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TITLE: VISAR: LINE-IMAGING INTERFEROMETER

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VISAR: Line-imaging interferometer

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ABSTRACT

This paper describes a Velocity Interferometer System for Any Reflector (VISAR) technique that extends velocity measurements from single points to a line. Single-frequency argon laser light was focused through a cylindrical lens to illuminate a line on a surface. The initially stationary, flat surface was accelerated unevenly during the experiment. Motion produced a Doppler-shift of light reflected from the surface that was proportional to the velocity at each point. The Doppler-shifted image of the illuminated line was focused from the surface through a push-pull VISAR interferometer where the light was split into four quadrature-coded images. When the surface accelerated, the Doppler-shift caused the interference for each point on each line image to oscillate sinusoidally. Coherent fiber optic bundles transmitted images from the interferometer to an electronic streak camera for sweeping in time and recording on film. Data reduction combined the images to yield a continuous velocity and displacement history for all points on the surface that reflected sufficient light. The technique was demonstrated in an experiment where most of the surface was rapidly driven to a saddle shape by an exploding foil. Computer graphics were used to display the measured velocity history and to aid visualization of the surface motion.

1. INTRODUCTION

Velocity Interferometer System for Any Reflector (VISAR) or Fabry-Perot interferometer systems can often be used interchangeably in experiments to measure velocity. However, because there are important differences between VISAR and Fabry-Perot interferometers, the requirements of an experiment can sometimes favor, or possibly exclude, either system.

The velocity of a line element on a surface was first measured by John Corfe of AWE, Aldermaston, U. K. Corfe used a Fabry-Perot interferometer to filter the Doppler-shifted line image for recording by an electronic streak camera. The technique, described in the previous paper of these proceedings, was reproduced by the authors.

This paper describes an easy experiment to demonstrate line VISAR. First, a diagram illustrates the experimental system. Then a brief discussion of VISAR quadrature signals is presented to introduce quadrature line images. Data from an experimental streak camera photograph of four quadrature line images are shown at various stages of processing, starting from the raw image and concluding with velocity history plots. Final results for velocity are mapped on a surface with coordinates of velocity, time, and position on the target.

2. SLAPPER EXPERIMENTAL SET-UP

A "slapper" experiment, where an electrically exploding metal foil drives a thin plastic membrane or slapper, was selected because the device's performance was known and the plastic could easily achieve the high velocities appropriate for demonstrating a line VISAR. Furthermore, one experiment could simultaneously provide a wide range of velocities. During the experiment illustrated in Fig. 1, a 1-mm-wide by 20-µm-thick copper bridge foil was electrically exploded behind a 75-µm-thick polyimide slapper. This accelerated the slapper in the area over the bridge to a velocity greater than 2 mm/µs in approximately 0.5 µs.

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To give structure to the velocity history, regions of zero velocity were included by making the illuminated line extra long compared to the bridge width. Single frequency laser light was therefore focused by a cylindrical lens to a line approximately 2-mm long on the slapper surface. A diffuse reflecting surface was provided by lightly sandblasting the illuminated region. The incidence and reflection angles were small and approximately equal to maximize the collection of diffusely reflected light. Light was collected and focused through the VISAR interferometer by a spherical lens.

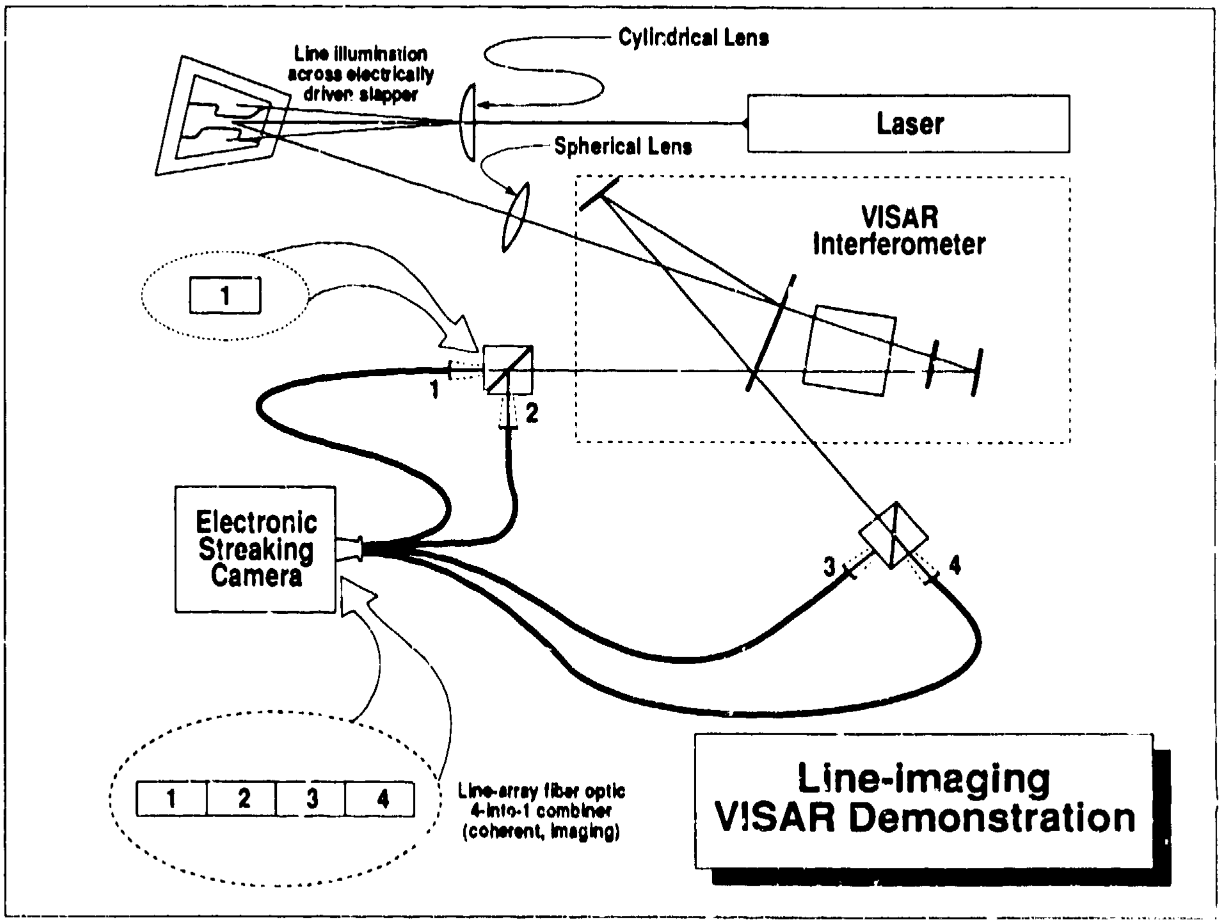

Fig. 1. Line-imaging VISAR demonstration. Laser light is focused by a cylinderical lens onto a target for velocity measurement. Reflected light is focused through the interferometer where it produces fringe images that respond to target motion. The images are transmitted by four fiber optic bundles to an electronic streak camera for recording.

While traversing the interferometer, the light was split into two beams. These beams were further split by two polarizing beamsplitters giving four optical outputs. All four optical paths from the spherical lens were equalized and adjusted individually to ensure that each image was properly focused onto the entrance of its respective fiber optic bundle. Overall magnification was adjusted until the four images filled the 6-mm-long by 0.2-mm-wide fiber optic bundles. At their exit ends, the four fiber optic bundles were combined end-to-end into a linear array 24 mm long by 0.2 mm wide. The fiber optic array was put into direct contact with the photocathode window on the streak camera. No slit was used at the camera because the images were already in the form of a line.

3. DISCUSSION

3.1 Obtaining VISAR interferometer quadrature images

A wide-angle Michelson interferometer[1-3] with a time delay in one leg is used by VISARs to detect and measure the Doppler-shift of light reflected by targets. Optical elements in the delay leg compensate for the delay path so that the magnifications of both interferometer legs are identical. Thus, for temporally coherent light, wavefronts traversing either leg will be identical upon recombination. Fortunately, in most VISAR experiments, temporal coherence is adequately preserved during target surface changes and by the Doppler-shift.

Interference between identical wavefronts provides a VISAR with high-contrast interference, even with light reflected from a diffuse surface. Equally important to line VISAR, identical magnifications allow light rays traversing both legs of the interferometer to produce identical images at the entrances to the fiber optic bundles.

The mechanism for encoding velocity information by interference in most VISARs is quadrature-coding[4]. Quadrature-coding yields four signals with 90° phase differences that can be recorded electronically or optically[5]. When a conventional VISAR is used to measure the velocity of one point, the light that produces the quadrature signals is reflected from a single point, or a very small area, on a target surface.

Light reflected from many points on a target surface, however, is focused through a line VISAR interferometer to form quadrature *images*. Each point in a quadrature image yields a quadrature signal for one point on the target. Care is taken to ensure that the images are well focused and registered so that corresponding points in all quadrature images will map to a single point on the target surface.

During an experiment, the line VISAR quadrature images are photographed over time by an electronic streak camera. The photograph is later digitized by a microdensitometer and stored on disk for processing by computer. In processing the digitized data, quadrature images with opposite polarity interference are subtracted. This subtraction yields important benefits: it converts the images to a true sine and cosine format, it doubles the dynamic range, and it eliminates undesirable common-mode optical noise. Common-mode optical noise is produced when temporally incoherent light, that because of the interferometer delay does not produce interference, is transmitted through the interferometer. The non-interfering light thus appears equally in all quadrature images and therefore is cancelled from the difference images.

When the line VISAR data are in the familiar sine and cosine format obtained by subtraction, they can be analyzed by modified point VISAR methods. The large quantity of data, however, demands robust algorithms so that excessive data analyst time and effort can be avoided.

3.2 Approach to data reduction

Areas approximately 150 by 1300 pixels were digitized for each quadrature image. The digitized film density data were converted to light intensity by exponentiation. Then the 0° quadrature image was subtracted from the 180° image and the 90° image was subtracted from the 270° image to give sine and cosine difference images.

After being processed in the form of images, the sine and cosine data were analyzed using an arctangent algorithm[6] to calculate velocity as a function of time. To speed computer calculations for many points, the data were input to a loop for calculation of all point velocity histories.

4. STREAK PHOTOGRAPH IMAGE PROCESSING

4.1 Line VISAR streak camera photograph of four quadrature images

Figure 2 shows the streak camera photograph after digitization by a microdensitometer. The 90° phase differences are apparent between the four quadrature images. The center of each streak image maps to the region on the target with highest velocity; the edges of each image are for regions of zero velocity. Fine structure is caused by target surface roughness, image intensifier noise, imperfections in the fiber optic bundles, and laser speckle. The orientation of the upper two traces is inverted relative to the lower traces.

4.2 Push-pull difference images

The film density data were exponentiated before further processing to convert from the logarithmic film response to light intensity. Figure 3 shows the difference images obtained by subtracting the top trace from the third and by subtracting the second trace from the fourth. After subtraction, the images were in the form of sines and cosines.

4.3 Intensity image: sum of four quadrature images

Although not presently used for data reduction, Fig. 4 shows the sum of all four quadrature images to indicate a time and position history of the total light returned from the target. This image is analogous to the intensity monitor of Ref. 1 for point VISAR. In future line VISAR tests, the light history in this image could be used to provide an estimate of measurement precision.

4.4 Isoplot of cosine image

Data for the cosine difference image are plotted in Fig. 5. The signals were very noisy, especially at high frequencies, because of low light intensity reflected by the target. Much of this noise could have been eliminated by increasing the laser power, by using a better reflector than the sandblasted polyimide surface, or by increasing the light collection efficiency.

4.5 Smoothed cosine image

Figure 6 shows the data from Fig. 5 after low-pass filtering to reduce noise. The low-pass filter was a general purpose two-dimensional Gaussian blur, commonly used for image processing.

5. VISAR DATA REDUCTION OF QUADRATURE IMAGES

5.1 Relationship between target velocity and fringe count

In this demonstration, it is assumed that the velocity is proportional to the interference fringe count for each point on the target. The fringe count is calculated from data for each point in the quadrature images by the algorithm of Ref. 6.

5.2 Velocity plots

Because there are many points in a line VISAR measurement, it was necessary to extend from single-point velocity calculations to multiple points. The line VISAR calculations are expressed in equation (1):

$$u(y,t) = F(y,t)[\text{Fringe Constant}] \quad , \qquad (1)$$

where y is the spatial coordinate along the target surface, t is time, u(y,t) is the target velocity at time t and spatial location y, F(y,t) is the fringe count at time t for location y, and the Fringe Constant with dimensions of mm/µs/fringe converts from fringe count to velocity.

The velocities for all points calculated in a loop by equation (1) are plotted in Fig. 7. Arbitrary units were used for plotting, but the maximum velocity was approximately 2.3 mm/µs, the spatial coordinate extends to about 2 mm and the total time was approximately 1 µs.

The velocity data were then integrated with respect to time. Figure 8 shows the distance traveled as a function of time and position on the target surface with arbitrary units used for plotting. The maximum distance was approximately 1.1 mm and the spatial and time coordinates were the same as Fig. 7. An intersection of the surface of this plot with a plane at constant time would represent the instantaneous shape of the slapper.

6. DISCUSSION OF EXPERIMENTAL RESULTS

In this demonstration, the intensity of light returned by the surface was marginal for streak photography. High image intensifier gain was therefore necessary and produced very noisy images that required filtering to reduce the high-frequency content. Even under these conditions, usable velocity information was obtained from the filtered image. The line velocity history agrees with other experiments to measure the velocity and shape of similar slappers.

Adequate registration between the quadrature images was accomplished visually by translating them to superimpose common features. This procedure was somewhat confused by the presence of random noise, but nevertheless, the matching of details in all images was good. The use of spatial fiducials on the target surface together with image correlation techniques may well improve registration of future line VISAR quadrature images.

When analyzing data for point VISAR measurements, it is usually necessary to adjust the phase difference and the amplitude ratio between the sine and cosine signals and to set the baseline zero values to account for interferometer and signal variations. Ideally, the values are determined from a dry run. In this demonstration, however, no dry run was performed so nominal values, a 90° phase difference, a 1:1 amplitude ratio, and zero baselines were used.

7. SUMMARY

Line-imaging VISAR has been demonstrated by measuring the velocity of a line element on the surface of an unevenly accelerated slapper. Data reduction yielded continuous velocity and distance histories over most of the illuminated line. Further development of line VISAR techniques is anticipated.

8. ACKNOWLEDGEMENTS

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Fig. 2 Microdensitometer image from the streak camera photograph [illegible] four quadrature images [illegible] increases to the right

Fig. 3 Sine and cosine images obtained by subtracting opposite polarity quadrature images

Fig. 4 Sum of four quadrature images from Fig. [illegible] This sum shows the total light intensity [illegible] from the target over position and time

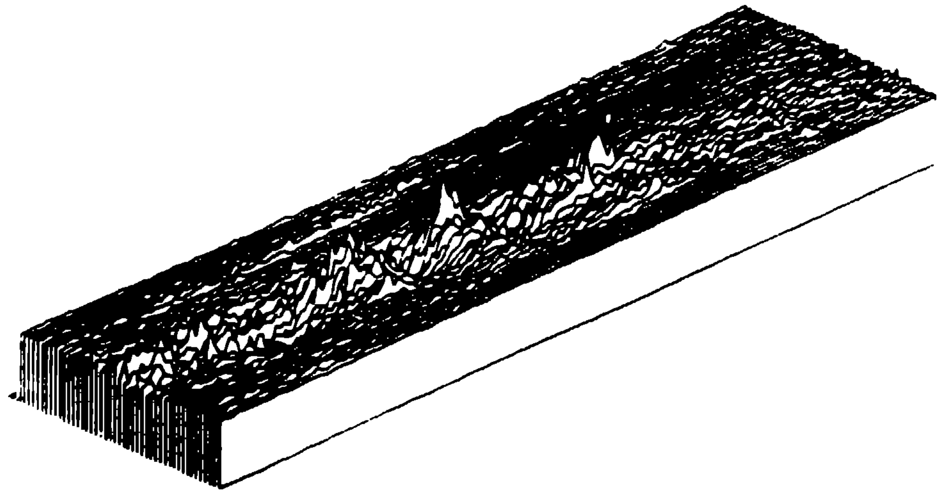

Fig 5. Isoplot showing noisy cosine image as a function of time and position on the target surface.

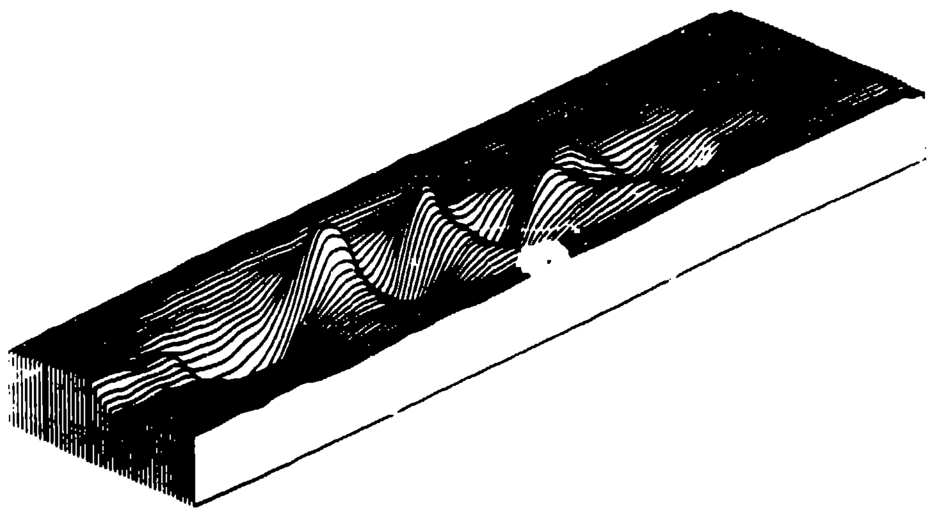

Fig 6. Isoplot showing low pass filtered cosine image as a function of time and position on the target surface.

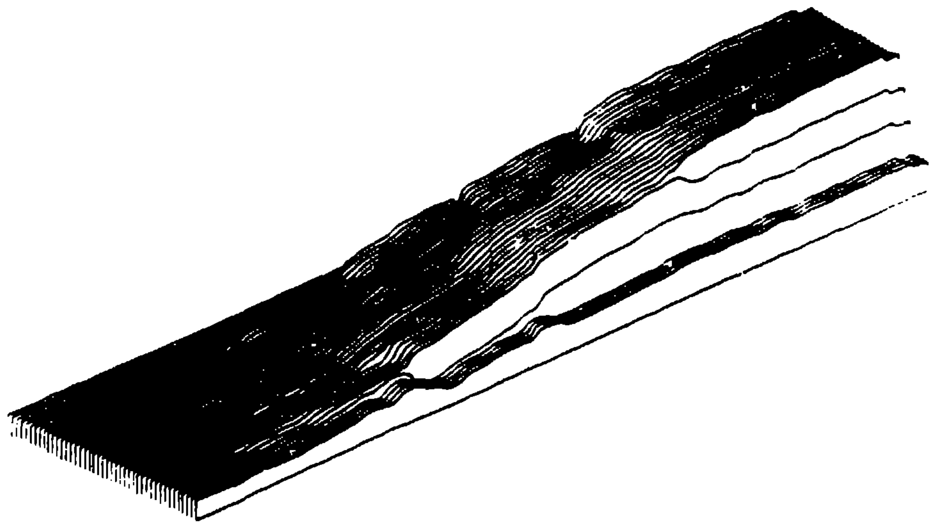

Fig 7. Isoplot showing velocity as a function of time and position on the target surface. Time increases back and to the right, velocity increases upward and the spatial coordinate increases back and to the left.

Fig 8. Isoplot showing distance as a function of time and position on the target surface. Time increases back and to the right, distance increases upward and the spatial coordinate increases back and to the left.