EXPERIMENTAL INVESTIGATION OF THE PLASMA BEHAVIORS IN A Z PINCH DISCHARGE

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ABSTRACT

A moderate size Z pinch discharge suitable for small scale labs. has been built. In this experiment, the behaviors of periments which have lost some of their interest as a possible fusion reactor conception [1]. Actually a growing interest on Z pinch discharges is due to their possible use as an intense X ray source [2]. For this reason a linear slow Z pinch is constructed, in the Zagazig plasma lab. , in order to study the pinch dynamics under different conditions. , In a Z pinch discharge a large current passes through either a filling gas or a solid gas jet. During the discharge time an implosion occurs due to the interaction of the current with its own magnetic field, this results in a compression and heating of the gas to a high temperature and density. The Z pinch has generally good confinement for a relatively very short time [3].

1. INTRODUCTION

Linear Z pinch discharges are relatively old experiments which have lost some of their interest as a possible fusion reactor conception [1]. Actually a growing interest on Z pinch discharges is due to their possible use as an intense X ray source [2]. For this reason a linear slow Z pinch is constructed, in the Zagazig plasma lab., in order to study the pinch dynamics under different conditions.

In a Z pinch discharge a large current passes through either a filling gas or a solid gas jet. During the discharge time an implosion occurs due to the interaction of the current with its own magnetic field, this results in a compression and heating of the gas to a high temperature and density.

The Z pinch has generally good confinement for a relatively very short time [3].

2. EXPERIMENTAL SETUP AND MEASURING DIAGNOSTICS

The Z pinch discharge sketched in Figure (1), occurs in a glass pyrex tube of 1.2 m long and 0.08 m diameter. At the ends of the glass tube two aluminum flat electrodes are placed, the gas is injected on one side by a needle valve, on the other side a pumping unit is connected, it consists of a double stage rotary pump and an oil diffusion pump.

The gas used is argon at a working pressure of 100 mTorr.

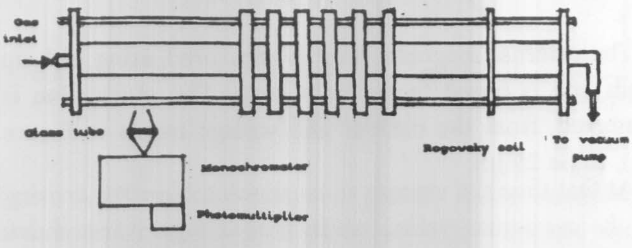

Figure 1. Z pinch experimental set-up.

The discharge is electrically fed by a capacitor bank of 100 μF and 4 KJoule, and is initiated by an air spark gap.

In order to maintain the plasma stable during the discharge, an external magnetic field is applied using 6 turns copper coils of 0.25 m diameter and covering a distance of o.37 m on the middle of the discharge tube, the coils are fed by the same discharge current applied between the two electrodes of the discharge. At the end of the discharge pulse, the experiment is connected to the ground by a safety system.

The main parameters of the discharge are measured using basic diagnostics. The plasma current is measured using a Rogowsky coil, the discharge voltage using a potential divider, and the external magnetic field using pick-up loops. The spectroscopic lines are examined using high resolving power monochromator, [4].

3. EXPERIMENTAL MEASUREMENTS DURING THE PINCH PHASE

the discharge is triggered manually, for one pulse the capacitor bank is charged up to 3.5 KV and is self discharged between the two electrodes. The discharge current, as shown in Figure (2), oscillates during the discharge period of 120 μS with a peak value of 9.6 KA.

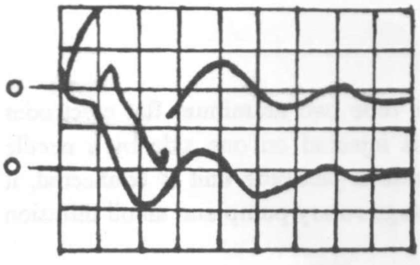

Figure 2. Oscilloscope traces of the discharge voltage and current, for one pulse.

The external magnetic field is measured using pick-up coils and is found to be 100 Gauss. The pinch time is observed, from the current and voltage traces in Figure (2), to be 25 μS.
At that time the current trace shows a dip after arriving at its maximum value, while the voltage trace shows sudden drop. This indicates that the plasma is pinched at that time.

Plasma spectral line intensities are measured using a mono-chromator connected to a photomultipler. The electron temperature is calculated from the measurements of the intensity of continuum radiation (recombination bremsstrahlung) at two different wavelengths λ_1 and λ_2, if p_1 and p_2 are the respective intensities of the two lines, the electron temperature is calculated from their ratio, [5], as:

$$\frac{P_1}{P_2} = \left[\frac{\lambda_1}{\lambda_2}\right]^2 \exp\left[-\frac{h\,c}{e\,T_e}\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)\right] \qquad (1)$$

h is the Planck's constant, c the velocity of the light, e the electron charge, and T_e the electron temperature in eV. This equation is valid for an optically thin plasma. The optical path and the photomultiplier are calibrated using a tungsten lamp for two different line intensities, 3500 A° and 6500 A°. The plasma continuum radiations are measured for those two lines during the discharge, and by taking the ratio of the measured lines, and using Eq. (1), the electron temperature can be computed. This is shown in Figure (3), in which the variation of the electron temperature, is plotted along the discharge time, the maximum temperature, is equal to about 16 eV and occurs at the pinch time.

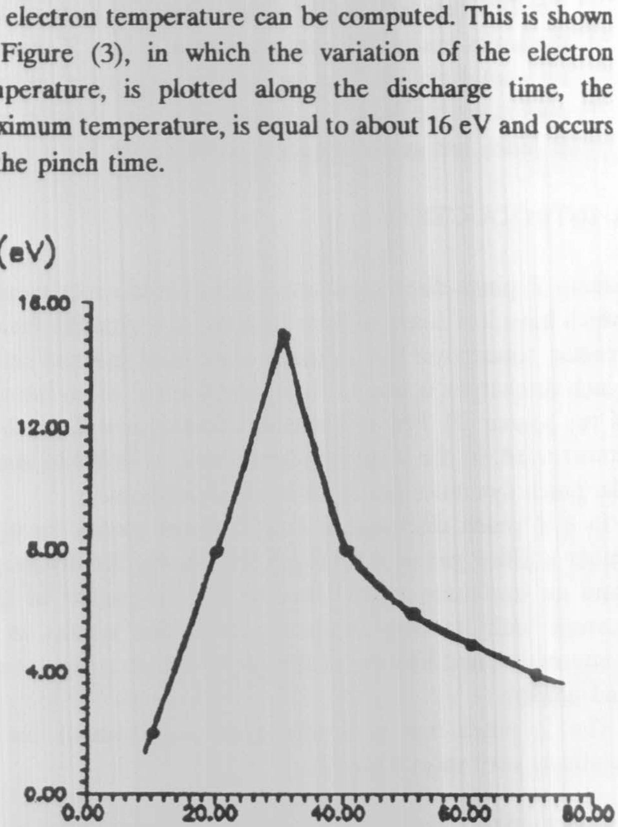

Figure 3. Temporal variation of the electron temperature along the discharge measured spectroscopically.

4. MODELING OF THE PLASMA BEHAVIOR DURING THE PINCH PHASE

In order to confirm the experimental results, a computer model of the radial motion of the plasma column during the pinch phase is made using the well known snowplow approach, [6], and [7].

The plasma in the Z pinch is taken as a cylinder, its main parameters varied with the time t, the radius is taken as r (t), the density as ρ (t), and the current as I(t). The total mass of the pinch is m, and its length is l. During , the implosion time the radial inertial force applied to the plasma is equal to the magnetic force:

$$\rho \frac{d^2 r}{dt^2} = j \times B \qquad (2)$$

Where J is the the plasma current density, and B is the magnetic field generated by the current I and is calculated using Ampere's law, after substitution we obtain:

$$\frac{m\, d^2 r}{l\, dt^2} = - \frac{\mu_o I^2}{2\pi (2 r)} \qquad (3)$$

Where μ_o is the permeability of the free space.
In Eq. 2 the term in parentheses comes from the fact that only opposite current elements, separated by a distance 2 r through the cylinder center, contribute to the magnetic force. We take the plasma current to behave sinusoidally as:

$$I = I_m \sin(\omega t),$$

Where I_m is the maximum current during the discharge, *and ω is the angular frequency which is equal to: 2* π/t_m.t_m is a characteristic time, taking r_m to be a characteristic radius we can normalize the time and radius of the, discharge to be respectively:

$$\tau = t / t_m \text{ and, } R = r / r_m$$

After changing the variables Eq. 3 can be written as:

$$\frac{d^2 R}{d\tau^2} = - \left[\frac{\mu_o I_m^2 t_m^2}{4\pi m / (l r_m^2)} \right] \frac{\sin^2 (2\pi\tau)}{R} \qquad (4)$$

In Eq. 4, the term between brackets can be evaluated taking the experimental data which are as follows:

I_m = 9.6 KA, t_m = 30 μS, r_m = 0.04$_m$, l = 1.2 m

Electron density = 3. 10^{21} m^{-3}

The second order differential equation in Eq. 4, is solved numerically to get R (τ). The result is shown in Figure (4), the curve decays from a radius r = r_m at t = 0., at the beginning of the discharge, to a value tending to zero at t = 0.8 t_m At this time the pinch occurs, and total mass of the plasma is compressed toward the center of the discharge to achieve maximum heating. In order to compare this model with the experimental results we have plotted, in Figure (4), points from the spectroscopic measurements of the 6500 A° line measured during the pinch discharge. The shape of the spectroscopic line which represents the motion of the plasma during the pinch, agrees very well with the computed motion of the plasma radius. This proves the validity of this model in our experiment.

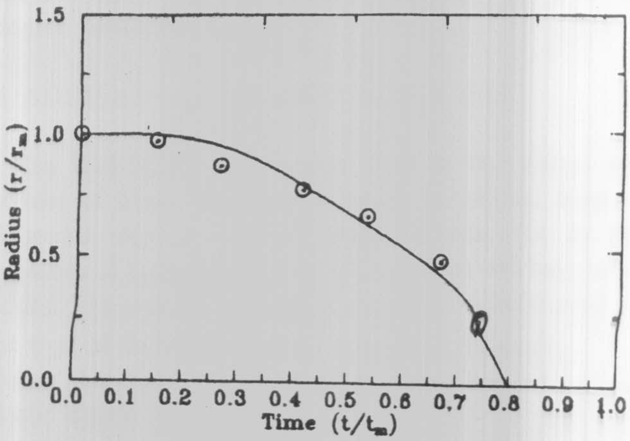

Figure 4. Normalized temporal plasma radius variation, solid line are the computed values and dots are the measured ones.

5. CONCLUSION

This small size linear Z pinch has found to be very suitable for small scale university labs. The study and the measurements of the Z pinch dynamics are still very actual due to its numerous applications, specially as an intense X ray source. The operation of the experiment was very satisfactory. The use of the snowplow approach to simulate the contraction of the plasma radius during the pinch has been found to be in well agreement with the experimental measurements.

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