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HIGH-SPEED CINE RECORDING OF REAL-TIME HOLOGRAPHIC INTERFERENCE FRINGES

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ABSTRACT

The use of high-speed cine cameras to record real-time holographic interference fringes of fast events has not been widespread, probably because of the relative inefficiency of amplitude holograms. However, recent advances in the processing of phase holograms has increased diffraction efficiency to the point where very high framing rates are possible. This note describes a technique which has easily given 11,200 frames per second and has the potential for producing framing rates a factor of 10 or more higher.

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High-speed holographic interferometry is a measurement technique usually restricted to the use of double exposure holograms produced with pulsed lasers. This results in interference patterns frozen at a single instant. The movement of interference fringes with time can be recorded with the real-time or live-fringe technique employing a continuous wave gas laser. Although still or cine photographs may be made of interference patterns, this method of holographic interferometry is not widely used(1) and little attention seems to have been given to the joint application of the real-time method and high-speed cinematography. This may be because the common use of the relatively inefficient amplitude holograms has restricted framing rates to less than about 3000 frames per second. Recent advances (2) in the processing of phase holograms has greatly increased diffraction efficiency and in this note we report a technique which allows cine photography of real-time interference patterns at rates of 11000 frames per second with the potential for increasing this by at least a factor of 10.

The holographic laboratory and the general techniques used have been described elsewhere (3,4,5) and are briefly illustrated here with the help of figure 1. The beam from a Spectra-Physics model 171-06 argon-ion laser equipped with a model 482 temperature controlled intracavity etalon and operated at 500 mW at 514.5 nm wavelength, was divided into reference and object beams using a beam splitting cube. A filter in the object beam reduced its intensity to half that of the reference beam, as measured in the plane of the photographic plate. Both beams were expanded by 20X microscope objectives through 11μ spatial filters. The object beam only was collimated by a 150mm diameter plano-convex lens of 500mm focal length and was perpendicular to the holographic plate. The divergent reference beam was incident on the plate at an angle of 45^{o} to the normal.

The main element in the optical train for light collection was a 100 mm diameter lens of 400 mm focal length. The moving fringes were photographed on Ilford Mk$\overline{V}$ negative motion picture film (200-400 ASA rating under tungsten light) using a Hycam high-speed cine camera supplied by John Hadland Ltd., Bovingdon, Herts, England). The film was processed by continuous development for about 3 mins. in Kodak DN13 and fixed with Super Amfix. Full-frame 16mm cine films were produced at a rate of 11,200 frames per second. The exposure time for each frame was about 36 μs.

The hologram used in the test was produced from a 4" x 5" Agfa 8E56 holographic plate exposed for 4 s at a total incident light intensity of 110 mW/m^2 (110 erg/cm^2s). This resulted in a photographic negative of optical density about 1.0 measured at 514.4 nm. The plate was developed for 3 min. in undiluted Neofin Blau (Tetanol-photowerk), stopped by a 1 min. rinse in 2% acetic acid, fixed for 2 min in 1:3 Amfix (May and Baker Ltd) without hardener and washed for 5 min. in running water.
Bleaching the plate to produce a phase hologram was carried out using a technique recommended by Phillips(6) and is similar to that described by Phillips and Porter(2). The plate was placed for 2 min. in a bleaching bath (20 g glycerol, 500ml water, 500ml i-propanol, 300mg phenosafranine, 150g ferric nitrate and 33 g potassium bromide), washed for 10 min. in water, sponged to remove excess water and allowed to dry in air.

The test subject chosen to demonstrate the technique was an 80mm length of nichrome resistance wire (6.9 Ω/m) heated rapidly in air to its melting point. The straight length of wire was positioned along the horizontal photographic axis and perpendicular to the photographic plate. The wire was heated from the 50 Hz, 240V mains supply stepped down through a manually controlled variable transformer. It melted in less than 200 ms after application of the power and at a maximum estimated current of about 8 amps. Prior to the test a phase hologram was produced of the air volume surrounding the wire and the processed plate was repositioned so that the virtual holographic image was super-imposed on the actual air volume. The holographic plate was then rotated very slightly about a vertical axis within the plate which resulted in the establishment of an optical interference pattern consisting of parallel, horizontal finite fringes. As the wire melted the air close to it was heated and the reduction in its refractive index led to displacement of the fringes which were recorded as described above.

Prints made from the cine film are presented in figure 2. The first photograph shows the interference pattern just before the application of power. The slight fringe displacement around the wire was due to a very small current passed by the transformer at minimum secondary voltage. The wedge shaped shadow is that of the electrical connections to the wire. Figure 2b shows the pattern 150ms later. The wire had fused and the hot or molten fragments were in motion. Further displacement after 160ms is evident in figure 2c along with the heating of a long filament of hot wire. By 200ms (figure 2d) cooling had commenced.

The system used in this test wasted much of the available light. Considerable losses occured through the use of an uncollimated reference beam and because of the filter in the object beam. These inefficiencies aside, the light utilised was more than adèquate for high-speed photography and no special efforts were required to enhance the cine film sensitivity. Bearing in mind also that only 500mW was used of the 2½ W of light available it is apparent that this application of high-speed cinematography could be extended easily to rates of 50,000 frames per second, with several hundred thousand frames per second a distinct possibility.

Acknowledgement

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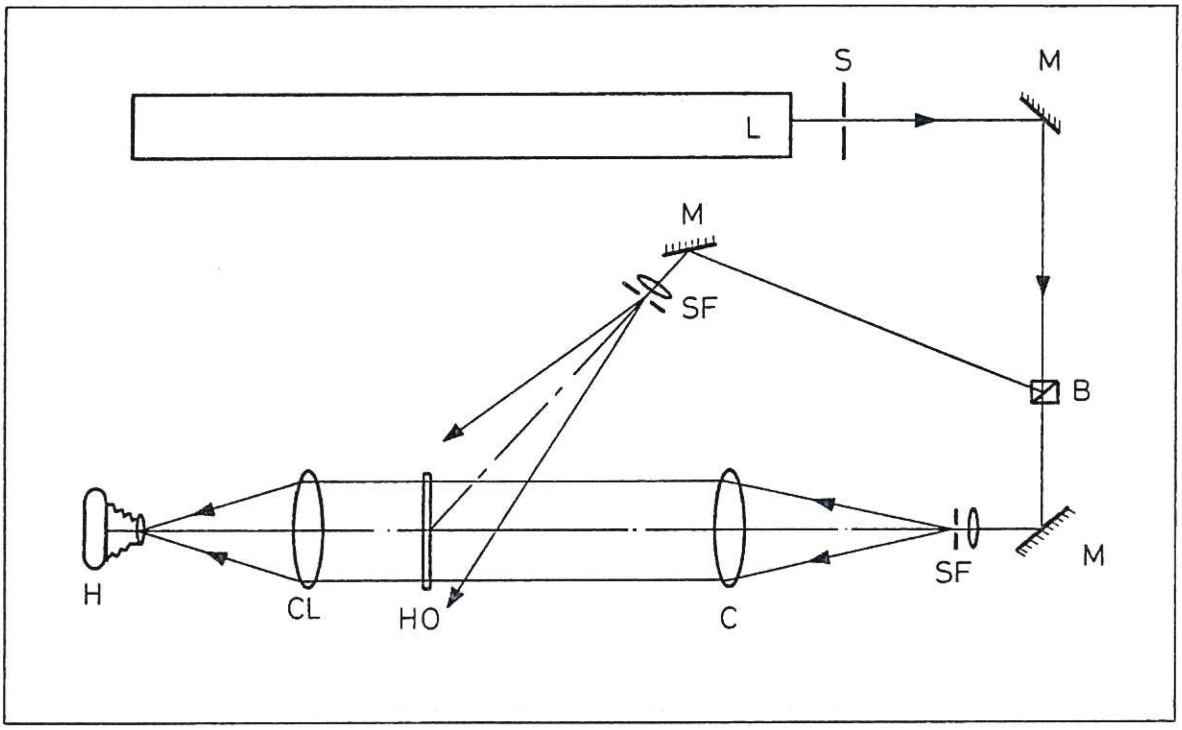

Fig.1 Schematic representation of apparatus. L—laser; M—mirrors; S—shutter; B—beam splitter; SF—spatial filter; C—collimating lens; CL—collecting lens; H—high speed camera and HO—hologram.

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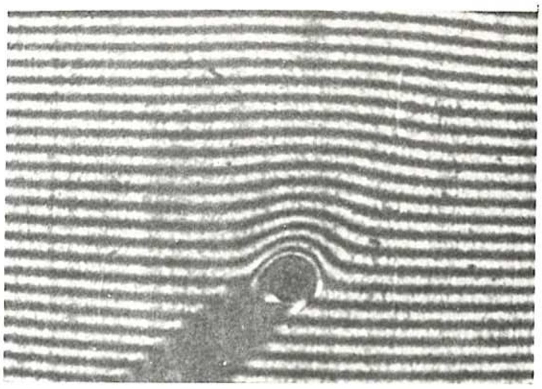

Fig.2(a) 0ms

Fig.2(b) 150ms

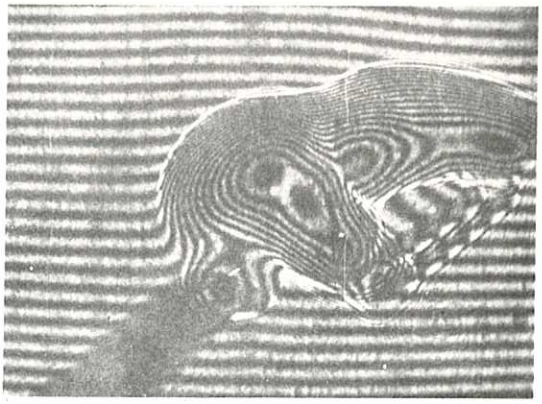

Fig.2(c) 160ms

Fig.2(d) 200ms

Fig.2 Selected frames from high speed ciné film taken at 11,200 fps.