MEASURING THE VELOCITIES OF DROPLETS IN A TWO-PHASE STREAM

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A holographic method is shown by which the velocities of droplets in a two-phase stream are determined with the aid of a ruby laser as the light source operating in the mode of two successive monopulses.

The measurement of particle or droplet velocities in a two-phase stream is very difficult. At the same time, the use of single-beam holography in the far field of an object makes it possible not only to rather simply determine the size and the concentration of particles in any location within the volume but also to measure the actual magnitude and direction of their velocity. If the velocity of an object is sufficiently small, then several holograms can be obtained on different photographic plates at definite time intervals. By sequentially reconstructing these holograms, one can track the motion of the object in time. When the velocity of an object is high, then it becomes practically impossible to obtain several holograms within the insufficient length of time.

In this study the authors used the holographic method for determining the velocities of water droplets in the core of a dispersive-annular air–water stream, based on the feasibility of recording several holograms on the same photographic plate. This problem has been discussed more thoroughly in [1].

Let us consider a plane wave front with the amplitude A_0. When this wave impinges on a flat opaque object, the amplitude of the resultant perturbation A in the hologram plane is

$$A = A_0 - A_p, \tag{1}$$

where A_p denotes the perturbation in the hologram plane produced by the object. In the case of two exposures, the amplitude of the resultant vibration in the hologram plane is, by virtue of the linear superposition principle,

$$A = A_{01} + A_{02} - A_{p_1} - A_{p_2}, \tag{2}$$

where subscripts 1 and 2 refer to the successive exposures respectively.

The light intensity I recorded on the hologram is

$$I = AA^* = |A_{01}|^2 + |A_{02}|^2 + |A_{p_1}|^2 + |A_{p_2}|^2 + A_{01}A_{p_1}^* + A_{01}^* A_{p_1} + A_{02}A_{p_2}^* + A_{02}^* A_{p_2}. \tag{3}$$

Within the linear range of the photoemulsion characteristic, the transmittivity of such a hologram is

$$T = 1 - \gamma I.$$

When the hologram is exposed to a plane wave with the amplitude A_{00}, then the amplitude of the reproduced wave will be

$$A' = A_{00}[1 - \gamma(|A_{01}|^2 + |A_{02}|^2 + |A_{p_1}|^2 + A_{p_2}|^2)] + \gamma A_{00}(A_{01}A_{p_1}^* + A_{02}A_{p_2}^*) + \gamma A_{00}(A_{01}^* A_{p_1} + A_{02}A_{p_2}). \tag{4}$$

The first term in this expression represents a partially modulated plane wave, the second term represents a real image of the object, and the third term represents a virtual image of the object. When the far-field condition is satisfied, then the effect of the virtual image on the focused real image becomes negligible.

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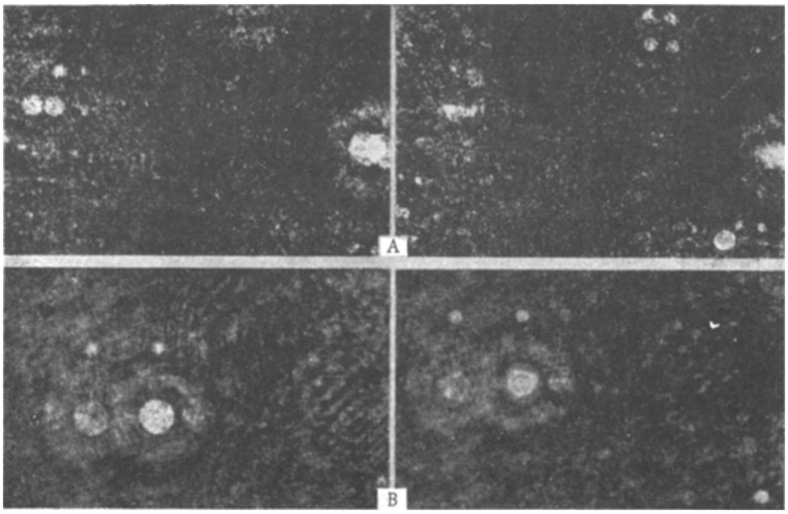

Fig. 1. Reproduced image of an air–water stream segment: double-exposure hologram (A), triple-exposure hologram (B).

An analysis of the second term in (4) shows that wave fronts which correspond to the object location during the time of the first and the second exposure respectively are reproduced without distortion. If one or a few objects are holographed twice on the same photo plate, therefore, then on the reproduced hologram there will appear undistorted real images of these objects which correspond to their location in space at the time of each exposure.

The object in this study was an air–water stream at an air velocity within the 20-100 m/sec range. Suspended water droplets 10-200 μm in size were holographed in the far field. Their concentration in the stream did not exceed 0.1 kg/m^3. The holography was performed with a single beam according to Thompson [2]. During single-beam holography the maximum concentration of droplets in a gas depends on the depth of the holographed volume and is determined from the requirement that sufficient intensity of the reference beam be maintained, i.e., that $\Sigma F_D/F_H \leq 1$ (ΣF_D denoting the projection of all droplets within the holographed volume on the hologram plane and F_H denoting the area of the hologram). The hologram was recorded on a Panchrome T-18 film. After reproducing the image which had been recorded on the hologram, we determined the size of droplets and their velocity distribution in the stream within the entire holographed volume of $36 \times 24 \times 30$ mm^3. With an optical quantum generator and a passive shutter, it was possible to obtain two or more monopulses within definite time intervals. Near the generation threshold the oscillator operates in the stable monopulse mode. Farther above the threshold one obtains 2, 3, etc., monopulses. By a change of the pumping level in such a pulse tube, one can adjust the time interval between individual monopulses. The proper length of this interval depends on the stream velocity and, in the general case, on the hologram size. In holography of microscopic objects, the proper interval between pulses is dictated by the magnitude of the maximum field of vision in the microscope. Thus, for a 100 m/sec stream velocity and a 5 mm field of vision, for instance, the interval between pulses should not exceed 50 μsec. If a droplet leaves the field of vision during this time, it can still be identified, in principle, but with great difficulties. In our tests the interval between pulses was varied from 3 to 40 μsec.

In some cases it is more convenient to operate with three monopulses. The behavior of a droplet during the exposure periods can then be more accurately tracked. The relative brightness of a droplet image during each exposure is proportional to the amplitude of the respective monopulse. Therefore, if the monopulses differ in amplitude – and this happens most often in operation with three monopulses – then the direction of a droplet velocity can be easily determined.

The number of monopulses and the intervals of time between them were measured with a model FÉU-12A photomultiplier, the signals from which were recorded on a model S1-13A oscillograph. During operation with several exposures the illumination power must be controlled more strictly. The total blackening of the hologram must not exceed the linear range of the photoemulsion characteristic. Otherwise, the image of the smallest droplets will not reproduce in the case of overexposure.

In Fig. 1A are shown two images of an air–water stream segment, these images having been taken in succession along the light beam. The air was discharging at a mean velocity of 59 m/sec. The interval between pulses was 3 μsec long. The velocity of individual droplets, as determined from the hologram, was 51-57 m/sec. If the local air velocity is known, then the slip between droplets and air $S = v_D/v_A$ can also be found. A comparison with earlier measurements of the air velocity profile in the core of a dispersive-annular air—water stream [3] indicated, depending on the droplet size and distance from the stream center, a relative slip within the 0.70-0.95 range.

In Fig. 1B is shown a stream image reproduced from a hologram with exposure to three monopulses. The interval between pulses was 15 μsec and 10 μsec. The stream velocity was 32 m/sec. The third image appears much weaker than the preceding two, and the direction of droplet flow is thus determined uniquely.

LITERATURE CITED

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