TIME RESOLVED OBSERVATIONS OF HELICAL DISRUPTIONS IN A GAS EMBEDDED Z-PINCH.

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Abstract

Multiframe holographic interferometry has beeen applied to a gas embedded Z-pinch driven by a 1.5 Ω, 100 kV coaxial line generator. The Z-pinch is triggered by a 1.06 μm, 10 ns laser pulse, at the onset of the applied voltage. A hydrogen background pressure of 0.33 atmospheres, with a 3 cm interelectrode separation is used. The laser output is also doubled and it is passed through an optical system giving two or more pulses separated by up to 10 ns for the optical diagnostics. The complete evolution of the helical instability is observed and the main features are discussed.

1.– Introduction.

The gas-embedded Z-pinch was originally proposed as a high-temperature high-density plasma device of thermonuclear interest[1]. Experiments have shown that high temperatures are not achieved due to accretion of neutrals from the surrounding gas blanket[2]. Nevertheless the gas-embedded Z-pinch exhibits a number of very interesting properties which fully justify further experimental investigations, namely, the observation of a period of enhanced stability which is followed by a fast growing helical instability and the absence of $m = 0$ MHD instablities[2]. A further understanding of the physical mechanisms involved in the unstable phase requires of improved diagnostics with high temporal resolution. In this paper we present a preliminary report on time resolved multi-frame interferometric observations on a gas-embedded Z-pinch in hydrogen with detailed observations of helical instabilities.

2.– Apparatus.

A 300 kV, 1.5 Ω water dielectric coaxial line generator is used in the experiment. The Z-pinch is triggered by a 1.06 μm, 10 ns laser pulse, at the onset of the applied voltage.

The laser pulse is focused onto the live electrode by a 15 cm focal length lens. A hydrogen background pressure of 0.33 atmospheres, with a 3 cm interelectrode separation is used. The laser output is also doubled and it is passed through an optical system giving two or more pulses separated by up to 10 ns for the optical diagnostics. Details of the optical set–up used for multiple beam separation have been published elsewhere[3]. In these experiments we have used two frame holographic interferometry with colinear object beams. The separation of the interferograms is achieved by angular multiplexing of the reference beam. A schematic of the holographic interferometry arrangement is shown in Fig. 1.

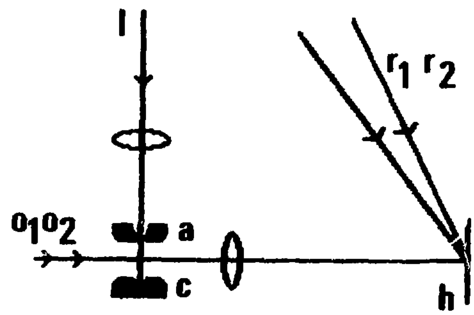

Figure 1: Two–frame holographic interferometry set–up. o_1 and o_2 are the colinear object beams, r_1 and r_2 are the object beams, I is the infrared laser beam, a is the anode and c is the cathode.

3.– Experimental results.

In these experiments the generator has been operated at 120 kV, with a maximum current of 50 kA through the pinch load. A typical pinch current trace is shown in Fig. 2. A 100 ns FWHM current pulse with a 10–90% rise time of 20 ns is obtained. Under these conditions the mean rate of rise of the pinch current is $2 \cdot 10^{12}$ A$\cdot$s^{-1}. The positive going signal at the begining of the current pulse is the infrared laser pulse used for pinch initiation. Figures 3 shows pairs of interferograms corresponding to times between 57 and 90 ns after the begining of the current pulse. Different stages of the evolution of the helical instability are shown. At 57 ns the instability is starting. The maximum line shift in the interferogram, which corresponds to the peak value in the electron density, oscillates along the pinch axis. 10 ns later the instability has grown and a helix begins to form. The radial expansion velocity of the pinch boundary is $1.4 \cdot 10^4$ m$\cdot$s^{-1}. At 80 ns a well defined helix is seen on the left hand side of the interferogram. 10 ns later the helix has propagated along the pinch moving from the anode side towards the cathode. At the cathode side a small section of the pinch is still not perturbed and expands at the same radial velocity observed at early times. Simultaneously the helix expands at a radial velocity which is twice the velocity of the unperturbed pinch.

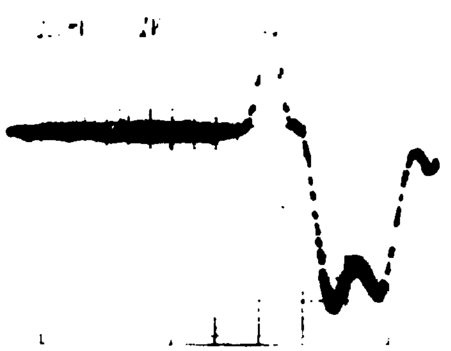

Figure 2: pinch current with initiating laser pulse. Scales are 13 kA/Div and 50 ns/Div.

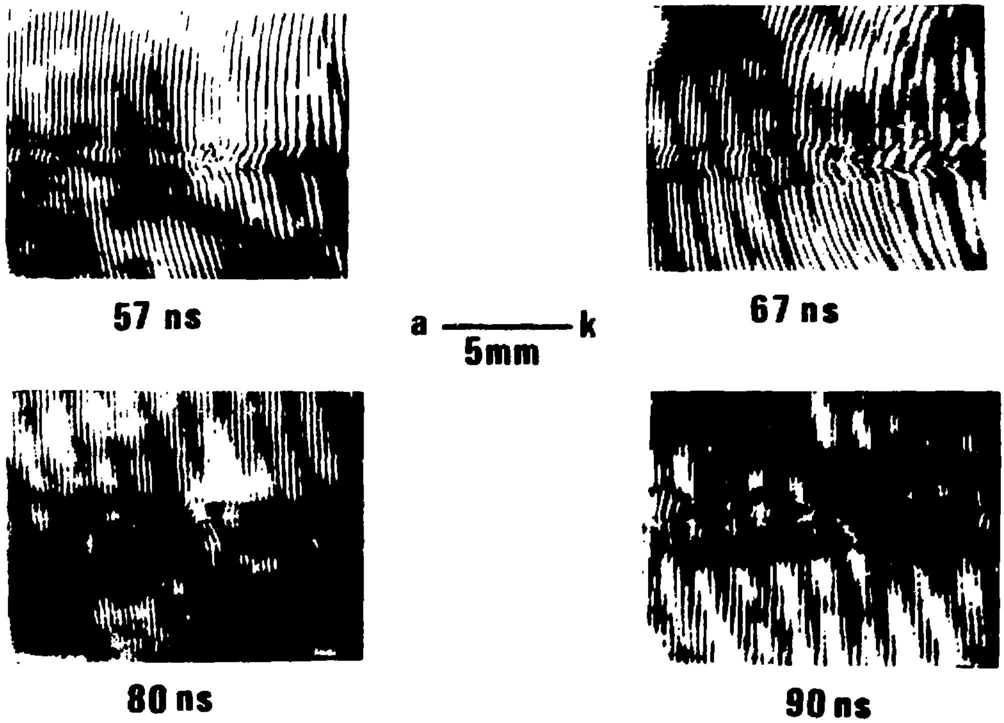

Figure 3: two–frame single–shot interferograms. Different stages of the evolution of helical instabilities are shown.

4.– Discussion.

It is well known that the stability of a gas–embedded Z–pinch depends on the initial conditions at the time when the main current is applied. Pre–heated gas–embedded pinches exhibit enhanced stability during the period of current rise[2,4]. The instability starts as an internal 2–D m=1 mode which at early times do not affect the external pinch boundary[2]. In these experiments the pinch is not pre–heated and the high current pulse starts at the time of pinch initiation. Nevertheless an stable pinch is observed to expand radially during a time of around 50 ns, with a radial velocity of the order of 10^4 m$\cdot$s^{-1}.
The interferograms in Fig. 3 show that the instability starts as an internal mode, in agreement with previous observations[2]. After a time of around 10 ns a localised helix starts to form following the initial internal perturbation. Later the helix expands radially and propagates along the axis and a helical pinch is formed. The observed radial expansion velocity of the helical pinch is twice the expansion velocity of the pinch boundary during the unperturbed phase. This is a good indication that the current is flowing in a helical path. Under this condition the confining magnetic pressure is reduced and the traped magnetic flux inside the helical pinch provides additional magnetic pressure to increase the expansion rate. The equilibrium and stability properties of a gas–embedded Z–pinch configuration have been studied theoretically[5,6]. A gas–embedded type of equilibrium is characterized by a non–zero minimum density at the plasma edge with heat flowing from

the pinch to the sorrounding neutral gas blanket. The current is fully diffussed, the temperature is nearly uniform over the pinch section and the plasma density is peaked on axis. In a low current regime ($I << 1$ MA) a gas–embedded pinch is predicted to be under pressure balance if $\Omega \simeq 3.429$, where $\Omega \simeq$ ohmic heating time/current rise time. According to this the radius r_0 of a hydrogen pinch has to satisfy the condition $r_0 < 3.22 \cdot 10^{-7} \cdot (N^{3/4} / I < \dot{I} >^{1/2})$ (SI units), where N is the pinch line density, I is the current and $\dot{I}$ is the rate of rise of the discharge current. At a larger radius the kinetic pressure rises faster than the magnetic pressure and the pinch expands. A direct comparison with our results is at present not possible because line density measurements are still not available. The absence of m = 0 MHD instabilities in gas–embedded pinches has been explained theoretically[6]. According to the theory the pinch becomes unstable to the m =0 mode if the Lundquist number, $S \simeq \tau_{Ohm}/\tau_{MHD}$, where τ_{Ohm} is the Ohmic heating time and τ_{MHD} is the growth time for MHD instabilities, exceeds certain critical value. In the gas–embedded pinch the plasma temperature is low enough to keep the Lundquist number below this critical value. A direct comparison with the theory based on experimental values is at present under way.

5.– Conclusion

We have presented preliminary results on time resolved observations of helical disruptions in a gas–embedded Z–pinch. Interferometric measurements have been performed and a direct comparison with recent theoretical predictions is at present under way based on these experimental results.

6.– Aknowledgements

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7.– References.

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