma focus inductance, and radius of plasma focus column as well as pinching ratio.

The diagnostics used in the experiments include a Rogowski coil and resistive high voltage probe to measure the discharge current and voltage signals respectively. All the results illustrated that, the best focus action has been achieved for IE length of 10.5 cm and at filling Argon gas pressures varied from 0.8 to 1.2 Torr.

Key words

Inner electrode length; Focus action; Voltage spike.

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1. INTRODUCTION

The plasma focus phenomenon was extensively studied from the early 70's and extensive literature was produced on it. The early work in the plasma focus has shown that in this device a hot (≈ 1 Kev) and dense (≈ 10^{19} cm^{-3}) plasma is created with lifetime ≈ 50 ns[1-4].

The dense plasma focus (DPF), is far more compact and economical than other controlled-fusion devices. It consists of two coaxial cylindrical electrodes in a gas-filled vacuum chamber connected to a capacitor bank. It is capable of producing high-energy x-ray and gamma ray radiation and intense beams of electrons and ions, as well as abundant fusion reactions [5]. The general operating principle of DPF is that the energy stored in the capacitor bank is discharged into the coaxial set by means of a fast switch. The discharge is initiated after a high pulsed voltage is applied in low pressure gas filled the annular space between the two coaxial cylindrical electrodes. Then a formation of an axisymmetric sheet is detected over the insulator surface, and it subsequent accelerated along the coaxial electrodes from breech to coaxial electrodes muzzle (axial phase) by the axial force $J_r \times B_\theta$, where J_r is the radial plasma current sheath, PCS density and B_θ is the azimuthal induced magnetic field. Afterwards, the rapid collapse of PCS off the end of coaxial electrodes and consequently a plasma focus with high density and temperature is formed [6]. The mechanism of plasma focus formation is accompanied by a distinctive strong discharge current dip and a voltage spike [7]. In most of the plasma focus devices, the duration time of axial phase is of order of a few microseconds and the formation of plasma focus time is approximately detected close to peak of discharge current time [8]. The study of PF attracts scientists of several directions related to plasma fusion technology and plasma applications [9].

Several studies were made in the past to investigate the effect of discharge conditions as well as the geometry, design and materials of the coaxial electrodes system and the insulators of plasma focus devices on operation, radiation emission from focused plasma and plasma focus parameters [10 – 15].

The purpose of the present study is to investigate the effect of changing the inner electrode length (9.5, 10.5 and 11.5 cm) on focus action as the Argon gas pressure in the range of 0.2 Torr to 1.8 Torr. The experimental data are taken from an average of several shots for every discharge condition in this work.

2. EXPERIMENTAL SETUP

A plasma focus device has been designed, fabricated and constructed in plasma focus laboratory, Plasma Phys. Dept., AEA, Egypt. The experimental setup is shown in figure (1), it consists of the electrodes assembly, the energy storage system, the electrical power supply, the vacuum system and the gas flow inlet.

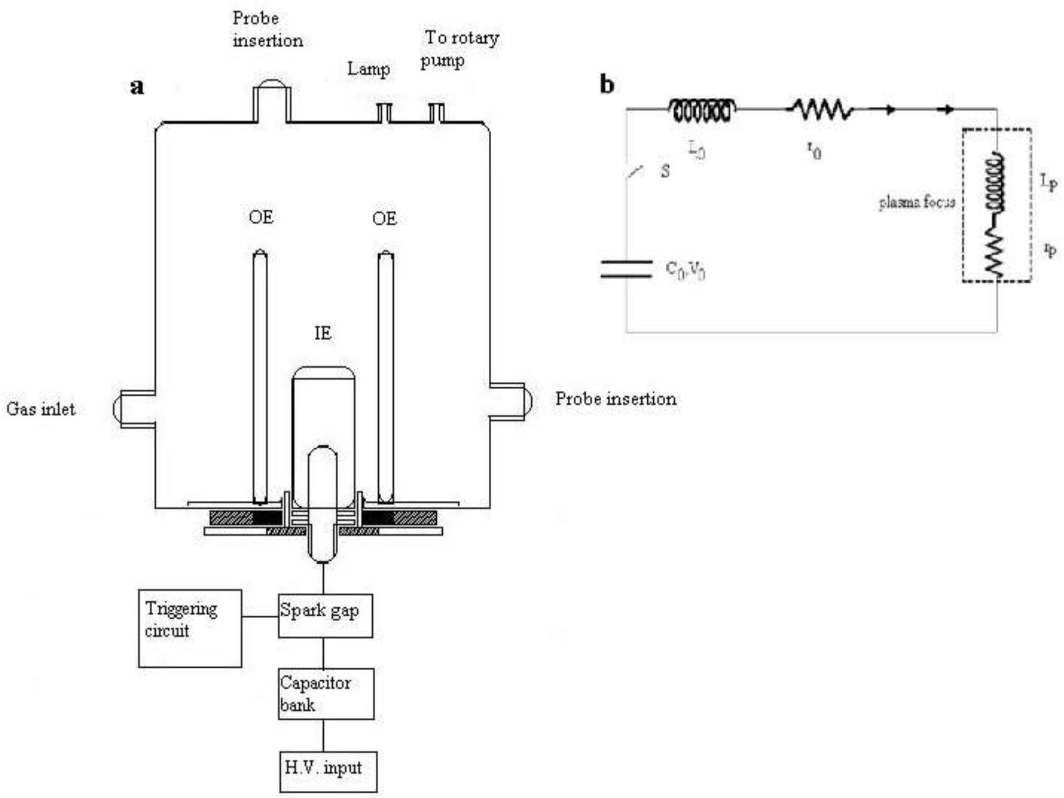


Figure 1 The experimental setup (a) and its equivalent circuit (b)

The electrodes assembly of the plasma focus device, PF, consists of a central cylindrical anode of diameter 4.5 cm with screw at its bottom to change its length (9.5, 10.5 and 11.5 cm) encircled by eight cathode rods of length 18 cm and diameter 1 cm each uniformly spaced coaxially at a diameter of 9 cm. The electrodes material is made of brass. The electrodes are screwed to a brass circular plate at the breech. The two electrodes are separated by a 2.1 cm long Pyrex glass cylindrical insulator fixed around the bottom of the anode as shown in figure 1. The electrodes system and the breech formed by the back vacuum end plate are enclosed in a stainless steel vacuum chamber of length 35 cm and diameter 41.7 cm, the chamber has facilities for axial and radial diagnostics.

The energy storage system consists of capacitor bank, pressurizing air gap switch and triggering circuit. The capacitor bank consists of three low inductance capacitors each of them has 20 nH self inductance and 10 µF capacitance, they are connected in parallel with two brass plates for positive and negative poles which in turn connected to the electrodes of the pressurized air gap switch via 24 coaxial cables. These plates are kept as close as possible with a separation of Mylar sheets to minimize the inductance. This bank is used to power the device through the triggering system which consists from a pressurized spark gap switch and a high current pulse triggering circuit.

The current pulse triggering circuit, figure 2, consists of a 120 volt power supply (transformer and rectifier) to charge a 950 µF capacitor. The capacitor is discharged by a central micro switch via the primary of T. V. line transformer to give an output sharp pulse of 15 kV amplitude and rise time less than one micro second. A power supply of SL type is used to charge the capacitor bank system with 12 kV charging voltage.

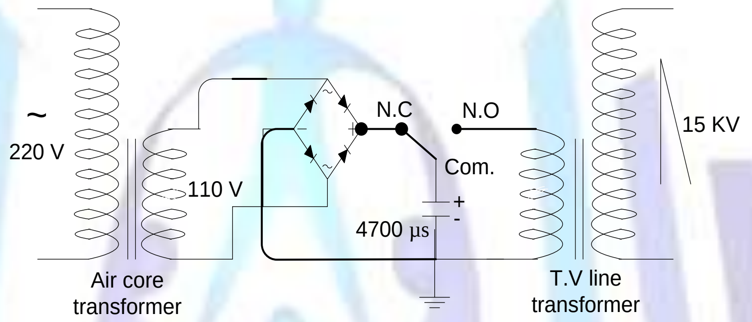


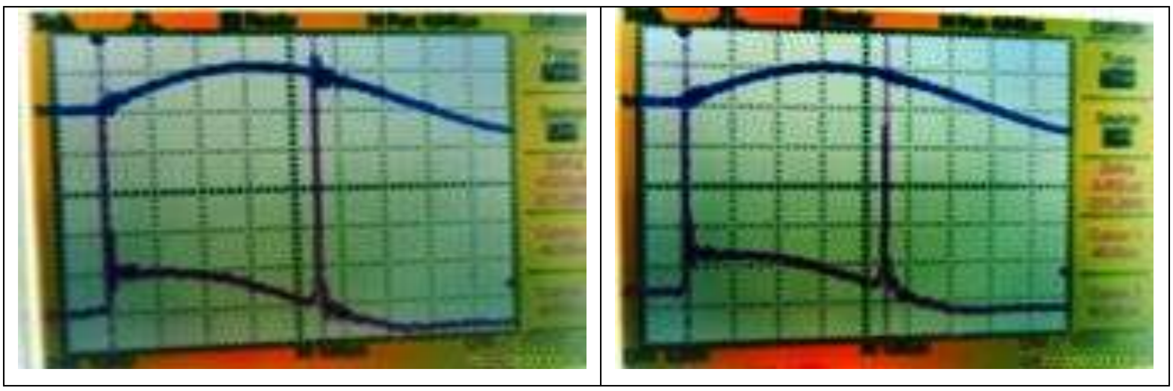
Figure 2 Pulse triggering circuit

The chamber is evacuated by means of a rotary pump to a proper air pressure then the working gas, Argon, is fed into the chamber through a needle valve which controls the gas pressure inside the chamber. An Alcatel µ Pascal digital vacuum meter and a vacuum gauge are used to measure the pressure inside the discharge chamber.

A resistive voltage divider was connected across the anode and cathode; it recorded the HV transients in the focus tube. A Rogowski coil was fixed around the coaxial cables to record the discharge current. The Rogowski coil was calibrated in situ by discharging the capacitor bank through the plasma focus device at high pressure of 13 Torr (to suppress development of the current sheath) and calculating the coil sensitivity from the waveform obtained.

3. RESULTS AND DISCUSSION

The discharge voltage and current signals have been measured respectively with resistive high voltage (1 - 100) and a Rogowski coil with a number of turns = 340, integrator circuit RC = 21 µs, and the calibration factor, k = 29.08 kA/v. the plasma discharge processes were performed in Argon gas at different pressures ranging from 0.2 to 1.8 Torr with changing of IE length, 9.5, 10.5 and 11.5 cm. All these measurements are done to get the regimes of operation for best focus action. Some of oscilloscopic traces of discharge voltage and current signals for a particular discharge shots at different IE lengths and gas pressures are presented in figure 3. It can be seen from this figure the sharp voltage spike and the current dip which are feature typical of a focusing discharge formation [16].



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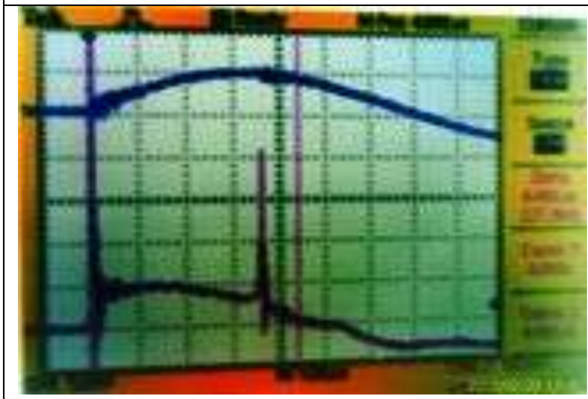
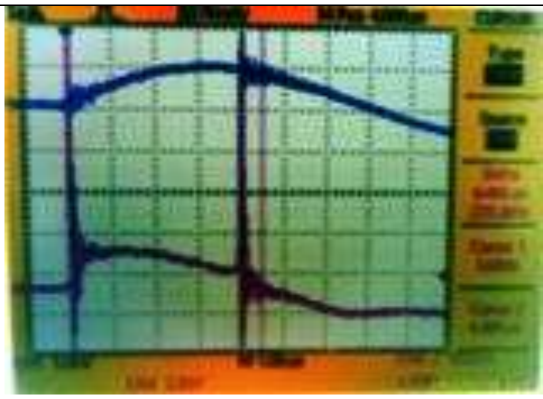
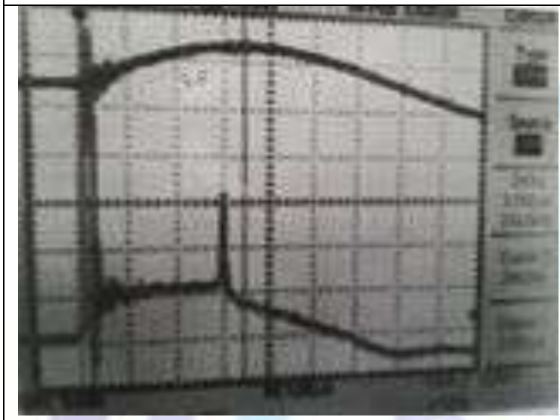
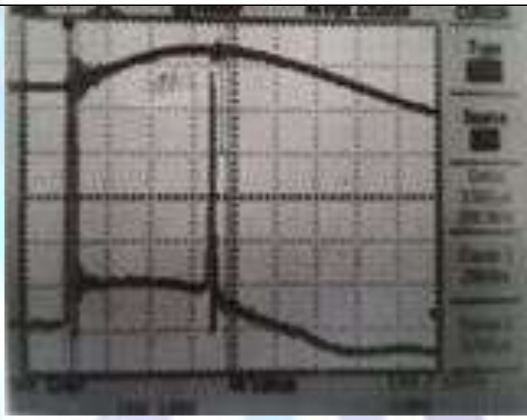
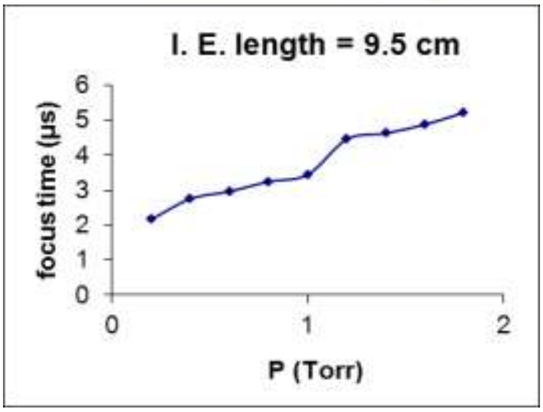
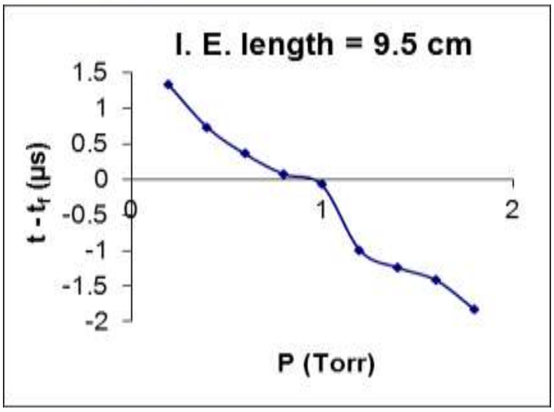
I.E. = 9.5 cm and P = 1.6 Torr	I.E. = 9.5 cm and P = 1.2 Torr
	
I.E. = 10.5 cm and P = 0.6 Torr	I.E. = 10.5 cm and P = 0.8 Torr
	
I.E. = 11.5 cm and P = 0.2 Torr	I.E. = 11.5 cm and P = 0.4 Torr

Figure 3 Typical oscilloscopic signals of current (upper trace) and HV pulse (lower trace) at different IE lengths and pressures with time scale 1 μs/div

Figure 4, a and b describes the variation of focus time and the difference between focus time and rise time of discharge current versus the Argon gas pressures and at different IE lengths respectively. Figure 4, a shows an increase of focus time by increasing the values of gas pressures from 0.2 to 1.8 Torr, these results can be attributed to the effect of gas pressure on the mean free path of plasma particles and consequently on the plasma current sheath velocity during the axial phase [17] for IE length of 9.5 and 10.5 cm while at IE = 11.5 cm the plasma focus formation is detected for gas pressures within the range from 0.2 to 1 Torr only and at gas pressure higher than 1 Torr no plasma focus is formed because the magnetic pressure is not strong enough to compress the plasma current sheath. Also, this figure illustrated that the focus time is almost similar for IE = 10.5 cm and Argon gas pressure changed from 0.6 to 1.2 Torr. Figure 4, b clears that the plasma focus is formed exactly at peak of discharge current time at p = 1, 0.6 and 0.5 Torr for IE = 9.5, 10.5 and 11.5 cm respectively.





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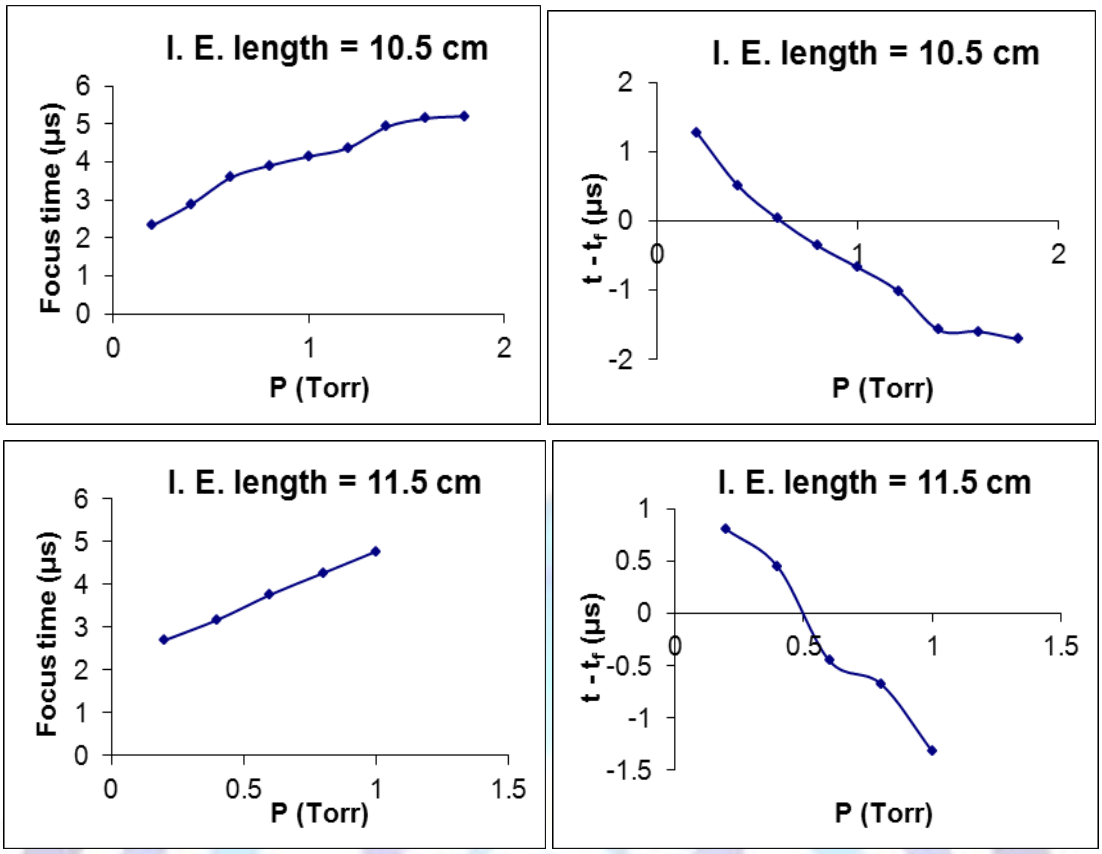

Figure 4 Variation of focus time (a) and difference between focusing time and time to peak of discharge current (b) with Argon gas pressure for the different IE lengths

Figures 5 and 6 show the variation of voltage spike amplitude and the focus action intensity as a function of Argon gas pressure and at different IE lengths respectively, as it can be seen from the figures that the distribution of voltage spike amplitude and the focus action intensity with gas pressure have approximately the same behavior for most IE lengths. The maximum value of voltage spike amplitude and focus action intensity on average ≈ 30.5 kv[18] and 23.5 AU respectively is detected for IE = 10.5 cm and for Argon gas pressure ranging from 0.8 to 1.2 Torr.

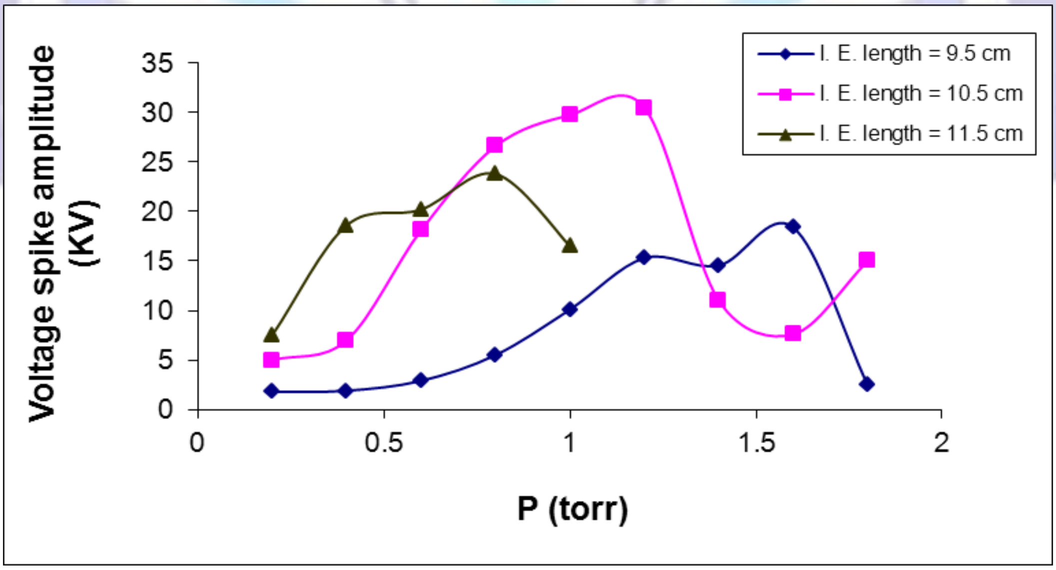

Figure 5 Voltage spike amplitude versus Argon gas pressure at different IE lengths

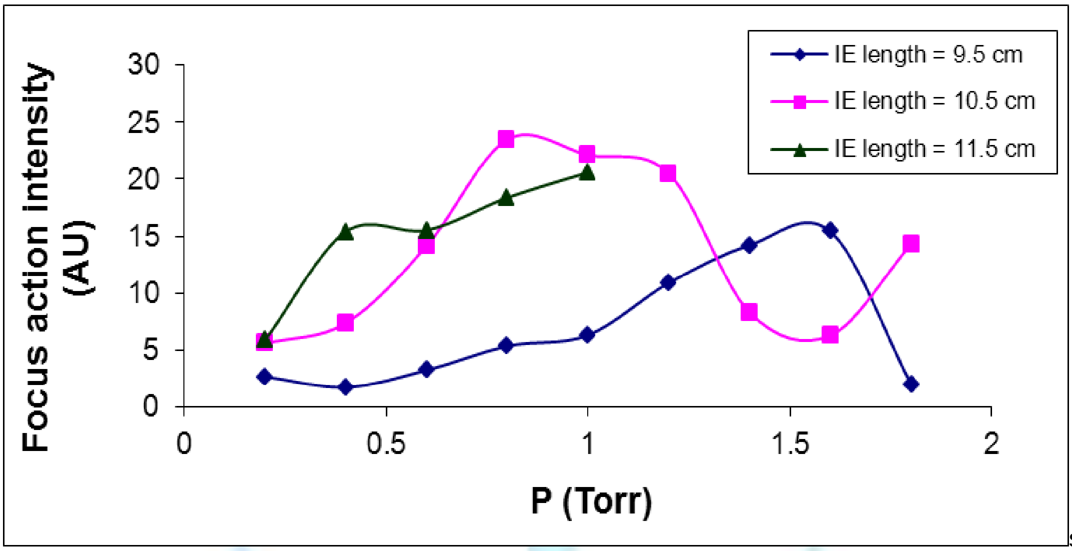

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Figure 6 Variation of focus action intensity variation with Argon gas pressure at different IE lengths

In figure 7 the plasma focus, PF duration time investigated from the voltage spike as a function of the filling Argon gas pressures is shown for different IE lengths, as can be seen for IE length = 10.5 cm the duration time is approximately has the same value for all Argon gas pressure under consideration. Also at this distance and at gas pressure ranging from 0.8 to 1 Torr, the focus duration time is less than the two other IE lengths (9.5 and 11.5 cm).

Plasma focus inductance, L_{pf} versus Argon gas pressures for different IE lengths is shown in figure (8), where:

$$L_{pf} = \frac{\int V_f \, dt}{I_t}$$

where V_f is the voltage spike amplitude, and I_t is the discharge current. As it evident from this figure the maximum value of L_{pf} = 20.8 nH is detected for IE length of 10.5 cm and p = 1.2 Torr and at Argon gas pressures ranging from 0.8 to 1.2 Torr the L_{pf} values are greater than that at IE lengths of 9.5 and 11.5 cm.

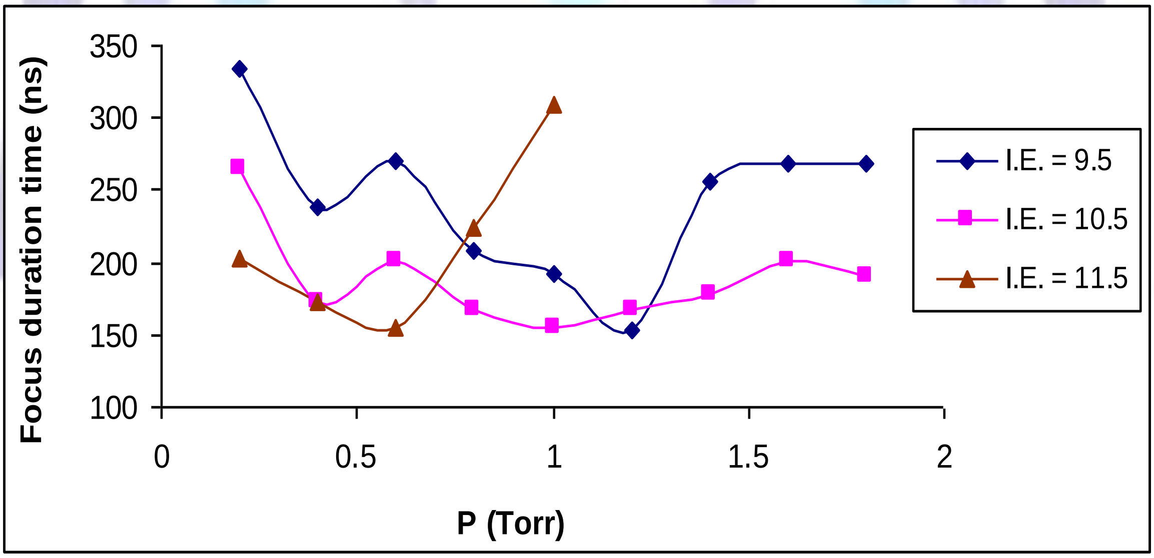


Figure 7 Variation of plasma focus duration time versus Argon gas pressure for different IE lengths

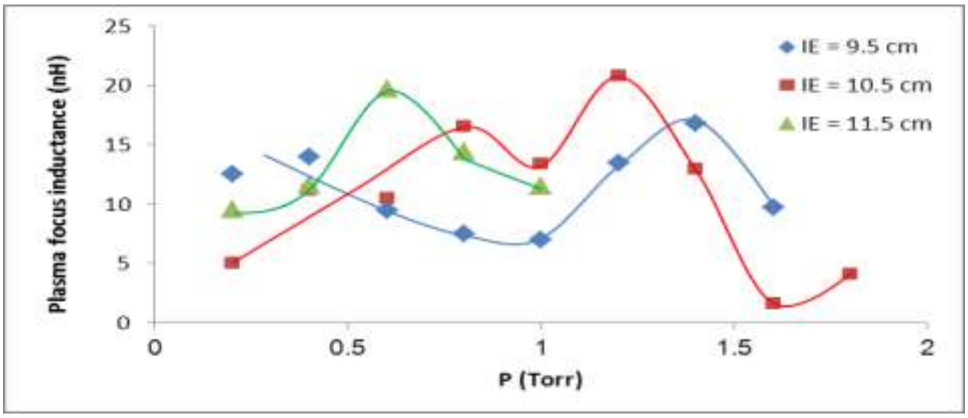


Figure 8 Plasma focus inductance versus Argon gas pressure at different IE lengths

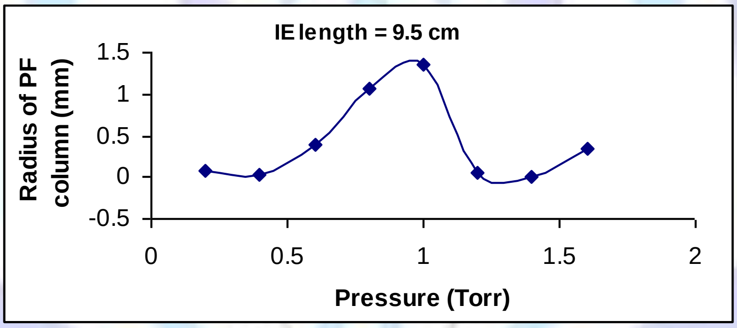
Radius of plasma focus column, r_p is evaluated from the relation [19]

$$L_{pf} = \frac{\mu_o}{2\pi} Z_f \ln\left(\frac{b}{r_p}\right)$$

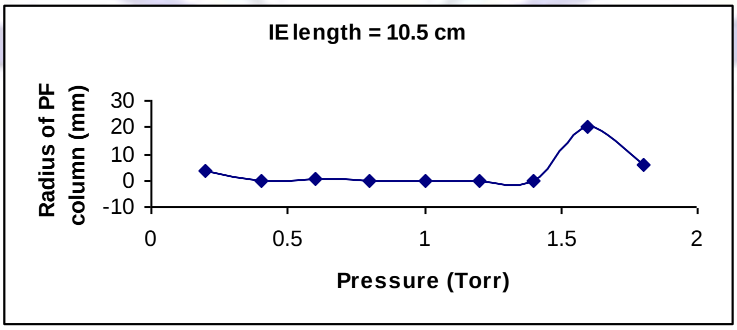
where μ_0 is the magnetic permeability = $4\pi\times10^{-7}$ Hm^{-1}, and Z_f is the PF column length. Taking Z_f = 1 cm [19] then the dependence of r_p and the pinching ratio (= r_p / a) on Argon gas pressures for different IE lengths is shown in figures (9 a, b, c and 10) respectively. These figures demonstrated that the optimum value of $r_p = 1.4\times10^{-3}$ cm and (r_p / a) = 0.061 is obtained for IE length of 10.5 cm and Argon gas pressure of 1.2 Torr.

4. CONCLUSION

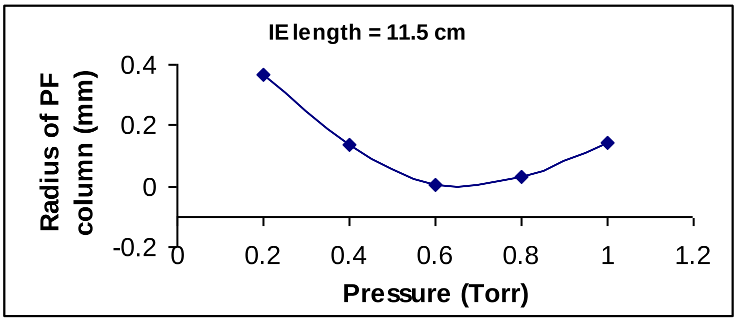
Results of focusing time, voltage spike amplitude, focus action intensity; focus duration time, plasma focus inductance, radius of plasma focus column and pinching ratio as a function of inner electrode, IE, length from (9.5 to 11.5 cm) for



(a)



(b)



(c)

Figure 9 a, b, c Variation of plasma focus column radius with Argon gas pressure at different IE lengths

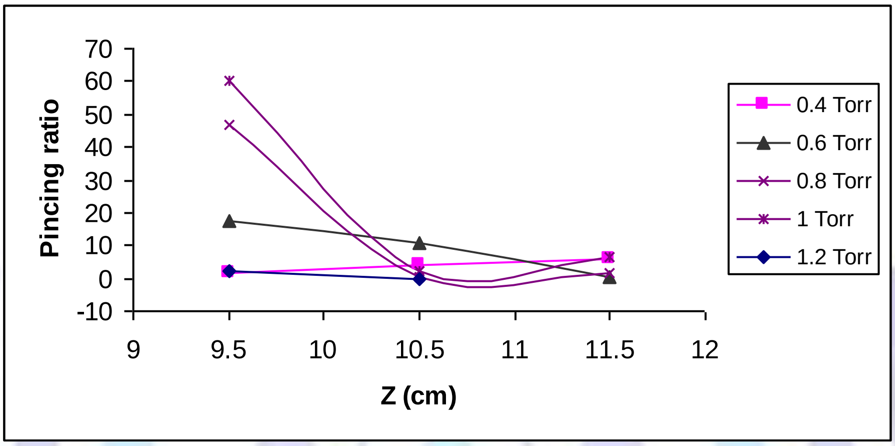


Figure 10 Variation of pinching ratio with IE length at different pressures

Mather type plasma focus device with energy of 2.2 kJ and at different Argon gas pressures varying from 0.2 to 1.8 Torr found that the changing of IE length has an effect on plasma focus action.

We concluded that our plasma focus device is best optimized for plasma focus action with 10.5 cm IE length and at Argon gas pressure varying from 0.8 to 1.2 Torr.

In future, the study of x-ray emission from a plasma focus at optimum condition for best focus action will be done to use the intense x-ray pulses in different applications such as microelectronic lithography and radiography of moving objects.

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