IL7801299

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WIS-PH--78/4

Interferometric Method for Measuring High Velocities of Diffuse Surfaces

[illegible]

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Abstract

An interferometric method for measuring the displacement of diffuse surfaces moving with velocities of a few millimeters per microsecond is presented. The method utilizes the interference between two light beams reflected from a constant area of the moving surface at two different angles. It enables the detection of high rate velocity variations. Light source of a fairly low temporal coherence and power around 100 mW is needed.

Recently[1)] a new interferometric technique for measuring displacements of surfaces moving at velocities in the range of a few millimeters per microsecond has been presented. This technique employs two light beams incident upon the moving surface at different incidence angles. The reflected beams interfere at the surface of a photodetector. The frequency of the resulting interference signal is significantly smaller than the Doppler shift of each of the beams. When velocities higher than a few tenths of a millimeter per microsecond are involved, an interference signal, with a frequency equal to the resulting Doppler shift of visible light (around 1 GHz or more), is not measurable with known electronic devices. The signal frequency in the proposed system can be made detectable by an appropriate choice of the difference between the incidence angles. Systems for measuring velocities of both specularly as well as diffusely reflecting surfaces were introduced.

In the measurements suggested for diffuse surfaces an error is caused by the shift of the surface area illuminated by the obliquely incident beam during the motion of the surface. This shift leads to the reflection of light by different point scatterers at different times, which alters the reflected wavefront during the measurement. This error has been estimated in Ref. 1 to be a few percents. In this note another system for measuring the velocity of diffuse surfaces, following the method introduced in Ref. 1, is described. The above mentioned error is avoided with this system.

The new suggested system depicted in Figure 1, is based on the interference of two light beams which are reflected from a point on the moving surface at two different angles. The incident beam ℓ_1 is focussed by the lens L_1 upon the reflecting surface s at the point P, hitting the surface at an approximately right angle. The diffusely reflected light is collected by the lenses L_1 and L_2 which fulfill the diffraction limit criterion: $d_0 = 1.22\lambda F$; where d_0 is the illuminated spot diameter, λ is the light wavelength and F is the lens f-number. Thus, the phase of each of the collected waves is well defined over the lens area$^{2)}$. Each lens gathers light reflected at a different angle. It is assumed that the center of the lens L_1 lies on the normal to the surface s while the center of L_2 lies on a line which forms an angle θ with the normal. Using the telescopes T_1 and T_2 and the beam splitters the collected beams ℓ_1' and ℓ_2' are directed onto the photo-detectors. The photo-detectors D_1 and D_2 measure the intensities of the reflected beams ℓ_1' and ℓ_2' respectively, and the detector D_3 measures the interference signal. It is easy to show that if the surface s moves with a velocity v parallel to its normal the resulting frequency of the interference signal is $\omega(v/c)\,(1-\cos\theta)$, where ω and c are the light angular frequency and velocity respectively. This implies that the signal frequency is smaller by a factor of $2/(1-\cos\theta)$ than the Doppler frequency shift $2\omega(v/c)$ of a beam normally incident and reflected from the moving surface. For each value of the velocity v the value of θ is adequately chosen so that the signal frequency is sufficiently reduced to be (around 1 GHz or less) trackable by the available electonic devices. For instance, when θ equals 25^0 the signal frequency is reduced more than 20 times relative to the Doppler frequency shift. The smaller the value of θ, the more reduced the fringe count, leading to a lower accuracy in the measurement. Velocity variations of various rates, occuring at the same experiment can be detected. The observation of relatively lower rate variations necessitates an averaging of the recorded signal over a larger time interval, while in measurements of higher rate variations better time resolution can be obtained.

As the beam ℓ_1 is normally incident upon the moving surface the illuminated spot upon the surface does not shift during the motion. This eliminates the error mentioned earlier.

In addition, in contrary to the system depicted in Figure 3 of Ref. 1, here the intensity of each of the reflected beams can be measured. Thus better accuracy can be achieved. Moreover, in this system, two types of interference signals can be measured: signals constructed from reflected beams with equal optical paths and from beams with unequal optical paths. With the systems described in Ref. 1 this was possible only for specularly reflecting surfaces. With the second type of signals (where one of the reflected beams is delayed relative to the other) the instantaneous velocity can be measured with an accuracy similar to that of the velocity interferometer technique$^{3)}$. However, in this case the employed light beams should be coherent at least during the delay time, while in the former type of measurements the needed temporal coherence of the light source is very modest.

As already mentioned, the illuminated spot diameter d_0 is determined by the f-number F of the lenses L_1 and L_2. This f-number should be high enough to prevent a considerable widening of the spot during the motion. For example, for $F = 100$ and $\lambda = 6000$ Å the initial spot diameter is $d_0 \simeq 70$ μm , and it is doubled when the surface moves 7 mm. When smaller displacements are concerned F may be chosen smaller. When $F = 100$ the light source power necessary for attaining a useful signal to noise ratio is at least few tens of milliwatts$^{1)}$.

It should be noted that diffuse surfaces are preferable in shock wave experiments involving interferometric velocity measurements. Their use increases the measurement convenience and accuracy because of the insensitivity to tilt.

The author is highly grateful to Y. Zarmi for careful reading of the manuscript.

References

1. Y. Maron, Rev. Sci. Instrum. 48, 12, p. 0076 (December, 1977).
2. R.D. Kroeger, Proc. IRE 49, 1960 (1961).
3. L.M. Barker, in Behaviour of Dense Media Under High Dynamic Pressures (Gordon and Breach, New York, 1968) p. 483.

Figure Captions

Fig. 1. Schematic diagram of the system for measuring the velocity of a diffuse surface. La - lasers; b_1, b_2, b_2', b_3 - beam splitters; C - beam expander; L_1, L_2 - lenses; T_1, T_2 - telescopes; s - diffuse surface; m - mirror; D_1, D_2, D_3 - photo-detectors; ℓ_1 - incident beam; P - incidence point; ℓ_1', ℓ_2' - reflected beams.

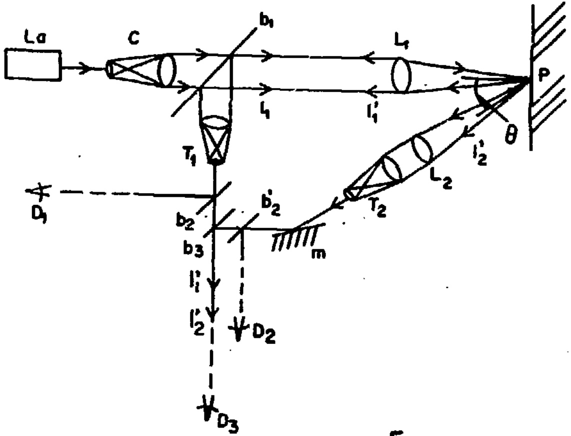

Fig. 1