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DIGITAL HOLOGRAPHY IN FLATNESS AND CRACK INVESTIGATION

Niveen Farid Abdel Maaboud, Mohamed Sadek El- Bahrawi, Fedia Abdel-Aziz

National Institute for Standards, Optical Metrology Department, Tersa st., Haram, P.O.B 136, 12211, Giza, Egypt
(✉ *niveen_farid@hotmail.com*, +202 3388 9760, *m.bahrawi@hotmail.com, fadia@nis.sci.eg)*

Abstract

Digital holography (DH) which is the technology of acquiring and processing measurement data via a CCD camera is spreading to industrial applications, finds wide employment in engineering problems of testing and investigation. In this paper, a simple digital holographic system, comprising a He-Ne laser source, CCD camera and analyzing software, is used for testing surface flatness and detecting the presence of a propagating crack on the surface plane and the effect of the crack on the neighborhood. Phase variations across the surfaces planes are extracted to represent the surface deviation from a reference plane. The analysis methods differ according to the interference fringes in the recorded holograms. Both fringe tracking and Fourier transform with phase unwrapping methods are used in the interpretation of interferometric fringe patterns.

Keywords: digital holography, fringe analysis, flatness testing, crack investigation.

1. Introduction

Non-destructive technique such as digital holography (DH) is widely used for delivering information about a component's deformation. This technique measures the phase across the plane using two-beam interference to record the hologram that carries information about the phase which corresponds to the relative difference between the test and the reference wave front. The phase variation across the plane variation can represent the component quality.

DH is a useful technique in which the wave front scattered the object can be tested against a reference wave front. One of the main reasons for the interest in DH is removing the most stringent limitation of classical interferometry, *i.e.*, that the object under investigation be optically smooth. So, the advantages of interferometric measurements – high sensitivity and non-contacting field of view – can be extended to the investigation of numerous materials, components, and systems outside the scope of optical study. Many interesting results have been achieved in DH due to the improvement in recording and analysis methods [1, 2] in which the stringent requirements of vibration isolation and dark room can be minimized to a considerable extent to make the technique suitable for testing and measurements.

The present paper uses a simple DH technique for testing the surface quality corresponding to the flatness errors and another surface with a propagating crack using an electronic detector "CCD camera" which is more compact and provides high sensitivity and accuracy of measuring interference phase with high spatial resolution [3]. Also simple image processing techniques of fringe tracking and Fourier transform are used for analyzing a single hologram with a feasible accuracy to meet the requirements of industrial testing fields without the need of expensive complicated systems.

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2. Analysis of hologram:

In DH, the ideal interference fringes are described by:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\ \cos(\varphi_1 - \varphi_2), \tag{1}$$

where: (φ_1–φ_2) is the phase variation across the surface of interest. The accuracy of measuring phase variation is limited by the resolution of measuring intensity. I_1 and I_2 vary due to the Gaussian profile of the laser beam. In addition, the interference equation may suffer a random phase term due to the speckle effect. Many procedures are required to analyze the hologram, such as smoothing, thinning, noise removal, fringe tracking, and phase unwrapping [4–8].

In the present paper, fringe tracking and Fourier transform are used to extract phase information from the recorded hologram. In fringe tracking, high accuracy information can be extracted from the fringe pattern including the calculation of aberration coefficients by using the CCD camera interfaced with the computer to measure and process the intensity distribution in the interference pattern. The shape of the fringe will be modified by the errors of the test wave front.

Some holograms require Fourier transform phase unwrapping to obtain a continuous phase map. This method is used in the case of existing holes, cracks, very dark, or very bright areas as in the present case. The number of fringes must be large enough to enable separation and filtration of the spectral orders at the spatial frequency of the fringes. The inverse Fourier transform is performed and the phase information encoded in the interferogram is obtained by the arctangent function of the real and imaginary parts of the inverse Fourier transform.

3. Experimental results and discussion

The optical system used to record holographic interferograms of the test specimen is shown in Fig 1. The beam from a He-Ne laser was expanded and filtered and divided by a beam splitter into a reference beam directed to a reference mirror and the other part is directed to the object. Both of the reference beams and the scattered beams of the object are directed to a CCD camera (Cohu 3810 model) interfaced with the computer. The different recorded holograms are stored and analyzed.

Mechanical stability and vibration isolation were achieved by mounting the test specimen and optical components on an optical Newport Platform.

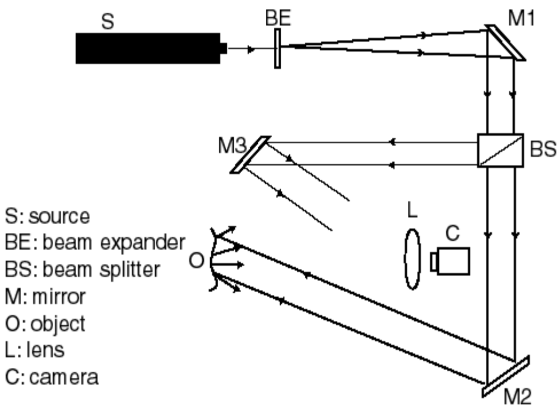

Fig. 1. The scheme of the holographic technique.

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3.1. Testing surface flatness

The flat surface is placed in the holographic system to be tested. After recording the hologram, high-accuracy information can be extracted from the fringe pattern including the calculation of Zernike circular polynomials.

Fig. 2 shows surface errors of an object's flatness recorded by digital holography and analyzed by the fringe tracking method. The object is tested by the Zygo laser interferometer (Fig. 3) to provide evaluation of the holographic technique.

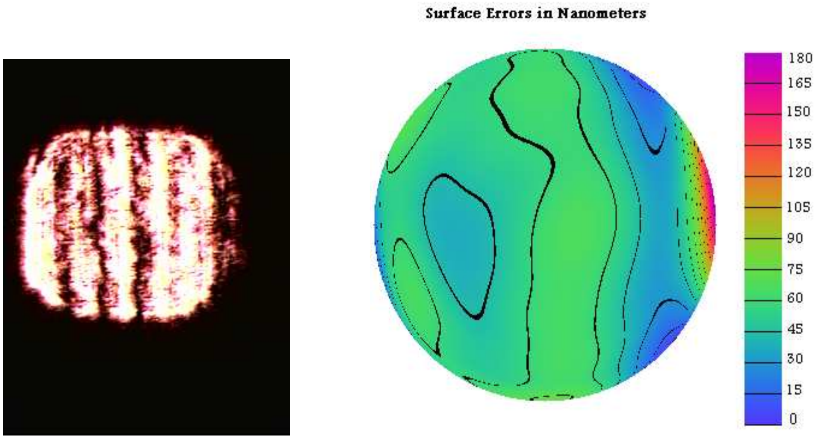


Fig. 2. Analysis of surface flatness using digital holography.

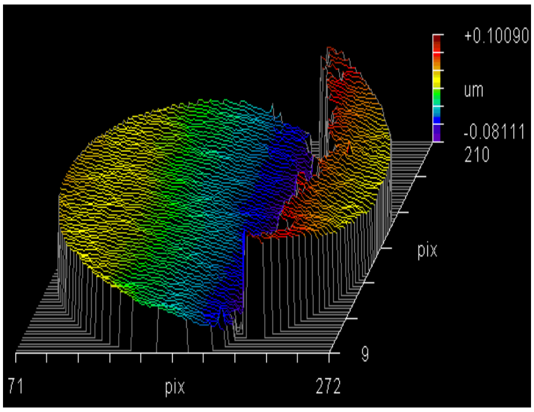


Fig. 3. Analysis of surface flatness by laser interferometer.

3.2. Investigating crack propagation

The presence of a surface crack in the object will cause some localized perturbation in the surface quality. If this perturbation is of a sufficient magnitude to cause a corresponding discontinuity in the fringe pattern, digital holography can be used to detect the presence of the crack and to observe its effect on the surface plane.

Digital holography is used to study deformation near cracks and fracture mechanics by interpretation of interferometric fringe patterns.

Each point on the object surface re-emits the light as a source of spherical wave. The complex amplitude of the scattered light is given by the sum of the amplitudes of the contribution from each point on the object surface. The crack location is identified by the discontinuities in the fringe patterns. Figs 4a, 4b show the cracked surface and the corresponding hologram. Processing of surface hologram using Fourier transform and phase unwrapping allows studying surface variation (Fig. 4c and 4d).

a) b) c) d)

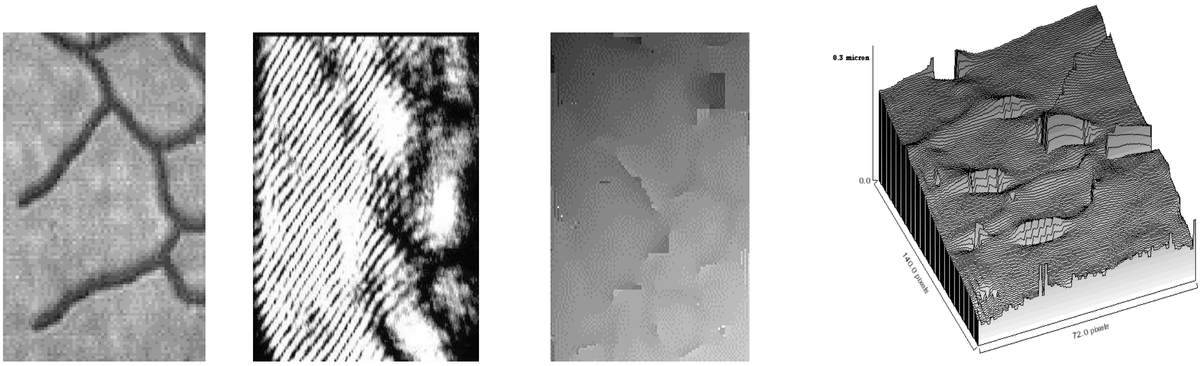
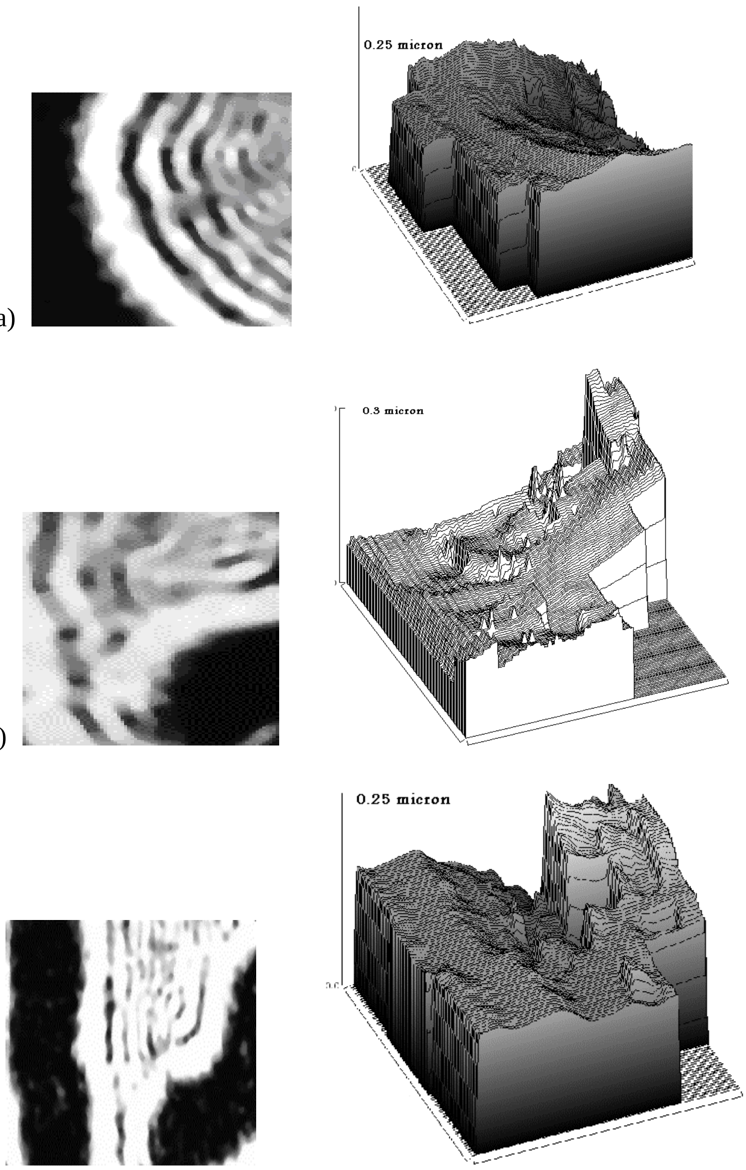


Fig. 4. a) Crack on a steel object; b) the recorded hologram; c) the unwrapped phase; d) crack effect on surface plane.



a) b) c)

Fig. 5. Surface variations at a) crack propagation; b) crack end; c) crack split.

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The effect of the cracking can be fairly localized in the neighborhood of the crack, or else yield abrupt changes of fringe curvature at the crack location.

Some magnified areas near crack propagation, crack split, and crack end are shown in Fig. 5.

The cracked surface is studied by the laser interferometer to provide additional evaluation to the holographic technique (Fig. 6).

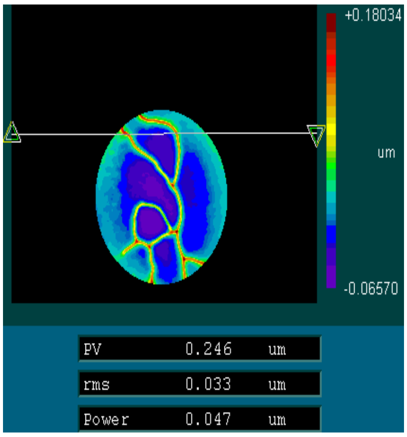

Fig. 6. Analysis of the cracked surface by a laser interferometer.

4. Conclusion

The paper discussed that it is feasible to test surface flatness and to investigate the crack propagation and its effect on the surface plane using a simple digital holographic technique in order to meet the industrial requirements without the need to employ expensive complicated systems. The recorded holograms are digitally analyzed to determine the surface errors using both fringe tracking and Fourier transform with phase unwrapping methods. In the experimental work, the holographic technique appeared to be comparable in accuracy with Zygo laser interferometer inspection.

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