Two-wavelength holographic interferometry for the measurement of large deformations

Holographic interferometry is widely used to measure objects' deformations and displacements by observing fringe patterns. Intensity is proportional to $\cos 2\pi(W' - W)/\lambda$, where W and W' are two object wavefronts, and the phase difference between two consecutive fringes is proportional to half of λ, the wavelength used. Because the fringe density is proportional to deformation magnitude, large deformations lead to high fringe densities that cannot be resolved easily by conventional detection systems (eye or CCD camera). One way to overcome this problem is to increase the wavelength by using IR laser lines, but holographic materials sensitive to these wavelengths are not common. Another way is to synthesize a longer equivalent wavelength from two visible wavelengths.

Earlier, Wyant[1] developed two-wavelength holography, in which a hologram of a sample is taken at a wavelength λ_1 and read out with another λ_2 while keeping the test object in the same state. An interferogram is observed that is proportional to $\cos 2\pi W/\lambda_{eq}$, where the equivalent wavelength λ_{eq} is equal to $\lambda_1\lambda_2/|\lambda_1-\lambda_2|$. The result shows the contour fringes of the test surface. The aim of our development is to mix the advantage of two-wavelength holography with classical holographic interferometry, in order to obtain an interferogram proportional to $\cos 2\pi(W' - W)/\lambda_{eq}$. The sensitivity of the interferometer can then be selected by choosing the correct pair of visible wavelengths.

Figure 1 illustrates the principle of measurement. Basically, two holograms are used in series in the set-up. The first object wavefront, W, is recorded at both wavelengths λ_1 and λ_2 on the same holographic plate H_1, and so becomes the "reference wavefront" (step a). Both laser beams propagate through the same path and can easily be switched into each other.

After processing, H_1 is correctly repositioned. It is illuminated, at λ_1, with the object wavefront that is now W' (the object wavefront after deformation), and not with the reference beam as is usual in holography. H_1 diffracts at different orders. One has a phase given by $2\pi(W' - W)/\lambda_1 + \alpha$, where α—an angular term that depends on the recording geometry and wavelength—indicates that the order propagates in a certain direction. This order serves now as an object beam and is holographically recorded at λ_1 on the second holographic plate H_2, with the help of a second reference beam (step b).

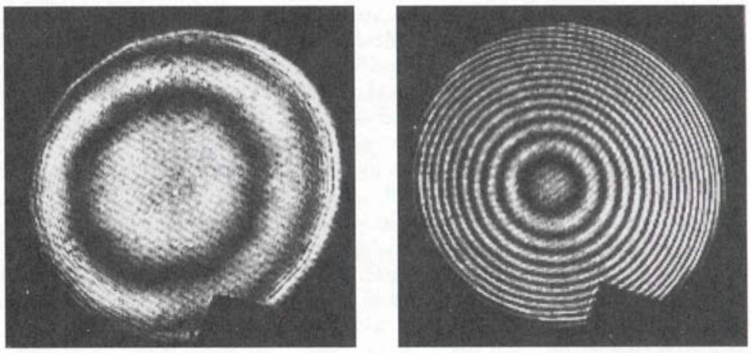

Figure 2. Interferograms of the same object deformation at λ_{eq} = 3819 nm (a) and at λ_1 = 633 nm (b).

After processing and repositioning of H_2, the beam at λ_1 is switched into λ_2 (step c). At that moment two processes occur. First, the hologram recorded at λ_1 on H_2 is read out with the H_2 reference beam but at the new wavelength λ_2. Its first diffraction order is a beam that reproduces the incident object, i.e., $2\pi(W' - W)/\lambda_1 + \alpha$, providing a correction of the readout beam incidence angle due to the change in wavelength. At the same time, H_1 is still illuminated with deformed wavefront W' but now at λ_2 and diffracts among others one term with a phase equal to $2\pi(W' - W)/\lambda_2 + \alpha$. This order propagates in the direction of hologram H_2 and, after passing through H_2, can interfere with the first order diffracted by H_2. This leads to an intensity distribution proportional to $\cos 2\pi[(W' - W)/\lambda_2 - (W' - W)/\lambda_1] = \cos 2\pi(W' - W)/\lambda_{eq}$, and the goal is reached.

To check the validity of the method, we developed an experimental set-up that permits us to compare interferograms from both single- and double-wavelength configurations. The two wavelengths used are λ_1 = 633 nm and λ_2 = 543 nm, yielding an equivalent wavelength of 3819 nm, about six times λ_1. The test object is the combination of a spherical mirror with a lens that can give two spherical wavefronts, W and W'. Figure 2 shows interferograms at wavelengths λ_1 and λ_{eq}. As expected, there were six times fewer fringes with two wavelengths than with one.

Presently the method does not work in pure real-time mode because it requires the recording and the readout of a second holographic plate, H_2, before producing the useful desensitized interferogram. The use of self-processable recording materials should improve this.

In conclusion, this method extends the applicability of classical holographic interferometry, enabling it to work with one wavelength if sensitive measurement with limited deformation range is required or with two wavelengths for extended range with lower sensitivity.

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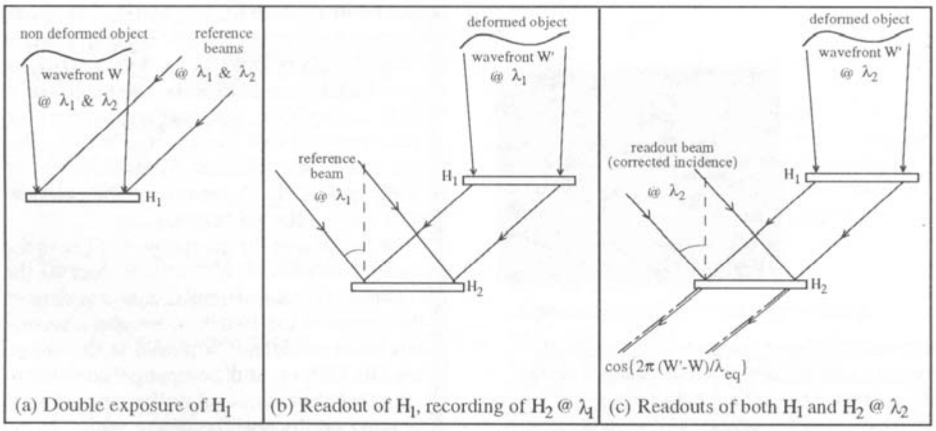

Figure 1. Principle of the method: consecutive steps leading to the production of a two-wavelength interferogram.

Reference
1. J. C. Wyant, "Testing aspherics using two-wavelength holography," Appl. Opt. **10**, 2113-2118 (1971).