SHOCK VELOCITY MEASUREMENTS USING A FIBRE-OPTIC REFLECTOMETER SYSTEM

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ABSTRACT

We describe experiments using a novel technique to measure the shock pressure inside a laser driven target. The technique relies upon reflectometry from a shock front using optical fibres embedded in a target.

INTRODUCTION

An important quantity which determines the performance of a laser driven implosion is the pressure produced by the surface ablation of the target. Also, many target designs use a shaped laser pulse to produce a pressure profile which increases with time. Estimates of the ablation pressure by others have inferred the driving pressure from detailed measurements of the plasma expanding from the surface of a target or by the time-integrated measurement of foil acceleration. Measurements of shock breakout at the rear surface of a target have used targets which had steps at the rear. These experiments, however, produce large perturbations in the target pressure profile, and the time and spatial resolution are rather poor. With the technique we describe here the pressure in the interior of a thick target is found by measuring the shock velocity as a function of position using detectors which are well-matched to a target material for which the equation of state is known to high accuracy. The method used here is intended to solve several of the other problems associated with the shock breakout technique as well. The method is based on the results obtained in a preliminary experiment carried out with the laser at the University of Essex.

The results can provide an accurate measurement of the hydrodynamic coupling of a laser beam to a target. They may also provide information on the weakening of shock waves as a result of two-dimensional effects such as lateral propagation of a wave and beam asymmetries. Calculations using computer codes aid in the analysis of the experiments.

A secondary aim of the experiment is to investigate the feasibility of using the visible light emitted by a shocked fibre to make a spectroscopic measurement of the fibre temperature and, thus, the pressure. Recent measurements by L. Veeser of Los Alamos indicate that the light intensity can give an accurate measurement of the pressure in the megabar pressure range, and the spectral measurement should be even more accurate. The shock velocity measurement will provide a calibration for this technique.

BACKGROUND

Shock waves in a solid satisfy simple physical relations, the Hugoniot relations, which allow one to determine all of the material parameters in the set of density, pressure, shock velocity, and particle velocity if any two of the parameters are known. If the strength of the shock wave is large, the relations simplify further and the calculation of unknown parameters becomes almost trivial. The importance of these well known observations is that shock and particle velocities are relatively easy to measure while the pressure in a material is usually difficult to measure. If the velocities are known, the pressure is simply the product of the shock velocity, the particle velocity, and the initial density. Further, there is a unique relation between shock velocity and particle velocity which has been determined for many materials by either measurement or calculation. Therefore, a measurement of shock velocity alone can, in many cases, determine the pressure in a material. Of course, the conditions are only determined at the shock front, and one must estimate the time delay between a change of pressure behind the front and a change of velocity at the front, but this is a fairly straightforward process.

Work supported by the Laser Division at the University of Essex in 1987 has led to the development of a technique which may solve many of the problems associated with older methods of shock propagation measurement. It was found that the reflectance of a shock wave was very low (less than 2 percent) and that the reflectance of a fibre optic tip when shocked, fell dramatically and rapidly. Measurements indicated extinction of reflected light in less than 0.1ns.

METHOD

The targets consisted of a group of optical fibres entering from the

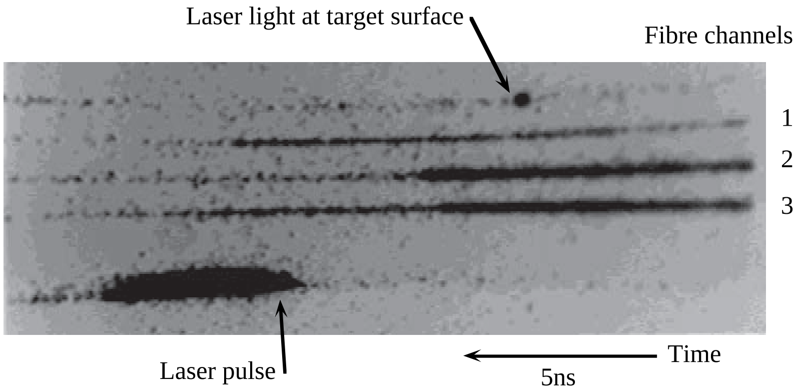

Figure 1. Typical Streak data showing three fibre channels extinguishing plus two fiducials of the incident laser pulse.

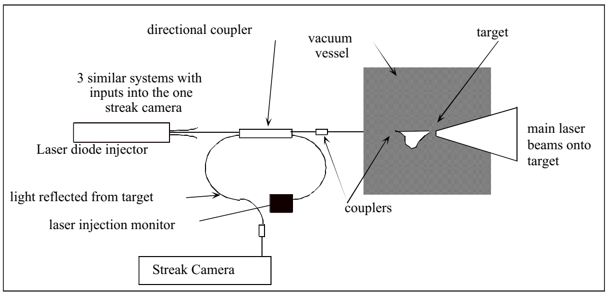

Figure 2. Experimental layout

rear of a copper substrate. The fibres extended to various depths into the target and occupied various radial positions. The overall diameter of the bundle was approximately 1 mm and the number of fibres varied from 2 to 3. The variation of the axial positions of the fibres was approximately 100µmm. The ends of the fibres were coated with a thin coating of chromium. A 100ns pulse from an 832nm, 20mW laser diode was injected into each fibre using a fibre directional coupler, and the light reflected from the metallic coating was sent back through the fibre to the slit of an S1 streak camera. The camera recorded the reflected light as a function of time, and a sharp reduction in reflectivity was seen when the shock wave generated by main laser irradiation struck the end of the fibre. The measurements were done using a single 6ns pulse of 0.53µm light formed by overlapping four beams from the Vulcan laser system. Figure 2 shows the layout of the experiment.

The method has several advantages over the other techniques. All of the signals are of the same amplitude and therefore the dynamic range of the camera does not have to be large. The fibres were matched to the substrate, and the radial separation of the fibres was small, so that the

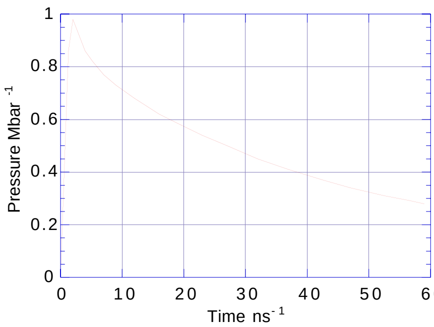

Figure 3. Simulation results of the pressure at the

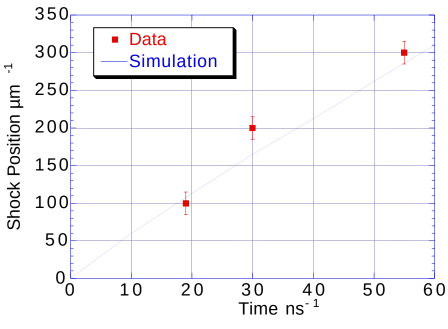

Figure 4. Simulation and experimental results

diagnostic perturbed the shock very slightly. The transit time of the light in the fibres was used to place the expected arrival times of the indication of the shock front at convenient positions in the streak so that they did not interfere with one another. The streak record length could be a very small fraction of the shock transit time as all the signals are delayed by an estimated amount so that they arrive at the camera at the same time. The use of single mode fibre optics allows long delays with very high bandwidth. The visible light from a shocked fibre was not filtered out and in some shots did cause some confusion. This will be amended on future experiments. By careful measurement of the fibre length from the target to the streak camera the relative arrival times of the shock at the fibre tips can be deduced. The fibre lengths were measured with an optical time domain reflectometer made by Opto-Electronics, Inc. With this device a short (150ps) laser pulse is injected into the fibre via a directional coupler. Light reflected from the tip of the fibre is detected and its arrival time compared with the injection time. Using sampling and averaging techniques the device is able to measure the fibre length with an accuracy of a several picoseconds. It is not practical to measure the lengths of a fibre with a ruler as this requires removing the fibre from the experiment. The fibre lengths were also changed frequently to allow for the expected arrival times of the signal. The target fabrication technique resulted in an inability to predict accurately the fibre position in the target. These were measured after the target was drilled, just prior to inserting the fibres.

RESULTS

Figure 1 shows typical raw data from the streak camera. The fall in the recorded intensity of the light reflected from the fibre tip when the shock arrives can be seen clearly. The background light level is due to reflections from various connectors in the system. This could be improved by using fibre splicing techniques instead of couplers. On some shots, however, after the signal initially falls there is a rise in signal level. This was not observed in earlier experiments where a narrow band (832nm) filter was placed in front of the detector. It is likely that this is light emission from the shock. Such emission has been observed in other shock experiments performed at Los Alamos National Laboratory.

The results obtained for the shock velocity along with the laser pulse shape and total laser energy were compared to those simulated with computers at Los Alamos National Laboratory. Whilst this work is still under way some initial results are shown in figures 3 and 4. Figure 3 shows the simulated pressure at the surface of the target as a function of time. Figure 4 using the same simulation shows the shock position as a function of time with the experimental data superimposed. Good agreement can be seen implying that the pressure time history at the target surface is reasonable.

CONCLUSIONS

We have shown that the technique although still in need of some refinement is capable of providing accurate information regarding the velocity of shocks inside materials. With more channels it will be possible too measure shock acceleration and coalescence.