Streak camera recording of shock wave transit times at large distances using laser illumination

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A pulsed laser illumination system for streak camera recording of impact-induced shock wave transit times ($\sim 1\ \mu$s) during impact experiments is described. Laser illumination of centimeter-sized subjects offers many advantages over diffuse illumination techniques for streak photography. Source-to-sample and sample-to-camera distances of $\sim 10^0$ m to 10^1 m can be employed. Light filtering, and simultaneous recording of both the impact event and the camera streak rate calibration, can be carried out easily. For use in such a system we describe a Pockels cell controller in which the reference 10-MHz oscillator signal is synchronously divided down to 38 Hz to provide a trigger signal for laser and streak camera testing.

INTRODUCTION

Sample illumination for streak camera recording of shock wave transit times during high-velocity impact experiments is commonly provided by diffuse discharge sources, such as xenon flash lamps.[1] The use of diffuse sources has several drawbacks, including the need for short source-to-target distances, large power requirements, and expensive charging and triggering circuitry. We describe a laser light sample illumination system which represents significant improvement in each of these areas over diffuse illumination methods. A portion of the laser beam is also diverted through a Pockels cell electro-optic modulator to generate a streak rate calibration signal for the streak camera. In addition to providing the bias and retardation signals required for modulation of the reference laser beam, the Pockels cell controller provides a synchronous trigger for laser and streak camera testing. The technique was developed in our laboratory for use with the 2½-in. light gas gun facility at Arnold Engineering Development Center (AEDC), Tullahoma, Tennessee.

I. INSTRUMENT DESIGN

A schematic diagram of the laser optical system is shown in Fig. 1. The novel components of the laser system are the pulsed Ar laser (TRW, Inc., model 71B) and the beam shaping and collimating lenses. A laser pulse (2.5 W, 40-μs duration, 514.5 nm) is triggered by a delayed 30-V pulse, initiated when the projectile breaks a continuous laser beam upstream from the target. The laser pulse passes through the beam shaping lens, which consists of two perpendicular cylindrical planoconvex lenses, each with a focal length of 4 mm. Lateral positioning of the cylindrical lenses can produce a choice of three modes of target illumination—a beam spread horizontally, a beam spread vertically, or a large circular beam for illuminating the entire target (Fig. 2). Thus, the target slits may be oriented either horizontally or vertically (see below). After shaping, the beam is collimated by an 89-mm-diam, 406-mm focal length achromat. All target mirrors are masked, exposing horizontal, colinear slits 0.25 mm wide. With the beam spread horizontally the collimating lens focuses the laser beam onto the slit plane with 0.1-mm overlap on each side of the slit. Thus, approximately 1/2 of the beam's intensity is incident upon the target mirrors. One important requirement, however, is that all reflections from the target mirrors fall within the entrance diameter of

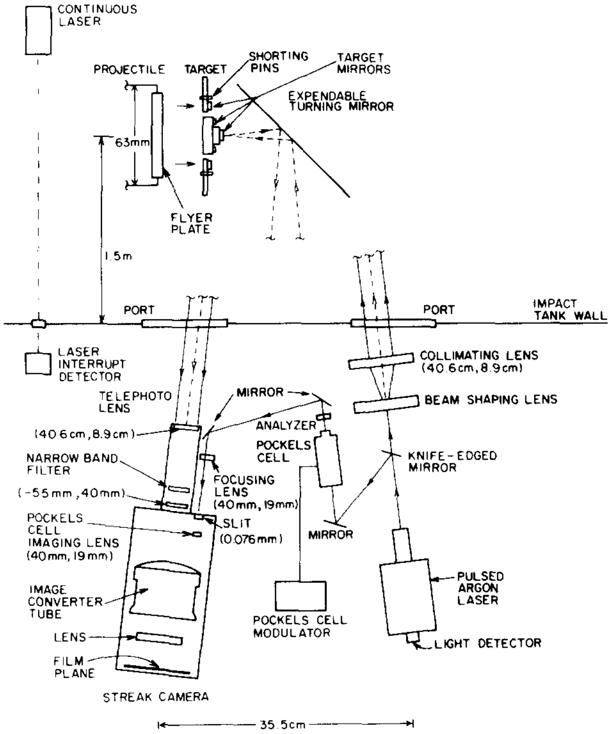

FIG. 1. Schematic diagram of the laser optical system for streak camera recording of shock wave experiments. The laser beam is split, shaped, collimated, and reflected off the turning mirror onto the target mirrors, from which it is reflected back off the turning mirror to the streak camera. The total optical path length is approximately 3.6 m. The timing calibration signal is split off from the main laser pulse, modulated by the Pockels cell, and fed into the streak camera. The timing calibration may be obtained simultaneously with a shock-wave experiment or in an independent determination. Numbers in parentheses refer to lens focal length and diameter, respectively. A negative value of focal length denotes a concave lens.

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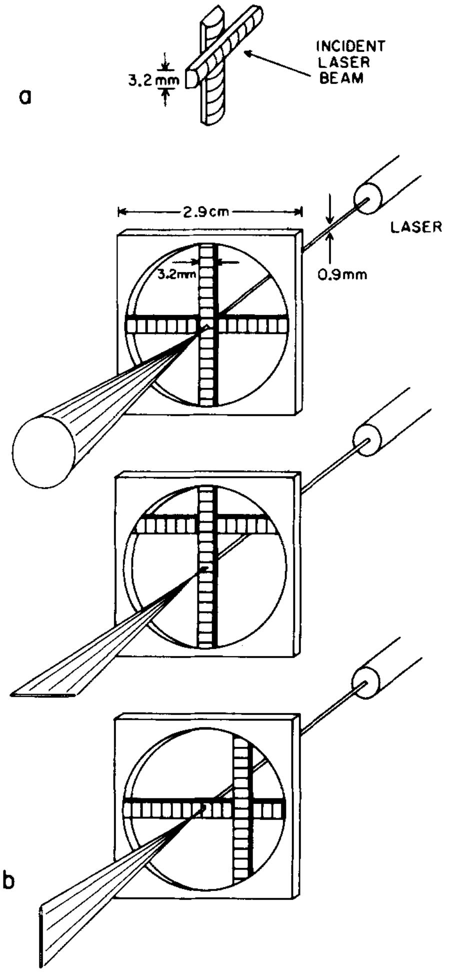

FIG 2. (a) Diagram showing the configuration of the perpendicular plano-convex lenses (4-mm focal length) which comprise the beam shaping lens. (b) Diagram showing the three modes of operation of the beam shaping lens system. The laser beam can be spread horizontally, vertically, or shaped into a beam with a circular cross section by varying the positions of the cylindrical lenses with respect to each other.

the camera lens. This requirement, in combination with the target-to-camera distance, places limits on allowable errors in flatness and mounting angles of the target mirrors. For example, with the geometry shown in Fig. 1 (camera-to-target distance $\sim$1.8 m, camera entrance diameter 89 mm) the target mirror reflecting surfaces must be parallel within ± 1.4°. The streak camera (TRW, image converter camera model 1D) is fit with a telephoto lens which focuses the target slits onto the cathode of the image converter tube with a choice of magnifications between 1:1 and 2:1. In the particular application demonstrated in Fig. 1 a narrow bandpass filter (3-nm FWHM at 514.5 nm, 80% transmission, Rolyn Optics) is placed in the telephoto lens in order to reject undesired radiation from incandescent propellant gases, shock-induced radiation, and ambient room light.

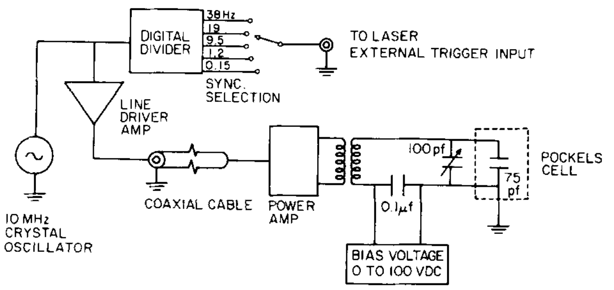

FIG 3. Block diagram of the Pockels cell synchronizer/modulator. The output of the crystal oscillator is a 5-V peak-to-peak square wave. The output of the line driver amplifier is a 7-V rms sine wave with an output impedance of $50\,\Omega$. The power amplifier boosts the signal to 100-V peak to peak.

A knife-edged mirror diverts a controllable portion of the laser beam through the Pockels cell modulator (Lasermetrics, Inc., model 3031W), a series of turning mirrors, and a lens (focal length 40 mm, diameter 19 mm), imaging the modulator output beam onto a 0.076-mm slit in front of the camera, and below the optical axis (Fig. 1). This illuminated slit is then focused by a second lens (focal length 40 mm, diameter 19 mm), through a port in the camera body, onto the image converter tube at a convenient position between, and colinear with, the images of the target mirrors. When appropriate modulation of known frequency (10 MHz, 100-V peak to peak in this case) is applied to the Pockels cell, a calibration scale of dots is traced adjacent to the target mirror streaks at the time of impact.[2] The calibrating scale can also be exposed separately from the actual shot streak, if the light intensity needs to be conserved (see Fig. 4). However, the possible error of a change in streak length or linearity is always of some concern.

The optical transmission of a KDP (potassium dihydrogen phosphate) Pockels cell is nominally a sine squared function of the applied retardation voltage. For a sine wave voltage symmetric about the zero voltage point, light pulses pass through the cell at twice the applied signal frequency. A light pulse rate equal to the signal frequency may be generated by passing the laser beam through a quarter wave retardation plate before or after the cell or alternatively, by applying a dc bias voltage to the cell.[3]

The Pockels cell controller outlined in Fig. 3 provides a 0- to 100-V adjustable bias voltage and also generates a 10-MHz retardation signal from a crystal reference oscillator. The 5-V peak-to-peak output of the crystal oscillator is fed into the line driver amp (output: 7-V rms sine wave into $50\,\Omega$) and then to the power amp (output: 100-V peak to peak). The signal is then applied to a parallel resonant circuit of which the 75-pF capacitance of the Pockels cell itself is the major tuning capacitance. The reference oscillator signal is also synchronously divided down to 38 Hz and used during testing as a trigger signal for the laser and streak camera. In this way the calibration pulses may be observed on a ground glass screen at the film plane while adjustments are made to the calibration system.

The laser beam used to generate the calibration is 0.9 mm in diameter, which is small compared to the 2.4-mm aperture of the Pockels cell. There are nonlinearities in the sine squared function of the cell which are spatially dependent on the position of the beam within the aperture. These nonlinearities may be corrected to a large extent by adjustment of the bias voltage.

Figure 4 is a streak camera photograph of a shock wave

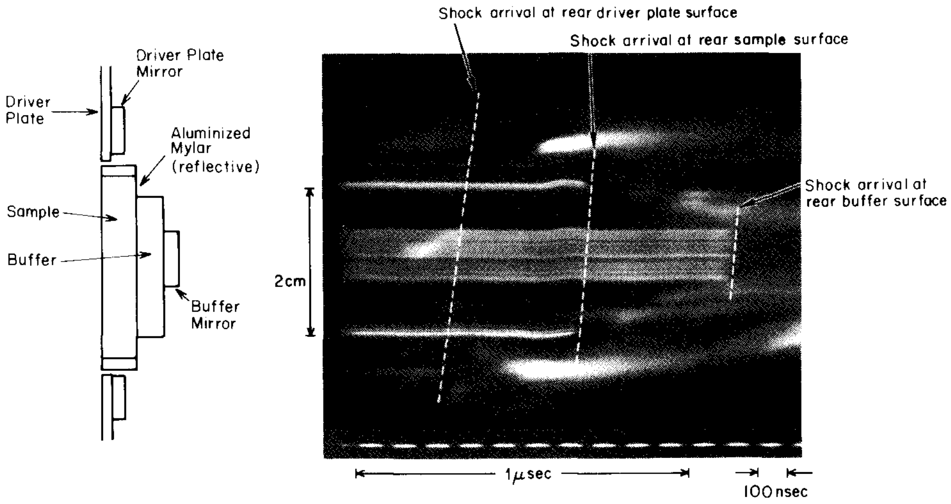

FIG 4. Streak camera photograph of a shock wave experiment performed at AEDC using the optical and electronic systems described in this report. A diagram of the target is shown for reference. The sample was a porous soil. The streak cutoffs are due to the disruption of the target mirrors when the shock wave reaches the mirrored surface. The modulated timing signal was obtained separately. Impact velocity of the Ta projectile was 6.42 km/s. Velocities of the shock waves traveling through the sample and the buffer were 9.07 and 9.25 km/s respectively. Diffuse bright streaks are due to flashing of the tank gases when the shock wave exits the target.

experiment performed at AEDC using the system described in this report and shown in Figs. 1–3. The impact tank diameter is 3 m and the total optical path length was approximately 3.6 m. The sample under study was a porous soil which was impacted by a Ta projectile traveling at a velocity of 6.42 km/s. Using the known thicknesses of the sample and buffer and the shock transit times obtained from the photograph, shock wave velocities through the sample and buffer of 9.07 and 9.25 km/s, respectively, were determined. The curved bright streaks on the right-hand side of the photograph were caused by flashing of the tank gases when the shock wave passesd through the sample. The tank pressure was 80 mTorr and the target was bathed in a He stream at the time of the shot. The Pockels cell timing signal was obtained separately.

The use of laser beam illumination obviates many of the disadvantages inherent in the diffuse illumination of a xenon lamp or other discharge source. Distance from the target sample to the camera can be extended to facilitate optimum mechanical position outside the tank without loss of image intensity. Focus of various levels of the driver plate, sample, and buffer mirror becomes less severe, and average power of the illuminating source can be much reduced. Triggering of the illuminator is simpler and more reliable. The laser can be triggered in a fast repetitive mode for observation of the streak image, and for obtaining a static photograph of the target. Monochromatic illumination has a distinct advantage in providing the ability to filter the light received by the camera, rejecting undesired light from incandescent propellant gases, shock-induced radiation, and ambient room light.

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