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Theoretical Study on the Effect of Mechanical Properties on the Holographic Interferogram

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Abstract

Optical Holography (OH) and Speckle Interferometry (SI) are the emerging optical techniques that can be used for the measurements of microscopic parameters such as displacement components, surface strain, surface roughness, contour, strain, slope, etc. These methods have evolved into an accepted branch of experimental stress analysis. In this paper, the computer aided interferometry for Non-Destructive Evaluation (NDE) is presented. A mathematical model is formulated for specimens of rectangular geometry and fringe patterns are generated using this model. Software program has been developed to simulate fringe patterns of the test specimen. A methodology is developed for optimizing the value of stress required to generate the visible fringe pattern in different materials. The effect of variation of fringe pattern with respect to mechanical properties such as Poisson's ratio and Young's modulus has been studied.

Keywords: *Holography, Speckle interferometry, Non-Destructive Evaluation*

1. Introduction

The Holographic interferometry technique has tremendous potential in the non destructive evaluation of critical components and materials [1,2]. In HNDT the object under inspection is subjected to a minute loading such as mechanical, thermal, pressure or vibration which can produce very small surface deformation in the object. These surface deformations are manifested by the fringe patterns in the holographic interferogram generated. The fringes represent contours of equal displacement caused by the loading. The defects in the object produce local changes in the surface displacement and in turn forms fringe anomaly otherwise uniformly varying fringe pattern. The mathematical modeling of holographic fringe pattern has already been established by Ravindran et al. In this paper the details of a mathematical model formulated for generating holographic fringe pattern has bee presented. A software program has been developed to simulate holographic fringe patterns of the test specimen. A methodology is developed for optimizing the value of stress required to generate the visible fringe pattern in different materials. The effect of variation of fringe pattern with respect to mechanical properties such as Poisson's ratio and Young's modulus has been studied.

2. Theoretical Model

A thin long plate with a circular hole at the centre is considered as the representative model. The plate is given uniform compressive stress S from top and bottom. A programmable defect at the centre with radius 'a' is also considered. The radius of the hole is very small compared to the size of the plate. The origin of the system is assumed to be at the centre of the hole. Let, $P(x, y, z)$ be any point on the specimen surface before loading, $S(X_S, Y_S, Z_S)$ is the point of illumination with (X_S, Y_S, Z_S) as the co-ordinates and $H(X_H, Y_H, Z_H)$ is taken as the point of observation in the CCD plane. When the plate is subjected to compressive stress S, surface displacement is taking place and the point $P(x, y, z)$ is displaced to $P'(x+u, y+v, z+w)$ as shown in Fig. 1.

The general equation for the holographic fringe has been derived as [3,4]

$$N\lambda = K_1\left[u(X_S - x) + v(Y_S - y) + w(Z_S - z)\right] + K_2\left[u(X_H - x) + v(Y_H - y) + w(Z_H - z)\right] \quad (1)$$

where N is the order of the fringe and λ the wavelength of the laser beam used.

$$K_1 = \left[(X_S - x)^2 + (Y_S - y)^2 + (Z_S - z)^2\right]^{-\frac{1}{2}}$$

(2)

and

$$K_2 = \left[(X_H - x)^2 + (Y_H - y)^2 + (Z_H - z)^2\right]^{-\frac{1}{2}} \quad (3)$$

Considering a defect free specimen, a = 0, the equations for displacement components used in the general equation (1) for generating the theoretical fringe pattern are

$$u = \frac{-S\mu x}{E} \quad (4)$$

$$v = \frac{S}{E}\left(y - \frac{L}{2}\right) \quad (5)$$

$$w = \frac{-\mu S z}{E} \quad (6)$$

where E is the Young's modulus and μ the Poisson's ratio of the material.

3. Theoretical Data

A typical interferometry set up used for experiment has been assumed for the theoretical modeling. The numerical values of the co-ordinates of the point of observation H and point of illumination S are used in the calculations. The low modulus material used as solid rocket motor is considered as the material of the specimen plate and its Young's modulus and Poisson's ratio are used for the numerical solution. A computer algorithm is developed for the numerical solution of the general nonlinear equation (1). The following experimental parameters are assumed as the values of the constants in the general equation.

μ = 0.3, E=40 kg/cm^2 S=0.015 kg/cm^2, λ = 6328 A^o , Xs =20 cm,Ys = 0

Zs = 25cm, Xh = -10 cm, Yh=0, Zh =25 cm l =100 cm, a =0, z =1.8 cm

4. Results and Analysis

4.1 Effect of Variations in Poission's Ratio

The program is executed after giving different values of Poisson's ratio for a defect free specimen. It has been observed that the fringe density increases with the increase in the Poisson's ratio. The different fringe density for different values of Poisson's ratio is due to dependence of the property of the material in the formation of fringe pattern under the loading condition.

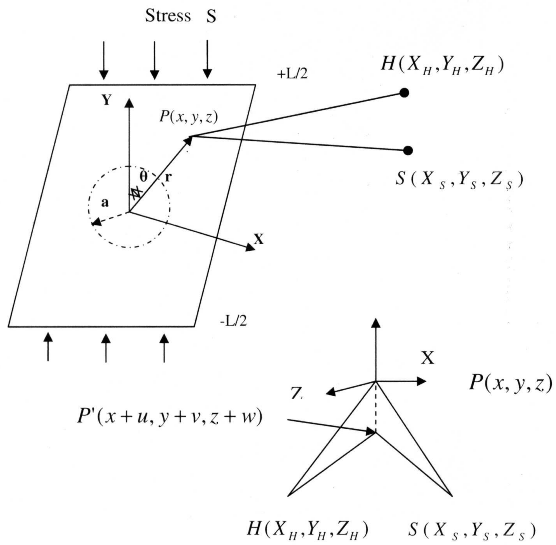
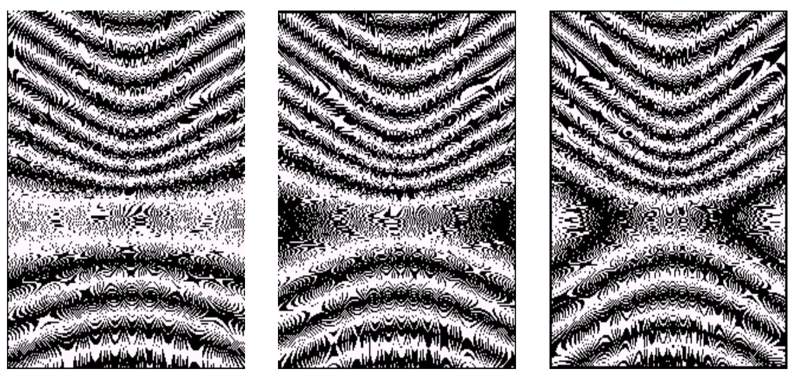
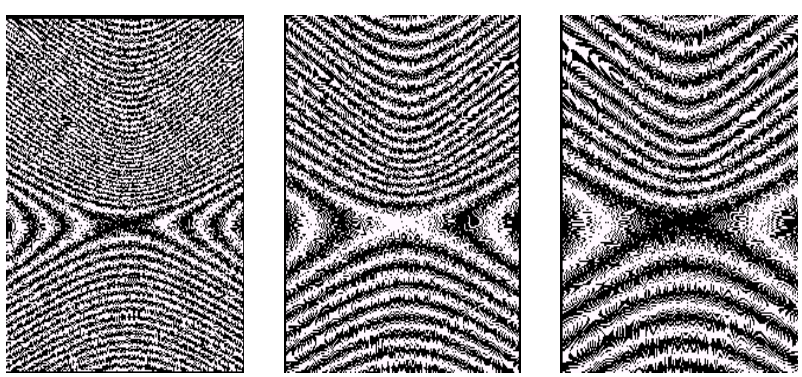


Fig. 1: Representative model of a plate with a hole at the centre



(a) (b) (c)

Fig. 2: Simulated fringe patterns for defect free model: with $\mu = 0.1$, (b) with $\mu = 0.2$, (c) with $\mu = 0.3$



(a) (b) (c)

Fig. 3: Simulated fringe patterns for defect free model: with E = 10 kg/cm^2, (b) with E = 20 kg/cm^2, (c) with E = 30 kg/cm^2

The fringe patterns generated for different values of μ , ranging from 0.1 to 0.3, for a defect free model are shown in Figs. 2a to 2c.

4.2 Effect of Variations in Young's Modulus

A new algorithm has been developed for studying the variations of Young's modulus of the material in the formation of fringe pattern. Different values of Young's modulus (E) ranging from 10 to 30 kg/cm^2 have been given and the variations in the defect free model have been studied. It is observed that the fringe pattern is highly dependent on the value of Young's modulus of the material and as the value of E decreases, the fringe density increases. The results showed in Figs. 3a to 3c gives the variation in the fringe pattern for materials with different E values.

5. Conclusion

A methodology for generating theoretical fringe pattern is demonstrated. This method can be utilized for predicting the fringe pattern with the prefixed parameters. The value of applied stress is fixed by considering the material properties. In the experimental procedure this can be made use of fixing the loading condition for generating fringe pattern. This theoretical method can be extended for predicting the nature of fringe pattern and anomaly, if any, based on the material properties and vice versa.

6. References

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