One-step two-wavelength holography

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One-step two-wavelength holography is obtained with two interferometric beams with different wavelengths by means of a polarizing modulation produced by a liquid-crystal light valve. This holographic method eliminates the need for preliminary static recording of the hologram and permits one-step two-wavelength holographic testing to produce results easily in real time. © 1998 Optical Society of America

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1. Introduction

Two-wavelength holography (TWH) has been shown to be a valuable tool for testing aspheric surfaces[1,2] and large deformations[3] because it can produce interferograms with a wide range of sensitivities. However, TWH has usually required static recording of one interferogram (or hologram). This requirement divides a two-wavelength holographic test process into two steps. The first step is to record the hologram on a photographic plate and develop the plate chemically. The second step is to replace the plate in the interferometer in the exact position that it occupied during exposure and perform a holographic test in another wavelength. Thus the use of TWH is complex and strict, and test results cannot be obtained easily and in real time.

In this paper I demonstrate how these two separate steps are combined into one step and the drawbacks and limitations of the usual TWH are overcome by use of one-step two-wavelength holography (OSTWH) in a holographic interferometer.

2. Configuration and Theory

Figure 1 is an overall sketch of the configuration and principles of a novel holographic interferometer based on OSTWH. In the configuration, polarizing beam splitters PBS_1, PBS_2, and PBS_3, plane mirrors M_3 and M_4, liquid-crystal light valve LCLV,[4] relay lens L_2, and spatial filter SF constitute the one-step two-wavelength holographic system. In this system, the LCLV is one of the key components; it acts as the holographic recording medium.

The LCLV used is a Hughes Model H-4160 device. Its square-wave modulation transfer function is equal to or larger than 50% at 16 line pairs/mm, and its contrast ratio is larger than 114:1. It has a usable aperture of 25 mm $\times$ 25 mm. Its rise time (0–90%) and decay time (100–10%) are 160 and 170 ms, respectively. Therefore it works in real time. In the interferometer, both the writing and the reading planes coincide with the imaging plane of the exit pupil of the test surface. The LCLV works in a linear working range.

A He–Ne laser with $\lambda_1 = 632.8$ nm and a tunable Ar-ion laser fitted with wavelength λ_2 work simultaneously. The two laser beams are coaligned through plane mirror M_1 and PBS_1. After this coalignment, beams λ_1 and λ_2 are linearly polarized, but their polarizing directions are orthogonal to each other. The coaligned beams are expanded and collimated by achromatic beam expander BE. The parallel beam is split by beam splitter BS into a reference arm and a test arm. Waves λ_1 and λ_2 in the reference arm are reflected directly to the BS by plane reference mirror M_2, while waves λ_1 and λ_2 in the test arm are diverged by lens L to and are reflected off the surface under test and are then recollimated by L_1 before reaching the BS. After passing through or reflecting off the BS, reference and test waves λ_1 and λ_2 are incident upon PBS_2.

Both reference and test waves λ_2 reflect off and travel in the reflective arm of PBS_2, turn at M_4, and finally reach the writing plane of the LCLV. Let the reference wave be incident at an angle θ_2 with respect to the normal upon the writing plane and the test wave have a distribution of optical path difference of $W(x, y)$ with respect to the same plane. The complex

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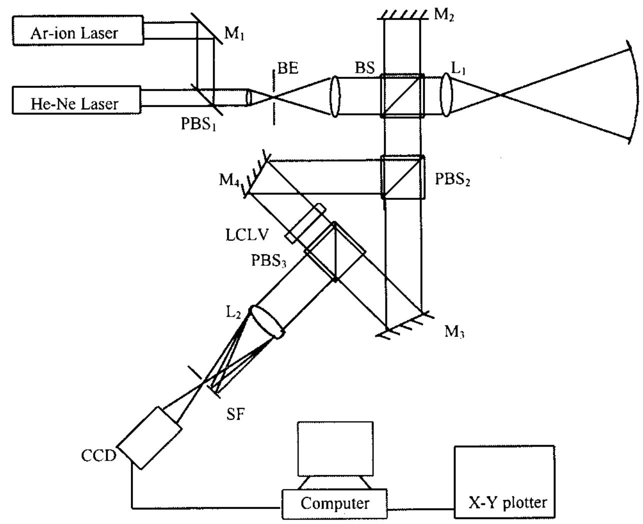

Fig. 1. Principles and configuration of a holographic interferometer based on OSTWH.

amplitude of the corresponding interferometric beam on the writing plane is

$$F_w(x, y) = a_w \exp\left[j \frac{2\pi}{\lambda_2} W(x, y)\right] + b_w \exp\left(j \frac{2\pi}{\lambda_2} x \sin \theta_2\right), \qquad (1)$$

where a_w and b_w are constants. The resultant intensity distribution, or dynamic hologram, is

$$I_w(x, y) = c_w + 2d_w \cos \frac{2\pi}{\lambda_2} [W(x, y) - x \sin \theta_2], \qquad (2)$$

where $c_w = a_w{}^2 + b_w{}^2$, $d_w = a_w b_w$.

Meanwhile, both reference and test waves λ_1 pass through and travel in the transmission arm of PBS_2, turn at M_3, pass through and travel in the transmission arm of PBS_3, and finally reach the reading plane of the LCLV. Similarly, the complex amplitude of the corresponding interferometric beam on the reading plane can be written as

$$F_r(x, y) = a_r \exp\left[j \frac{2\pi}{\lambda_1} W(x, y)\right] + b_r \exp\left(j \frac{2\pi}{\lambda_1} x \sin \theta_1\right), \qquad (3)$$

where a_r and b_r are constants and θ_1 is the incident angle of the reference wave with respect to the normal to the reading plane.

The resistance distribution of the photoconductive layer of the LCLV responds in real time to the dynamic hologram incident from the writing plane. Then the twisting direction of the liquid-crystal molecules in the spatial liquid-crystal layer of the LCLV responds correspondingly to the spatial resistance distribution. The polarizing state of the interferometric beam of λ_1 entering the LCLV from its reading plane and passing through the liquid-crystal layer twice is modulated by the dynamic hologram in real time. The complex amplitude of modulated interferometric beam λ_1 with its polarizing direction perpendicular to that of the incident beam can be expressed as

$$\begin{aligned} F_{\text{out}}(x, y) \propto & \left\{a_r \exp\left[-j \frac{2\pi}{\lambda_1} W(x, y)\right] + b_r \exp\left(-j \frac{2\pi}{\lambda_1} x \sin \theta_1\right)\right\} \\ & \times \left\{c_w + 2d_w \cos \frac{2\pi}{\lambda_2} \left[W(x, y) - x \sin \theta_2\right]\right\} \\ = {} & a_r c_w \exp\left[-j \frac{2\pi}{\lambda_1} W(x, y)\right] + b_r c_w \exp\left(-j \frac{2\pi}{\lambda_1} x \sin \theta_1\right) \\ & + a_r d_w \exp\left\{-j2\pi\left[\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) W(x, y) + \frac{1}{\lambda_2} x \sin \theta_2\right]\right\} + b_r d_w \exp\left\{-j2\pi \right. \\ & \left. \times \left[x\left(\frac{\sin \theta_1}{\lambda_1} - \frac{\sin \theta_2}{\lambda_2}\right) + \frac{1}{\lambda_2} W(x, y)\right]\right\} \\ & + a_r d_w \exp\left\{-j2\pi\left[\left(\frac{1}{\lambda_1} + \frac{1}{\lambda_2}\right) W(x, y) - \frac{1}{\lambda_2} x \sin \theta_2\right]\right\} + b_r d_w \exp\left\{-j2\pi \right. \\ & \left. \times \left[x\left(\frac{\sin \theta_1}{\lambda_1} + \frac{\sin \theta_2}{\lambda}\right) - \frac{1}{\lambda_2} W(x, y)\right]\right\}. \end{aligned} \qquad (4)$$

Test surface M_2 and SF set at the focal plane of lens L_2 are adjusted to let only the first and the fourth terms in Eq. (4) transfer to the CCD plane by means of PBS_3, L_2, and SF. So the complex amplitude of the interferometric beam on the CCD plane is

$$F_D(x, y) = a_D \exp\left[-j \frac{2\pi}{\lambda_1} W(x, y) + b_D\right] \times \exp\left\{-j2\pi\left[x\left(\frac{\sin \theta_1}{\lambda_1} - \frac{\sin \theta_2}{\lambda_2}\right) + \frac{1}{\lambda_2} W(x, y)\right]\right\}, \qquad (5)$$

where a_D and b_D are constants. These two waves interfere and form a final interferogram whose intensity distribution is given by Eq. (5) times its complex conjugate, or

$$I_D(x, y) = F_D(x, y)F_D^*(x, y) \propto 1 + \alpha \cos 2\pi\left[\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)W(x, y) - x\left(\frac{\sin\theta_2}{\lambda_2} - \frac{\sin\theta_1}{\lambda_1}\right)\right], \quad (6)$$

where α is a constant.

In this way we obtain an interferogram in which the fringes are spaced as if the surface were tested with an equivalent wavelength given by $\lambda_{eq} = \lambda_1\lambda_2/|\lambda_1 - \lambda_2|$.

3. Discussion

From the test principles and process presented above we can see that there is no need for static recording of a dynamic hologram in OSTWH because a dynamic hologram takes effect on another interferometric beam by means of a photoconductive effect and a hybrid field effect produced by a LCLV. Thus the need for film and processing is eliminated, and the two steps required in the usual TWH are reduced to one step performed finished in real time. This is the reason for calling this two-wavelength holographic method OSTWH.

In the one-step two-wavelength holographic system each interferometric beam λ_1 and λ_2 travels in a common path, so this system does not contribute any error to the accuracy. One of its advantages is that it can produce test results in one step and in real time. A second advantage is that it is straightforward and easy to implement because only routine alignment is needed in the holographic interferometer based on OSTWH, as in an ordinary optical interferometer. A third advantage is that the amount of tilt and defocus shown in the final interferogram can be adjusted in real time because the hologram used is dynamic. Another advantage is that high accuracy can be obtained easily.

4. Conclusions

OSTWH has been obtained with two interferometric beams with different wavelengths by means of polarizing modulation. This is entirely different from the usual TWH, which is obtained by amplitude or phase modulation and so needs a static hologram.

A two-wavelength holographic interferometer based on OSTWH can give test results in an easy way, in one step, and in real time. Therefore this method is excellent for routine testing of surfaces and should offer new possibilities in the field of nondestructive holographic testing of objects that change with time.

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