XII. INTERACTION OF LASER RADIATION WITH PLASMAS AND NONADIABATIC MOTION OF PARTICLES IN MAGNETIC FIELDS*

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A. EFFECTS OF HIGH ENERGY ABSORPTION ON A FREELY EXPANDING FLUID FLOW

A fluid freely expanding through a high-pressure ratio nozzle has a large density gradient which suggests possible use as a gas target. For example, by using high-energy tritium ions and a deuterium-free expansion jet, it is hoped that neutrons can be produced at higher flux densities than was possible before.[1] For interestingly high tritium ion currents, large amounts of power are delivered to the deuterium while it is undergoing its free expansion. The effect of this power addition to the fluid flow is of interest because if the flow rate of the fluid is decreased or if the density gradient is reduced, the attractiveness of this neutron source is diminished. Colombant has computed the effect of the energy absorption at high power levels on the deuterium jet.

The purpose of this work is to determine experimentally the effects of high-power absorption on a free expanding jet and therefore give some experimental basis to judge the validity of the theoretical calculation. Because the expanding fluid's mass flow rate is of particular interest, the possibility of thermal choking has been investigated.

To simulate a 1-A, 250-keV tritium ion beam impinging on an MW deuterium-free expansion gas target, a 35-W CO_2 laser is focused on an ethylene-free expansion jet with a 0.9 mm nozzle orifice. The CO_2 laser is used as the means of adding power, because just as with the tritium ion beam, the power absorbed is dependent on density. The ratio of absorption length to nozzle orifice diameter is 4.2, as compared with 0.5 for the tritium-deuterium system.

Figure XII-1 shows a highly schematic diagram of the experiment; there are 3 subsystems. The first creates the free jet expansion by expanding ethylene through a large pressure ratio. For the flow rates used (150 cc-atm/sec) and pumped volumes indicated in the figure, the useful operating time was approximately 2.5 sec. The second major subsystem is the 10.6 μ CO_2 laser and associated focusing optics. The laser beam is

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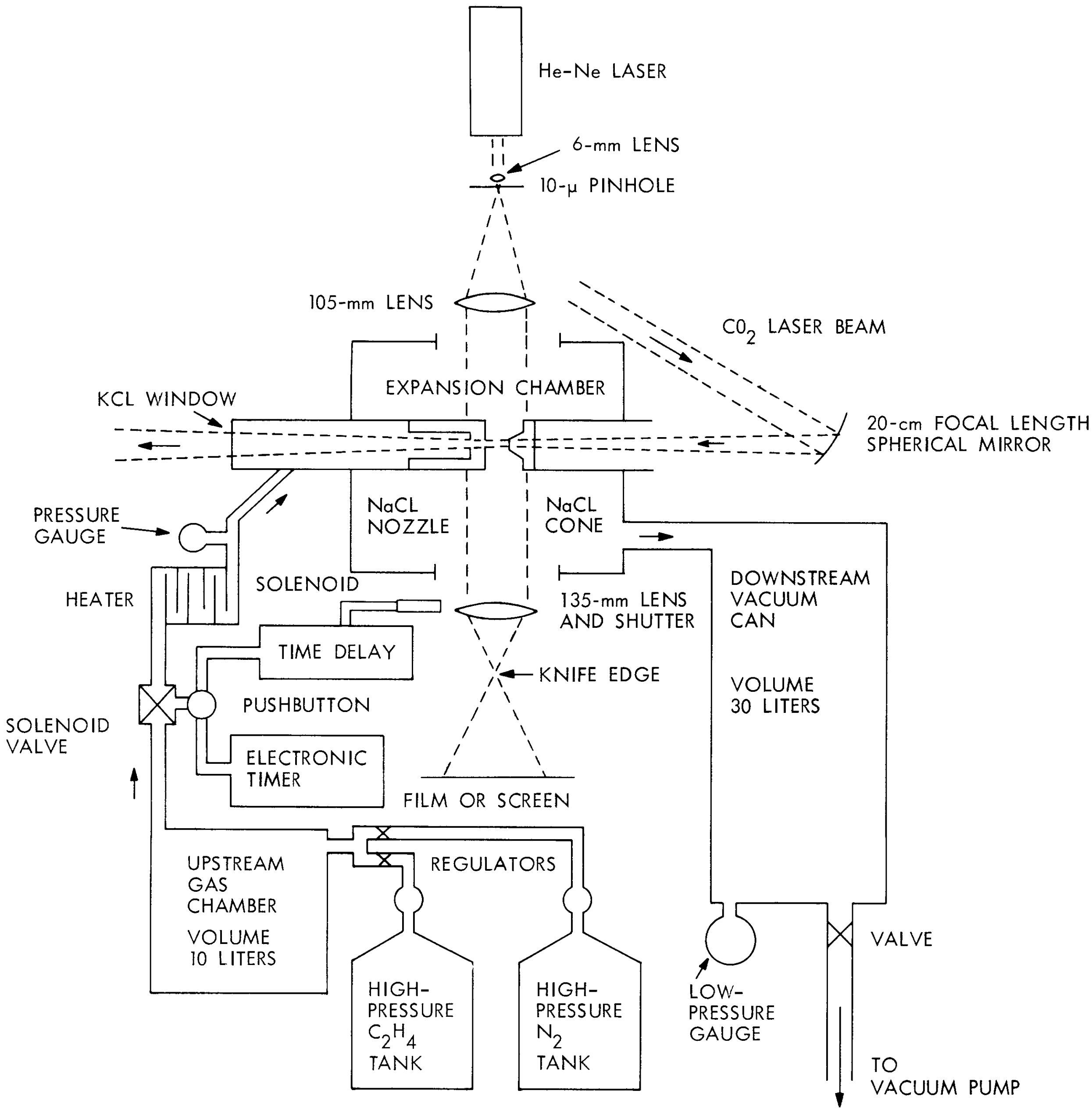
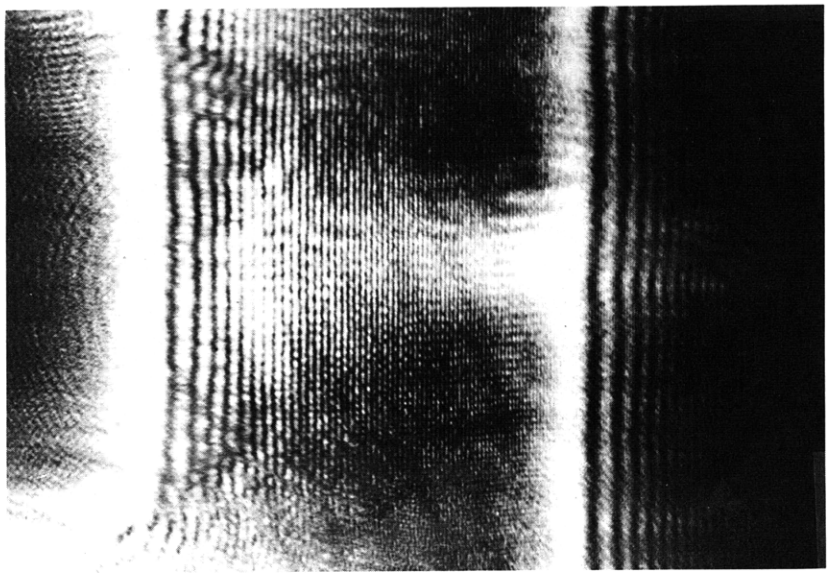
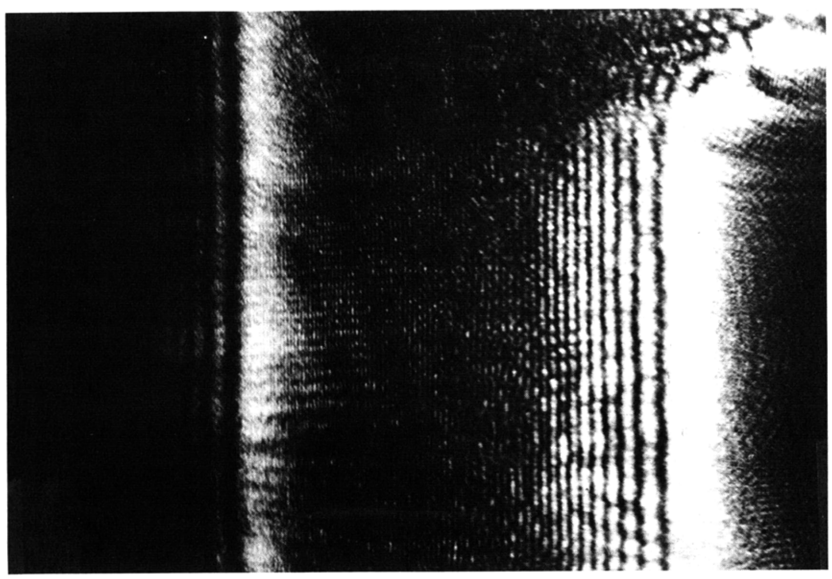


Fig. XII-1. Highly schematized configuration of the experiment.



(a)



(b)

Fig. XII-2. Schlieren photographs sensitive to density gradients along the flow axis. The nozzle is at the left, and the CO_2 laser beam enters through the crystal at the right. (a) Without heating. (b) With heating.

focused at the nozzle orifice with a 20-cm focal length spherical mirror used slightly off-axis. We find that approximately 80% of the laser power can be passed through the 0.9 mm diameter nozzle. The optical diagnostics is based on a 1-mW He-Ne laser and "spatial filter." The spatial filtration is necessitated by the large optical magnification ratio (~20X).

The change in pressure versus time measurement was used to determine whether thermal choking occurred. Large changes in the characteristics of the flow were observed using a Schlieren system (see Fig. XII-2).

Approximately 25 W of the laser's power was delivered to the ethylene expansion jet. The resultant heating increased the ethylene's internal energy 25%, and the following effects were observed: (i) 5% reduction in the mass flow rate; (ii) 10% increase in the expansion plume's maximum diameter; and (iii) a larger density gradient close to the sonic line.

The Schlieren photographs show that the flow experiences very large changes in the density gradient as a result of laser heating and, at the same time, the pressure measurement shows that the flow rate is only slightly reduced. These two results strongly suggest that the sonic line bows slightly outward into the expansion plume. This two-dimensional effect increases the sonic cross-section area and helps eliminate the choking effect. With two dimensions for expansion available, the flow can spread out over the expansion cone in a much shorter distance, thereby keeping the density gradient closer to the nozzle.

The data on thermal choking will have to be checked by Colombant to see how it compares to what is expected theoretically in a one-dimensional flow. Increasing the stagnation pressure overcomes the effect of thermal choking, and thus the attractiveness of a gas target remains. The fractional change in enthalpy is not quite as large as would be encountered in interesting neutron targets. We plan to repeat these measurements with a more powerful laser.

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References

1. L. M. Lidsky and D. Colombant, IEEE Trans. on Nuclear Science 14, 945 (1967).