SPACE AND TIME RESOLVED OBSERVATIONS OF PLASMA DYNAMICS IN A COMPRESSIONAL GAS EMBEDDED Z-PINCH

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Recent experiments in a gas embedded compressional Z-pinch are presented. The experiments have been carried out in H_2 at 1/3 *atm*, using a pulse power generator capable of delivering a $dI/dt > 10^{12}$ *A/s*. The pinch is initiated by a focused laser pulse, which is coaxial with a cylindrical DC microdischarge. This configuration results in double column pinch at early times, which at current rise evolves into a gas embedded compressional Z-pinch. Diagnostics used are Rogowskii coil, single frame holographic interferometry and holographic shadowgraphy, visible streak camera images from which, current, density, line density, pinch radius and plasma motion are obtained. The pinch is characterized by a maximum on axis density which is much higher than the expected value from filling pressure, with a Bennett temperature of 40 *eV* at 130 *kA*.. Results shown confirm the high degree of compression achievable with the composite preionization scheme.

INTRODUCTION

The study of various Z-pinch configurations has provided some understanding of the relevant mechanisms leading to instabilities. Disruption of the discharge by these instabilities severely limit the maximum temperature and density. A number of experiments have been carried out in Z-pinches using our small pulse power generator(GEPOPU). Experimental results obtained show that generally in gas embedded Z-pinches, after an initial expansion, $m = 1$ instabilities leading to a helix develop, eventually disrupting the plasma column. The development of these instabilities happens during tens of nanoseconds.

Recently a new configuration of a gas embedded Z-pinch has been reported [1], a double column pinch in that it is possible to obtain a gas embedded *compressional* Z-pinch. This configuration exhibits axial compression up to twice the expected value from filling pressure, and some 20 times the density obtained in a conventional laser initiated Z-pinch. In previous work we have compared the behavior in three gas embedded Z-pinch configurations under different preionization conditions: laser initiated, needle Z-pinch, and a composite Z-pinch, performed in the same generator. Anomalous stability has been observed in the needle Z-pinch and compressional gas embedded Z-pinch. It is conjectured that the stability observed is explained by resitive effects and finite Larmor radius effects[2,3]. In the present work new experimental results in the gas embedded compressional Z-pinch in H_2 at 1/3 atm are presented.

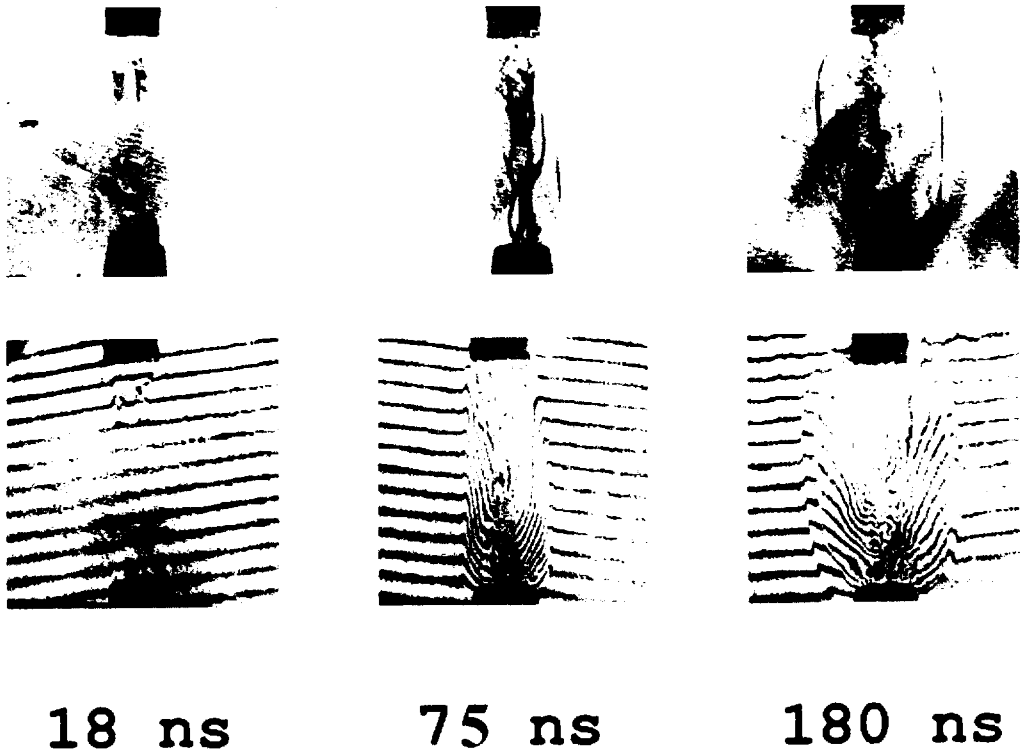
EXPERIMENTAL APPARATUS

The experiments were carried out on GEPOPU, a generator capable of delivering currents up to 200 *kA* to a 1.5 Ω impedance load for 120 *ns*. The value of *dI/dt* of the current ramp was approximately $2 \cdot 10^{12}$ *A/s*. A DC microdischarge is established between two stainless steel conical hollow electrodes with 2 *mm* diameter, separated by 10 *mm*. A few nanoseconds before the application of the main voltage from the driver, a pulsed Nd-YAG laser (20 *ns*, 200 *mJ* at 1.06 μm) is focused through the anode onto the cathode. As the main voltage is applied, the laser generated plasma acts as an electron source to provide preionization on a central plasma column. Initially this conduction channel is highly resistive. The combined preionization scheme produces two parallel concentric conductive paths.

A Nd-YAG frequency doubled 6 *ns* laser pulse was used for optical diagnostics to obtain simultaneous single shot image-plane holographic interferometry and holographic shadowgraphy. Visible streak camera provides radial and axial plasma motion. In this way the evolution of the electron density profile, $n_e(r)$, the electron line density, N, and the external Z-pinch radius, a, are obtained with good temporal and spatial resolution. The total current, $I(t)$, and the external voltage, $V(t)$, were also measured with a Rogowskii coil and a capacitive divider. A maximum voltage of 200 *kV* was used.

RESULTS AND DISCUSSION

In previous work [1] we have obtained a sequence of eight interferometric frames with a 10 *ns* separation between frames from the same discharge. This diagnostics has good temporal resolution but limited spatial resolution[4]. From these holographic multiframe interferograms it became apparent that the electron density at the centre is an increasing function of time, during the initial 110 *ns*. However, the low spatial resolution of the interferograms provided deconvolution of the density profile which resulted in large error margin in the line density estimates. Simultaneous single frame holographic interferogram and shadowgram presented here, confirm earlier results and provide quantitative information about electron density profile and a significantly better measurement of the line density.



18 ns 75 ns 180 ns

Figure 1 Sequence of simultaneous holographic shadowgrams (top) and interferograms (bottom) obtained on three separate shots.

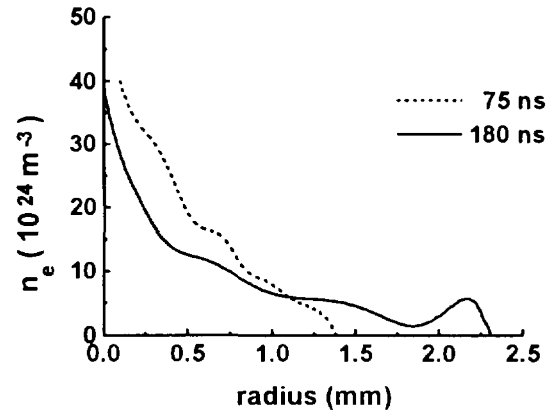


Figure 2 Density profiles obtained from interferograms shown in Fig. 1. At early times the density is not measurerable in the interferogram.

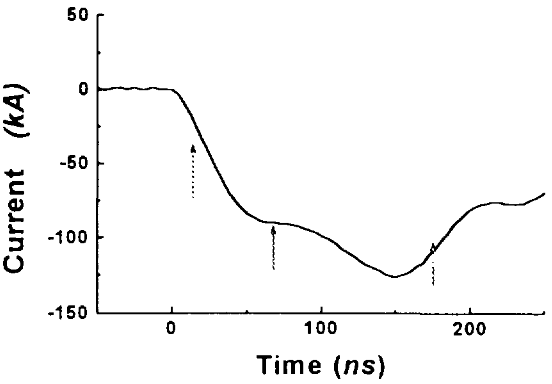


Figure 3 Typical current trace, arrows show the corresponding times for the interferograms shown in Fig. 1.

In figure 1 shadowgrams and interferograms are shown for three different times. Figure 2 shows the corresponding Abel inversions which provide electron density as a function of radius. A typical current trace, with arrows showing the times for the interferograms, is shown in figure 3. At 18 *ns* ionization at the pinch edge is observed, whereas no fringe deviation is apparent near the axis. This indicates that the axial electron density is smaller than $1.2\text{x}10^{23}$ m^{-3}, being larger than $4\text{x}10^{25} m^{-3}$ at 75 *ns* after the current start. From the corresponding shadowgram it can be seen that the refractivity is high at the pinch centre, which is in agreement with the fact that no fringes are visible at the centre of the interferogram. At later times, 180 *ns*, near the peak current of 130 *kA*, the electron density at the centre is $3.8\text{x}10^{25}$ m^{-3}. The line density under these conditions is of the order of $5\text{x}10^{19}$ m^{-1}, which is significantly higher than reported previously. This difference is due to a higher electron density at the pinch centre and a much better defined plasma edge density profile. The Bennett temperature can thus be estimated at only 40 *eV*, which is consistent with the negative results obtained with soft X-ray diagnostics used to measure temperature.

From axial streak photographs it is observed that the initial laser spark at the centre has independent dynamics, which is consisten with a metallic laser spark in expansion. The spark remains near the electrode. This observations agree with previous inteferometric results[1] which show that the maximum spark size is 2 *mm* at 50 *ns*. From radial streak photographs, as shown in figure 4, an initial 10 *ns* fast expansion phase is observed, followed by about 50 *ns* expansion of the central channel of $2\text{x}10^4$ *m/s*. The expansion of the internal wall of the annular plasma is of the same order, whereas the externel wall has a slower expanding velocity of $6\text{x}10^3$ *m/s*. A direct comparison with either a laser initiated gas embedded Z-pinch, needle Z-pinch (both with_single axial current channel), or annular initial microdischarge only, does produce a significantly different behaviour. The reduced expanding rate of the external wall in the composite pinch compared with the microdischarge only case, is presumably due to the presence of the central current channel. The fact that the laser initiation does make a difference is an indirect evidence that there is a significant fraction of the current flowing near the axis. At the end of this phase the two initial plasmas coalesce into one with an apparent internal structure, a brigther central region which is maintained during the following 110 *ns*. At the end of this phase the maximum current is achieved (130 *kA*). This interpretation is consistent with

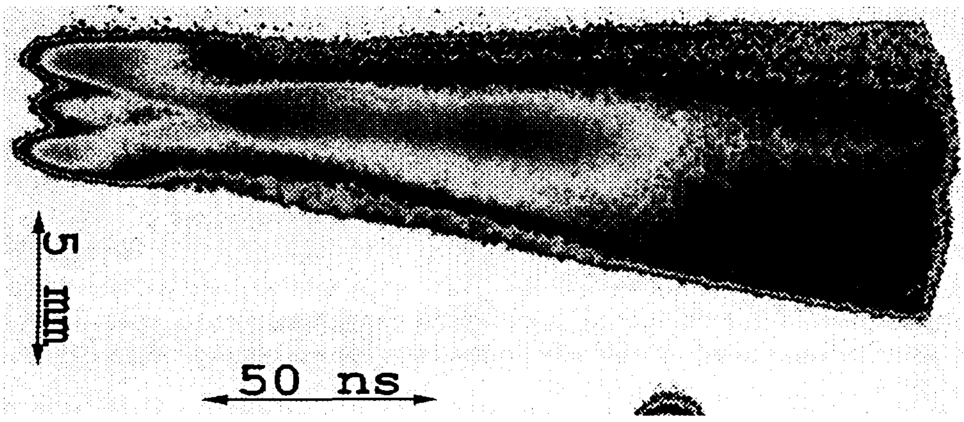


Figure 4 Radial streak photograph in which the different expansion rates are observed, having separate coaxial initial current channels coalescing at later times.

the holographic observations. Densities achieved in the composite pinch are significantly higher than those observed in a laser initiated gas embedded pinch. The results shown here confirm that in the composite pinch radial compression is obtained. This is the only gas embedded pinch in which this behaviour has been observed so far.

Results obtained with the present configuration suggest that by controlling the initial preionization conditions it migth be possible to improve the stability properties of a gas embedded Z-pinch. Future work being considered includes experiments with smaller intial radius for the annulus, lower background pressure and up to 1.2 *MA* peak current in the LLAMPUDKEÑ generator[5].

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