HOLOGRAPHIC INTERFEROMETRY

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Contents

Summary

The aim of this article is to introduce readers to the concept of wavefront recording and reconstruction in holographic interferometry, and to its use in measuring noncontact and full-field displacement and deformation gradient distributions in experimental mechanics.

1. Introduction

Holography, or the principle of wavefront recording and reconstruction, was discovered by Denis Gabor in 1948. Two decades later, this discovery was to lead to the creation of intriguing three-dimensional visions of objects that floated in space and appeared to move as the viewer walked around them! Gabor (1900–1979), awarded the Nobel Prize in Physics in 1971, considered himself "one of the few lucky physicists who could see an idea of theirs grow into a sizable chapter of physics."

The greatest boost to the development of holography came in the early 1960s with the roughly simultaneous appearance of lasers and of the pioneering work of Leith and Upatnieks, who introduced the concept of "carrier frequency," prevalent in communications theory, to this field of research. The development of holography has considerably broadened our centuries-old perception of interferometry. Its unique property of using a wavefront generated at some earlier time, that has been stored in a hologram for subsequent release, to interfere with a comparison wavefront, has paved

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the way for drawing interferometric comparisons between a rough surface that is subject to stress and its normal state.

Holographic interferometry has established itself as one of the most promising techniques in the field of non-destructive measurement and testing. The methodology used in the quantitative analysis of holographic interferograms saw extensive development during the 1990s, and the books cited in the bibliography cover this field in detail.

2. Wavefront Recording and Reconstruction

Gabor's original method—*in-line holography*—suffers from a serious disadvantage in that the reconstruction is displayed with an extra image behind it (the so-called "twin image problem"), illuminated from behind by a point source. The carrier frequency approach developed by Leith and Upatnieks first made it possible to eliminate the twin images. This is achieved by bringing two sets of light waves, both of which originate from a coherent light source, to interfere on a photographic plate (Figure 1a).

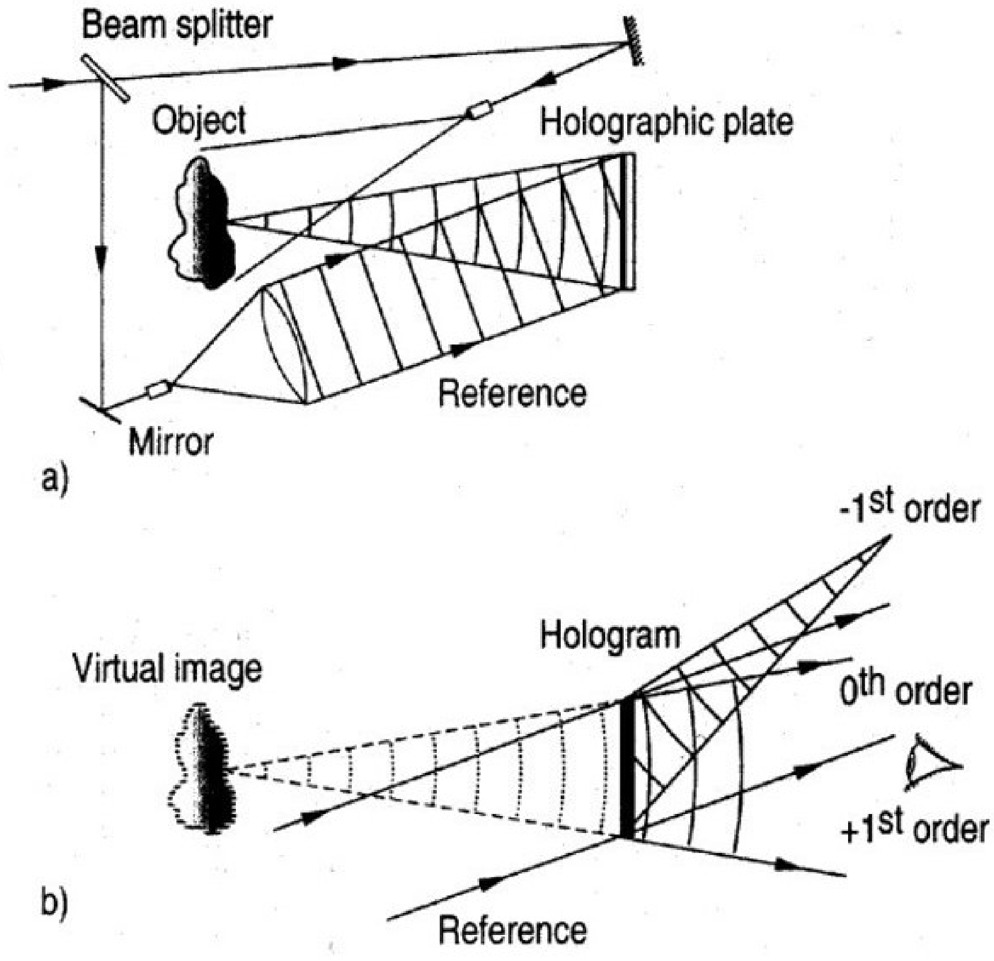

Figure 1. Diagrammatic representation of wavefront (a) recording and (b) reconstruction

The set of waves, called the *object beam*, is scattered by the object; the second set of waves is termed the *reference beam*. The total field at any point *(x,y)* on the plate is *o(x,y) + r*, where *o* and *r* are the object and reference fields, respectively. The irradiance *I(x,y)* on the photographic plate is given by

$$\begin{aligned} I(x,y) &= |o(x,y)+r|^2 \\ &= |o(x,y)|^2 + r^2 + o(x,y)r^* + o^*(x,y)r \end{aligned} \qquad (1)$$

where the asterisk denotes a complex conjugate. Assuming that the amplitude transmittance of the photographic plate after processing is linearly related to the intensity in the interference pattern:

$$t(x,y) = t_o + \beta T I(x,y) \qquad (2)$$

where t_O is the background light transmittance, T is the exposure time and β the slope (negative) of *t(x,y)* versus exposure characteristics of the photographic emulsion.

In the reconstruction stage (Figure 1b), the hologram is illuminated with the same reference wave *r* that was used to record it. The field distribution of the transmitted wave at the hologram plane is:

$$\begin{aligned} a(x,y) &= rt(x,y) \\ &= r\left[t_o + \beta T\left(r^2 + |o(x,y)|^2\right)\right] + \beta T o(x,y) r^2 + \beta T o^*(x,y) r^2 \end{aligned} \qquad (3)$$

The first term on the right-hand side of Eq. (3) represents the attenuated reference beam diffracted through the plate and traveling in the same direction. The amplitude of the reference beam is modulated due to the term $|o(x,y)|^2$. The second term is identical within a constant multiplier to the object wave, and generates a virtual image (orthoscopic) of the object in its original position that can be seen when looking through the hologram. The last term represents the conjugate of the object wave, and generates a real image of the object but with a reversed sense of depth (pseudoscopic).

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Biographical Sketch

Pramod Rastogi is a Senior Research Engineer at the Swiss Federal Institute of Technology Lausanne, Switzerland. He received his Ph.D. from the University of Franche-Comté, France, in 1979. His main current research activities are in the areas of holographic interferometry, speckle metrology, phase-shifting, and moiré. He is the author or co-author of more than 110 scientific papers, of which over 70 are published in peer-reviewed archival journals. He is a member of the teaching staff for advanced courses in optical technologies of the Free University of Nuoro, Italy.

Dr. Rastogi has edited five books and two issues of International Society for Optical Engineering (SPIE) conference proceedings. He was a guest editor of three special sections in optical engineering, “Optics in Switzerland, Part 1: Federal Institutes of Technology” (July 1995), “Optics in Switzerland, Part 2: Universities and Research Institutes” (August 1995), and “Optics in Switzerland, Part 3: Industries and Observatories” (September 1995). As a guest editor in 1997, he prepared two special issues of the journal *Optics and Lasers in Engineering* devoted to speckle and speckle-shearing interferometry and, in 1998, a special issue of the same journal devoted to speckle photography.

Dr. Rastogi was made a Fellow of the Optical Society of America (OSA) in 1993, “for the development of new techniques in laser and optical metrology and the application of these techniques in various branches of engineering.” He was made a Fellow of the SPIE in 1995 “for his work in holographic interferometry, speckle metrology, and moiré techniques.” He is a co-recipient of the Hetényi award for the most significant research paper published in *Experimental Mechanics* in 1982.

He is the co-editor-in-chief of the *International Journal of Optics and Lasers in Engineering*, published by Elsevier, Oxford.

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