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VISAR: LINE-IMAGING INTERFEROMETER

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A line-imaging Velocity Interferometer System for Any Reflector (VISAR) was applied to measure velocity across the diameter of a metal plate explosively accelerated to 5.5 km/s. Amplified, single-frequency laser light was focused to illuminate a line on the metal surface. The line's image was focused through the interferometer to a streak camera that swept in time and recorded directly on film. During the experiment, the Doppler-shift caused motion of the interference fringes. Analysis of the digitized film record yielded a continuum of time-resolved velocity histories. Velocity gradients across the plate that first swept radially inward, then reflected outward, were clearly measured. Increased power provided by the laser amplifier greatly improved the signal-to-noise ratio compared to our previous line VISAR experiments.

1. INTRODUCTION

A line-imaging Velocity Interferometer System for Any Reflector (VISAR)[1,2] was demonstrated last year with a 2-W, single-frequency, argon-ion laser to measure many velocity histories simultaneously. However, an image intensifier was required and the resulting signal-to-noise ratio was poor because of the marginal laser power.

An amplifier[3,4] was recently installed to boost laser power to approximately 600 W. It eliminated the requirement for an image intensifier, allowing an increase from 40- to the full 63-mm-diam camera image, and greatly improved the signal-to-noise ratio. This enabled velocity measurements to be made across the diameter of an explosively driven plate over a 10-m optical path between the experiment and the VISAR. During the experiment, the 2-mm-thick, 25-mm-diam 304 stainless steel plate was unevenly accelerated to a velocity of 5.5 km/s in 4 μs. The plate, initially in an evacuated barrel capped by an optical window, was followed to a distance of 15 mm before the optical path became obscured by smoke from the explosive driver. Simultaneous differences in velocity, greater than 0.5 km/s, were measured between center and edge regions across the plate.

This paper begins with a diagram to illustrate the experimental system. Its operation is explained. Then acquisition and analysis of the experimental streak camera photograph with its four images is described, starting from the raw image and concluding with velocity histories.

2. EXPERIMENTAL SETUP

Figure 1 illustrates the experiment. Light from a single-frequency, argon-ion laser was amplified from 1 to 600 W by a dye-laser amplifier. Its output was focused by a cylindrical lens to illuminate a line 25-mm long on a lightly sanded region across the plate, to be launched in vacuum. A spherical lens collected diffusely reflected light from the plate and focused it through the VISAR interferometer.

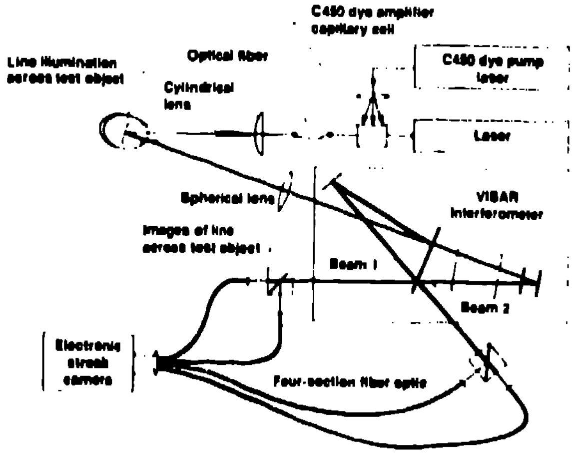

FIGURE 1
Line-imaging VISAR experiment.spherical lens collected diffusely reflected light from the plate and focused it through the VISAR interferometer.

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Light traversing the interferometer was split into two beams: one was slowed by transmission through a 100-mm-long glass bar and an eighth-wave retardation plate while the other traveled through air. This provided a relative delay yet gave identical magnifications in both interferometer legs. The delay made the interferometer sensitive to acceleration; the retardation plate provided quadrature coding[5]. After being recombined, the light was output from both sides of the beamsplitter, in "push-pull" mode, to maximize light efficiency and minimize noise.

Polarizing splitters separated the push-pull beams into four quadrature-coded components with 90° relative phase differences. The beams then formed images at the focal plane of the spherical lens on the entrances to fiber optic bundles for transmission to the streak camera.

Each bundle was aligned individually to ensure good focus and equalize magnifications so that corresponding points in all quadrature images would map to a single point on the plate surface. Overall magnification was adjusted for the images of the illuminated line to fill the 0.2-mm-wide by 6-mm-long fiber optic bundles. At their exit ends, the bundles were combined side-by-side into a 0.2- by 24-mm linear array placed in direct contact with the streak camera fiber optic photocathode window.

3. DATA ACQUISITION AND ANALYSIS METHOD

3.1 Data acquisition

Acceleration of the plate during the experiment produced a Doppler-shift of the light. This caused interference to modulate the quadrature images when they were swept across recording film by the electronic streak camera. The resulting time-resolved photograph was later digitized by a microdensitometer and stored on computer disk for analysis.

3.2 Approach to data analysis

The streak record was digitized with approximately 500 pixels along the time coordinate and 400 pixels across the spatial coordinate. Four 500 by 100 pixel quadrature images were cut from it and registered to each other. The digitized film density data were exponentiated to approximate light intensity. Then the 180° quadrature image was subtracted from the 0° image to obtain a sine image, and the 270° image was subtracted from the 90° image to give a cosine image. Subtraction yielded images with both positive and negative values, canceled common optical noise and improved the signal-to-noise ratio.

A pointing device was used to manually trace the interference fringes on a computer display of the difference images. Each fringe was assigned a number, counting from zero at the beginning of the record. Velocity was calculated by multiplying the fringe count at all points in each trace by the fringe constant of 411 m/s/fringe. No acceleration reversals were observed or counted. Velocities for times between traced fringes were estimated using interpolation.

A previously developed arctangent algorithm that calculates velocity semiautomatically from the sine and cosine images was not used for this analysis because of imperfections in the photograph and because sufficient data were easily traced. Software tools are being developed to use pre-experiment, static photographs to account for interferometer and optical imperfections.

4. STREAK PHOTOGRAPH IMAGE ANALYSIS

4.1 Line VISAR quadrature streak image

The microdensitometer-digitized streak photograph is shown in Fig. 2. Note the 90° relative phase differences between interference fringes visible in the four quadrature images. The optical fiber bundles were oriented so that the images were reversed about the streak-tube centerline to minimize effects of distortion. Before further analysis, each quadrature image had to be separated from the group, reversed if necessary, and registered with the other images.

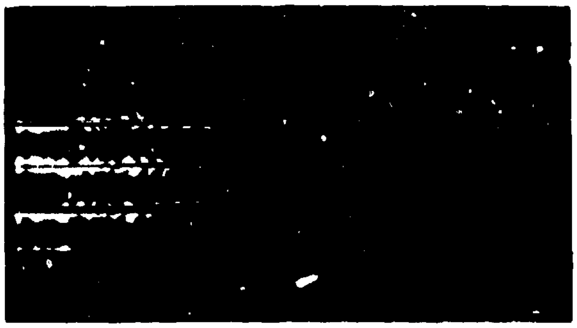

FIGURE 2
Microdensitometer image from the streak camera photograph of four quadrature images. Time mark interval is 0.3 µs, increasing to the right. Position along the line on the metal surface is represented by the vertical coordinate.

4.2 Push-pull difference images

The film density data were exponentiated to convert them to approximate light intensity. Figure 3 shows the difference images obtained by subtracting the (–sine) image from the sine image and the (–cosine) image from the cosine image.

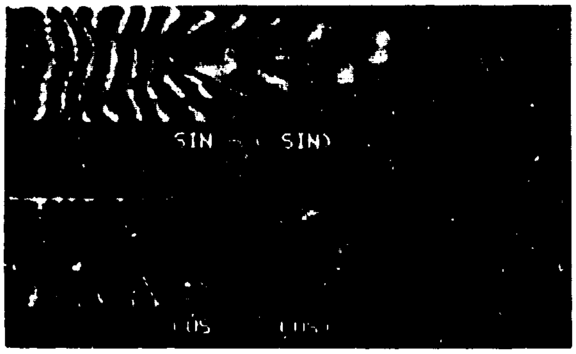

FIGURE 3
Sine and cosine difference images.

4.3 Intensity image: sum of four quadrature images

Figure 4 shows the sum of all four quadrature images that provides a time vs position history of the total light returned from the target. This image is useful to indicate correct registration between all four quadrature images. When properly registered, there should be no interference information visible in the sum image. Imperfect registration is apparent to the upper left where fringes are slightly visible. Laser intensity variations are also visible, especially near the right end. Dark regions have insufficient light for analysis.

FIGURE 4
Intensity image: sum of four quadrature images.

5. FRINGE COUNT AND VELOCITY CALCULATION

5.1 Fringe tracing

Individual bright and dark interference fringes were manually traced from both the sine and cosine difference images. Each trace was numbered starting at zero before the start-of-motion. The traced points are plotted in Fig. 5.

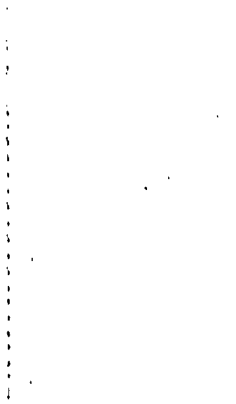

FIGURE 5
Manually traced points on fringes from difference images.

5.2 Relationship between velocity and fringe count

Velocity was calculated for each traced point by multiplying its interference fringe count by 411 m/s. This left gaps in velocity data between tracings.

5.3 Velocity plots and interpolation

A simplex interpolation algorithm was then used to estimate velocity between the traced points. It yielded a continuous velocity history across the metal plate over the time of the experiment. Results are plotted in Fig. 6.

Visible in Figs. 2,3,5 and 6 is a triangular region

FIGURE 6
Isometric plot showing velocity as a function of time and position on the target surface. Time increases to 5 µs from left-to-right, velocity increases upward to 5.5 km/s and the position along the plate extends to 25 mm up and to the left.

bordered by the start of the record on the left and by abrupt changes in fringe position, produced by corresponding plate acceleration, on the right. The abrupt acceleration resulted from a radially converging stress wave, or shock, in the explosive driver that first propagated inward to the center axis and later reflected outward.

Data from several discrete times in Fig. 6 are replotted in Fig. 7 to emphasize the large velocity differences that existed across the plate during its acceleration. Interestingly, at 1.5 µs the velocity difference exceeds 0.5 km/s.

5.4 Displacement plots

Displacement information was calculated by integrating the velocity data with respect to time. Curves plotted in Fig. 8 represent the physical shape of the illuminated line on the plate at several discrete times during the experiment. Note the change from concave to convex. By comparing Fig. 8 to Fig. 7, it can be seen that subtle changes in shape mask the large differences in velocity that existed across the plate.

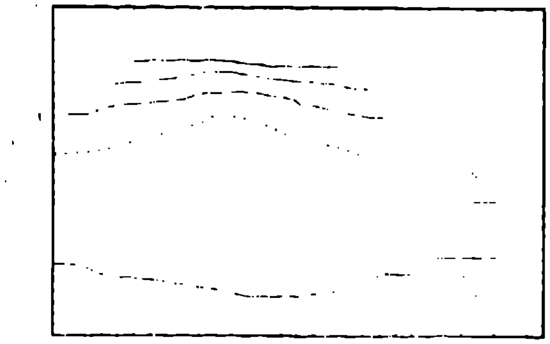

FIGURE 7
Velocity vs position across the plate at several discrete times during the experiment.

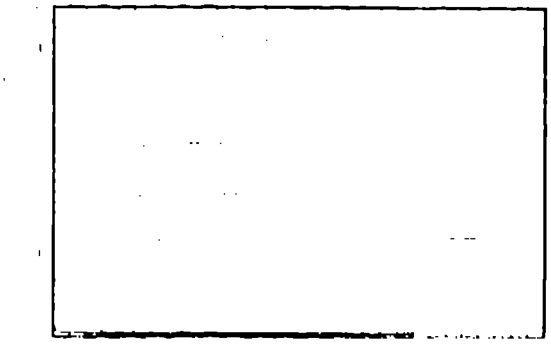

FIGURE 8
Displacement vs position across the plate at several discrete times during the experiment.

6. CONCLUSION

A dye amplifier has provided 600-W single-frequency power starting from an argon-ion laser. The increased power enabled imaging velocity measurements over a 10 m optical path, greatly improved the signal-to-noise ratio and eliminated the requirement for an image intensifier.

The capability to sense acceleration was especially useful in this experiment. Strong velocity pertubations that swept inward and later reflected outward were measured as the plate accelerated to 5.5 km/s in 4 µs. The existance, structure and >0.5 km/s magnitudes of the velocity differences that existed simultaneously were clearly measured in a single experiment by the line-imaging VISAR but might have been masked by shot-to-shot variations in many, separate, single-point velocity experiments.

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