

A preliminary study on the (SERAJ) theta pinch device using external magnetic probes

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Abstract: Magnetic field measurements were carried out on the 40kJ "SERAJ" Theta pinch device under different experimental conditions (different values of capacitor voltages and pressures) using two types of external probes, namely: the one loop probe (one turn) which winded on the outer diameter of the discharge tube in different places, and the local probe (ten turns) located between the pinch coil and the discharge tube at certain locations and distances . The results proved that the plasma reaches its minimum radius of 0.08 cm at the maximum value of the discharged voltage of the main bank. In the same time the plasma radius decreases with the increase of the vacuum pressure. Also the variation of the speed of pinched plasma can initially increase sharply with time. Therefore, the conditions of generating a steady plasma with a specific parameters can be accomplished and can be applied in different application.

Key words: plasma diagnostic, plasma radius, Magnetic field, Magnetic probes, Theta Pinch system (SERAJ)

INTRODUCTION

Magnetic field measurements are usually made by sensing directly the magnetic fields in various places, inside and outside plasma using Magnetic probes (i.e. internal and external) of various types[3]. The magnitude of the magnetic field is usually determined using the following equation :

$$B = \frac{VRC}{NA} \quad (1)$$

where

B: magnetic field.

V: max. voltage signal collected by the probe.

RC: time constant of the circuit.

N: number of probe turns.

A: cross-sectional area of each probe.

The cross-sectional area of the one loop probe ($A_{one\ loop}$) is determined using the following equation :

$$A_{one\ loop} = \pi r^2 = \pi(r_1 + r_2)^2 \quad (2)$$

where r_1 is the discharge tube radius and r_2 is the wire radius.

The cross-sectional area of the local probe (A_{local}) is determined using the following equation:

$$A_{local} = (a + r_1)(b + r_1) \quad (3)$$

where a is the width and b is the length of the local probe and r_1 is the wire radius.

The flux (ϕ) is usually calculated using the following equation :

$$\phi = BA \quad (4)$$

The radius of the plasma can be determined using the following equation :

$$r_s^2 = r_L^2 \left(1 - \frac{\phi_P B_0}{\phi_0 B_P} \right) \quad (5)$$

where

r_s : is the plasma radius.

r_L : is the inner radius of the discharge tube.

B_0, ϕ_0 :are the reference magnetic field and flux (i.e. without plasma).

B_P, ϕ_P :are the magnetic field and flux (i.e. with plasma).

The plasma radius is calculated using equation 5, and these results are obtained using the one loop and local external probes[4] . The aim of the experiment is to determine whether the plasma is reaching its minimum radius.

1. Experimental procedures first sub-title

Figure 1 shows a schematic diagram of the SERAJ theta pinch device. It is a 40kJ theta pinch device, consisting of three main capacitor banks, namely: main; bias and pre-ionize banks beside the delay time unit. The discharge tube is made of quartz and it is 1500 mm in length with 84 mm inner diameter and 96 mm outer diameter. The tube is usually evacuated to a pressure of 2×10^{-6} Torr several days before admitting the working gas, which is hydrogen. The magnetic compression coil is a single turn coil 12nH consists of four equal parts each of 195 mm length and 160 mm inner diameter, surrounding the discharge tube with spacing between them equals to 10 mm. The coil covers a length of 830 mm of the discharge tube. The detailed description of the device can be found elsewhere[1,2].

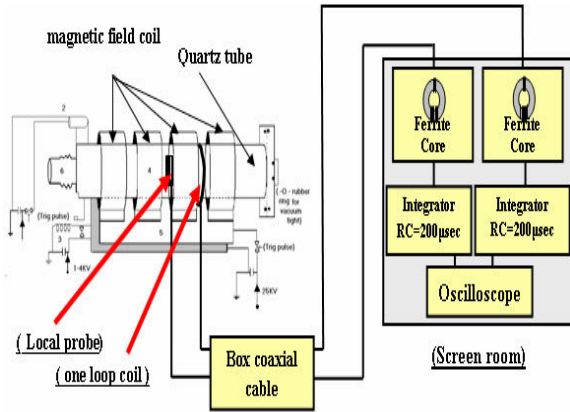


Figure 1. A schematic diagram of the SERAJ theta pinch device and the set up of the experiment

Magnetic field measurements were carried out using two types of external probes, namely: the one loop probe (one turn) and the local probe (10 turns). The one loop probe is a copper wire with 0.62 mm diameter and 96 mm turn diameter. Whilst, the local probe is a copper wire wrapped around a piece of plastic, with dimensions of 5 mm x 20 mm x 2 mm as shown in figure 2. As can be seen, the one loop probe was wrapped around the tube and the ten-turn coil was placed on the tube. The two probe were connected to an Agilent made oscilloscope via an integrator with time constant of 200 μ s. The Results obtained at different experimental conditions are listed in Table 1.

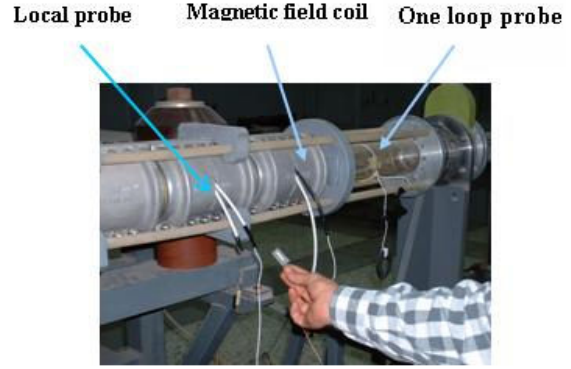


Figure 2. A schematic diagram of the one loop and local probes and their position on the discharge tube

Condition number	Main (kV)	Bias (kV)	Pre-ionize (kV)	Pressure (torr)	r_s (cm)
1	15	5	15	8×10^{-2}	0.32
2	16	5	15	8×10^{-2}	0.13
3	17	5	15	8×10^{-2}	0.11
4	18	5	15	8×10^{-2}	0.10
5	18	5	16	8×10^{-2}	0.34
6	18	5	17	8×10^{-2}	0.31
7	18	5	18	8×10^{-2}	0.08
8	18	6	18	8×10^{-2}	0.13
9	18	6.5	18	8×10^{-2}	0.13
10	18	7	18	8×10^{-2}	0.08

Table1. the experimental conditions List and the calculated plasma radius at each condition

2. Results and discussions

2.1. Magnetic fields measurements using external probes

Figure 3 shows the oscilloscope signal for the one loop probe (with and without plasma). Figure 4 shows the oscilloscope signal for the local probe (without and with plasma). The magnitude of the magnetic field (B) and the flux (ϕ) were calculated using equations 1 and 4, where V is the maximum voltage value of the collected signal (V_{max}). Table 2 lists the values of B and ϕ as obtained from the two sets of measurements averaged over 47 measurements using the two types of probes.

Probe type	B (Tesla)		ϕ (Weber)	
	Without plasma	With plasma	Without plasma	With plasma
One loop	3.16E-06	7.31E-07	4.6E-04	1.8E-04
Local	4.52E-13	1.96E-13	7.21E-08	3.07E-08

Table2. magnetic field and flux values as obtained by the one loop and local probe

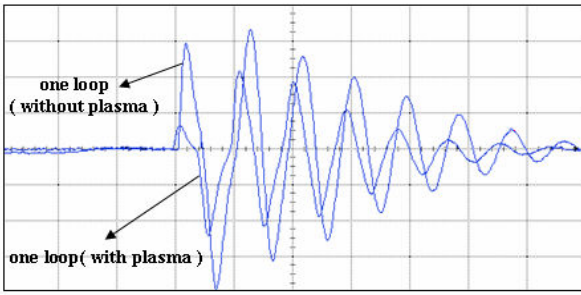


Figure 3. The oscilloscope signal of the one loop coil (with plasma and without).
 (with plasma $V_{max} = 2.29 \text{ V} \rightarrow H = 1 \text{ mV/div}$)
 (without plasma $V_{max} = 1.666 \text{ V} \rightarrow H = 500 \text{ mV/div}$)

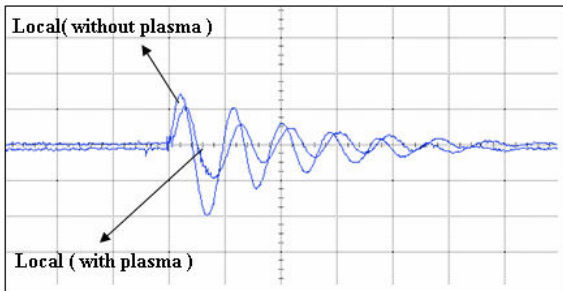


Figure 4. The oscilloscope signal for the local probe (with plasma and without)
 (without plasma $V_{max} = 54.1 \text{ mV} \rightarrow H = 0 \text{ mV/div}$)

2.2. Determination of the plasma radius

The radius of plasma was determined using equation (5) at the experimental conditions listed in table 1. The variation of plasma radius with time was calculated from the collected signals. Figure 5 shows an example of its behavior. As can be seen, the radius changes rapidly with time. When a part of the signal (the first quarter of the second half of the signal) was analyzed, a clearer relationship between the plasma radius and time was observed. As shown in figure 6, the radius decreased initially with time and remained almost unchanged thereafter. Table 3 lists the minimum plasma radius obtained at the different experimental conditions. As can be seen, the minimum plasma radius was obtained at condition number 10 and found to be equal to 0.08 cm. The experiment was also repeated at different values of the pressure inside the tube, whilst using similar values of the capacitor voltages (namely 18kV, 7kV and 18kV for the Main, Bias and the preionize respectively). The minimum radius was again calculated for every experimental conditions and the results are listed in table 4. As shown in table(4), the minimum radius of plasma decreases with the increase of pressure. And again the value of the plasma radius was found to be 0.08 cm. Figure 7 shows the variation of the speed of plasma with time, the speed increased initially and sharply with time, reached a maximum value and decreased at a slightly lower rate. Table 5 lists the speed of plasma verses time. As can be seen, the speed increased generally with decreasing radius

Condition number	Main (kV)	Bias (kV)	Pre-ionize (kV)	r_s (cm)	V_r (cm/sec)
1	15	5	15	0.32	1×10^3
2	16	5	15	0.13	1.7×10^4
3	17	5	15	0.11	7.8×10^4
4	18	5	15	0.10	4.4×10^4
5	18	5	16	0.34	3×10^4
6	18	5	17	0.31	4.7×10^4
7	18	5	18	0.08	6.2×10^4
8	18	6	18	0.13	2.1×10^4
9	18	6.5	18	0.13	5.7×10^4
10	18	7	18	0.08	9.2×10^4

Table3. Plasma radius and speed at different experimental conditions.

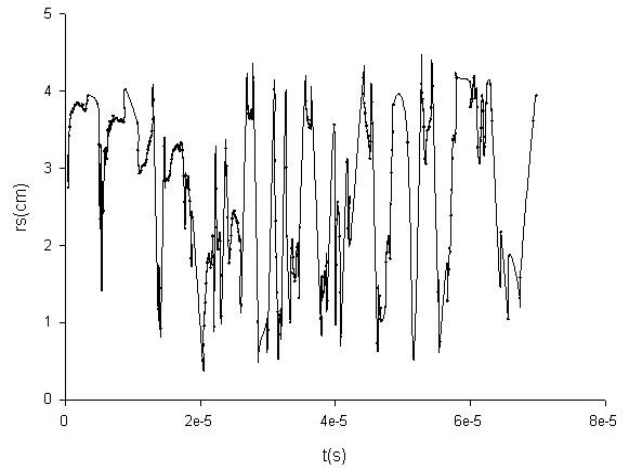


Figure 5. Variation of plasma radius with time

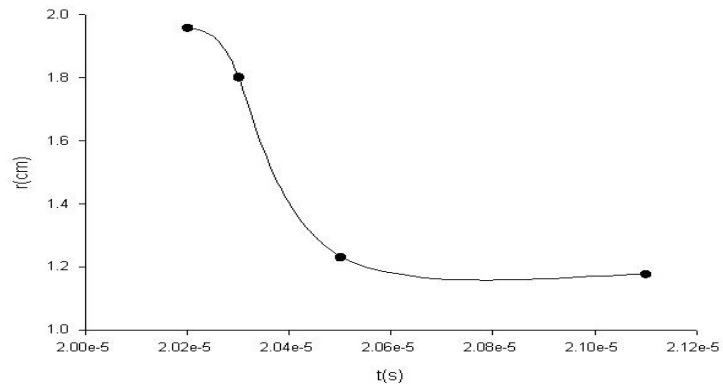


Figure 6. Variation of plasma radius with time (only part of the signal was analyzed)

Pressure (Torr)	r_s (cm)
4×10^{-2}	0.44
5×10^{-2}	0.29
6×10^{-2}	0.22
8×10^{-2}	0.08

Table 4.List of the minimum radius of plasma at different pressures inside the tube

t(s)	Vr (cm/sec)
2.02E-05	6.69E+04
2.03E-05	1.57E+06
2.05E-05	3.61E+06
2.11E-05	8.88E+04

Table 5: the plasma speed versus time

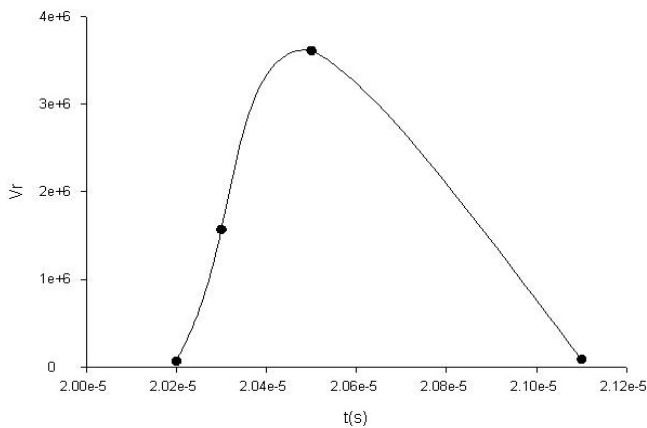


Figure 7. Variation of plasma speed with time

3. Conclusions

The preliminary study using The external magnetic probes indicated that the plasma generated by the SERAJ theta pinch device has a minimum radius of 0.08 cm. This minimum plasma radius was obtained when the values of the capacitor voltages are 18kV, 7kV and 18kV for the Main, the Bias and the preionize respectively, and the pressure inside the tube was 8×10^{-2} Torr. Also The result shows the variation of the speed of plasma with time, whereas the speed increased initially and sharply with time, until reached a maximum value and be decreased at a slightly lower rate. The variation of plasma radius with time was also calculated, and found to be changes rapidly with time.

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