Fan Fring Cam Rdy 2 Col 3 UCRL - JC - 121520 Seattle 95 Camera Ready

Shock Compression of Condensed Matter-1995
ed. S.C. Schmidt, W.C. Tao
Seattle, Aug 13, 1995
AIP Press

WHITE LIGHT VELOCITY INTERFEROMETRY

David J. Erskine and Neil C. Holmes

Lawrence Livermore National Laboratory, Livermore, CA 94551

We describe a generic method for using broadband and incoherent light in velocity interferometry. Single frequency lasers are no longer necessary. Compact, powerful and inexpensive light sources previously prohibited due to their incoherence are now suitable for Doppler velocimetry of remote objects through air, including arc lamps, flash lamps, light from detonations, pulsed lasers, chirped frequency lasers and lasers operated simultaneously in several lines. These powerful sources should allow practical line and areal velocimetry. In our technique, the light source is imprinted with a coherent echo having a delay matching the delay in an analyzing interferometer. The technique is generic to all wave phenomena (i.e. radar, ultrasound).

INTRODUCTION

The VISAR[1-4] velocimeter (velocity interferometer system for any reflector) is an optical interferometer having a fixed delay τ between its arms. This delay converts small Doppler shifts into fringe shifts in the interferometer output. Let the delay be specified by the distance ($c\tau$) light travels in that time, where c is the velocity of light in vacuum. The idealized velocity per fringe proportionality[1,2] (η) of a VISAR is

$$\eta = \frac{c\lambda}{2(c\tau)} \qquad (1)$$

where λ is the average wavelength of light. Equation (1) neglects dispersion[2] in the glass optics inside the interferometer and assumes $v/c \ll 1$, where v is target velocity.

In previous VISARs, the coherence length (Λ) of the illumination must be as large as $c\tau$ in order to produce fringes with significant visibility. This severely restricted the kind of light source which could be used. The Λ of white light (~1.5 μm) was insufficient. Previously, lasers were the only light sources used in VISARs because their coherence length could be made sufficiently long when operated in a single frequency mode. However, in this mode the output power is low. Typical laboratory measurements in shock physics were limited to measurement of velocity at a single point on the target due to low laser power. Measurement of velocity over a surface, or of a remote object through a telescope in the field demands orders of magnitude more power. Optical amplification of the single frequency source has been used to construct a line-VISAR[5]. However, this is expensive and cumbersome.

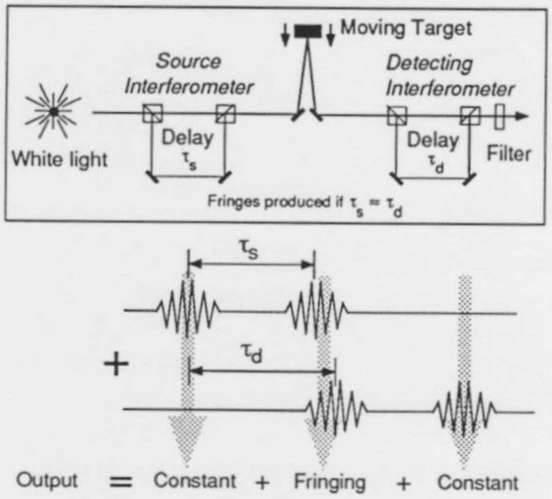

Figure 1. White light velocimeter concept. Two interferometers before and after target have similar delays τ_s and τ_d. White light is a series of independent wave packets. The first interferometer splits each wave packet into two identical packets-- the second does the same to create a total of four. Two of those packets will overlap if $\tau_s \approx \tau_d$, producing fringes. The other packets contribute constant intensity. Target velocity will change the apparent τ_s due to the Doppler effect, causing a fringe shift. The wave packet length is inversely proportional to system bandwidth, represented by the filter.

METHOD

1003

We have invented[6] a simple and generic method (Fig. 1) of preparing any wave source, regardless of its initial coherence, to illuminate a velocity interferometric experiment. A coherent echo is imprinted on the illuminating light by an interferometer (denoted the source interferometer) having a delay τ_s. The reflected light from the target is observed through a second interferometer (denoted the detecting interferometer) having delay τ_d. Partial fringes result when $c\tau_s$ and $c\tau_d$ are within a coherence length of each other. Target velocity causes the apparent value of τ_s to change due to the slight Doppler scaling of the spectrum reflected from the target, producing a fringe shift.

Double interferometer arrangements using short coherence length light have been used previously in communication[7] and to multiplex serial fiber optic sensors[8], and to measure target motion where the target is internal to one of the interferometers[9-11]. However, we believe we are the first to apply this concept to remote targets external to an interferometer. This allows the fringe phase to be independent of target distance, surface roughness, and the scattering and dispersive properties of the interposed medium. A single interferometer technique by Geindre et al.[12] measures high velocity (100 km/s) plasma by illuminating the plasma with two subpicosecond pulses separated by ~1 ps, then dispersing the reflected light with a grating. Their Doppler shift is resolvable by a grating rather than a second interferometer because it is so large.

Figure 2 shows the fringing behavior calculated[6] for a stationary target for narrow and wide system bandwidths. The white light velocimeter operates where $c\tau_s \approx c\tau_d$. The widths of the fringe bands is inversely related to the system bandwidth. Thus these widths can be increased by insertion of a bandpass color filter.

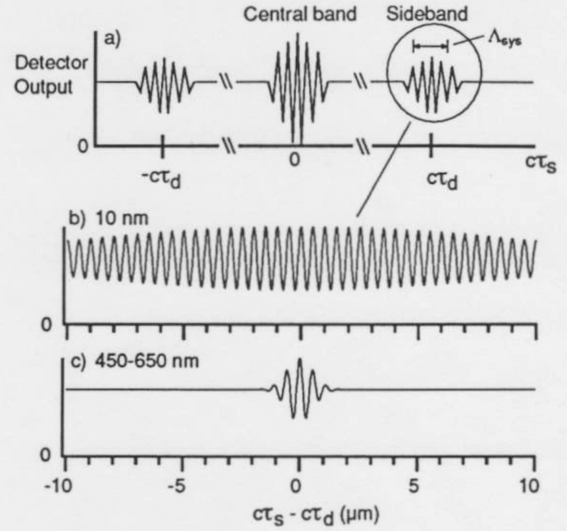

Figure 2. White light velocimeter output versus source interferometer delay length ($c\tau_s$), for a stationary target. Both source and detecting interferometers are the Michelson type. A moving target Doppler shifts apparent $c\tau_s$ by $\Delta(c\tau_s)=-(2v/c)$ $(c\tau_s)$. a) Schematic of global behavior: sidebands have the same shape and width as the central band, but lower amplitude. Their width, the system coherence length (Λ_{sys}), is inversely proportional to the bandwidth of the system. b) Calculated detail for 495-505 nm bandwidth. c) For 450 - 650 nm bandwidth.

A moving target Doppler shifts apparent $c\tau_s$ by $\Delta(c\tau_s)=-(2v/c)\,(c\tau_s)$. If λ is the average wavelength, then the fluctuating part of the intensity varies locally approximately as

$$\Delta I \propto \cos\left[\left(\frac{2\pi}{\lambda}\right)(c\tau)\left(\frac{2v}{c}\right)+\phi_0\right] \qquad (2)$$

where ϕ_0 is some constant. From this we obtain Eq. (1).

The fringe visibility is defined $(I_{max}-I_{min})/(I_{max}+I_{min})$, where I_{max} and I_{min} are local maximum and minimum output intensities. Figure 2 shows the fringe visibility in the sidebands is less than unity. This is not a practical difficulty. Since the two outputs of an interferometer are of opposite phase, they can be subtracted numerically to cancel the incoherent signal portion. Also, using a Fabry-Perot interferometer as the source interferometer can increase fringe visibility arbitrarily at the expense of absolute signal strength[6].

Since a conventional VISAR uses monochromatic illumination, a discontinuous velocity jump will cause an ambiguity in the fringe shift to an integer. This because fringes are periodic. However in the white light velocimeter, by recording fringe shifts for different colors separately, the velocity can be uniquely determined. One implementation of this is to disperse the velocimeter output by a grating and record the spectrum versus time by a multi-channel detector or streak camera. Figure 3 shows a calculated streak pattern for a hypothetical velocity history. Because of Eq. (2), the output intensity varies sinusoidally versus $1/\lambda$ as well as with velocity. The number of fringes across the streak record in the wavelength direction scales with the velocity, and therefore the velocity skip across the shock is determinate.

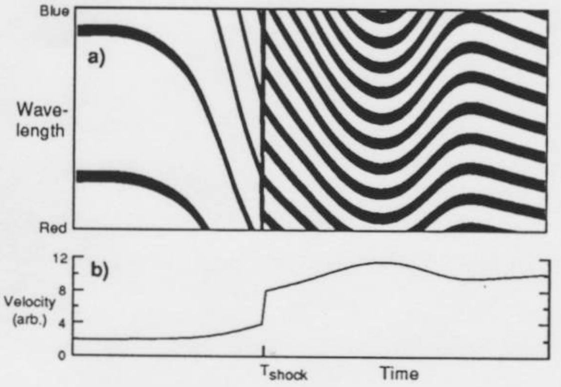

Figure 3. Multi-color fringes can be used to determine velocity absolutely. a) Output intensity map versus wavelength and time, from Eq. (2) using hypothetical velocity history b). Dark bands represent light minima (fringes). This simulates dispersing the light from the target with a grating and recording it by a streak camera or multi-channel detector. The number of fringes along the wavelength dimension scales with velocity, allowing unambiguous determination of the velocity after discontinuous shock at T_{shock}.

This type of streak record may remind readers of the use of a Fabry-Perot interferometer in conjunction with a streak camera. In that system, because the illumination is quasi-monochromatic, the number of fringes across the record in the wavelength direction is constant, so there is a fringe ambiguity across the shock.

CONCLUSION

The ability to use broadband and incoherent light sources is a great practical advantage of the white light velocity interferometer. These sources can be inexpensive, compact and powerful. Line and areal velocimetry should now be practical.

ACKNOWLEDGMENT

This research was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

REFERENCES

1. Barker, L.M., & Hollenbach, R.E., J. Appl. Phys. 43, 4669-4675 (1972).
2. Barker, L.M., & Schuler, K.W., J. Appl. Phys. 45, 3692-3696 (1974).
3. Hemsing, W.F., Rev. Sci. Instrum. 50, 73-78 (1979).
4. Sweatt, W., Rev. Sci. Instrum. 63, 2945-2949 (1992).
5. Hemsing, W.F., in *Shock Compression of Condensed Matter-1991*, edited by S.C. Schmidt et al., (North-Holland, Amsterdam, 1992), p. 767-770.
6. Our report to be published by Nature.
7. Delisle, C., & Cielo, P., Can. J. Phys., 53, 1047-1053 (1975).
8. Brooks, J., Wentworth, H., Youngquist, M., Kim, B.Y., Shaw, H., J. Lightwave Tech., LT-3, 1062-1071 (1985).
9. Gusmeroli, V., & Martinelli, M., Opt. Lett. 16, 1358-1359 (1991).
10. Ribeiro, A., Santos, J., Jackson, D., Rev. Sci. Instr. 63, 3586-3589 (1992).
11. Harvey, D., McBride, R., Barton, J., & Jones, J., Meas. Sci. Technol. 3, 1077-1083 (1992).
12. Geindre, J.; Audebert, P., Rousee, A.; Falliès, F., Gauthier, J.; Mysyrowiczk, A.; Dos Santos, A.; Hamoniaux, G.; & Antonetti, A., Opt. Lett. 19, 1997-1999 (1994).