NON DESTRUCTIVE TESTING AND DEFECT DETECTION USING MOIRE DEFLECTOMETRY

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Abstract: Nondestructive testing and defect detection using optical techniques has been extensively investigated. This communication presents a simple method for defect detection in deformed circular plates using moiré deflectometry. The experimental arrangement is simple, inexpensive and does not require elaborate vibration isolation requirements.

1. INTRODUCTION

Non-destructive testing (NDT) may be stated as an area encompassing techniques used for evaluation of materials and components, in such a way that materials are examined without changing or destroying their usefulness. These techniques are gaining increasing significance in the field of quality assurance and testing of individual components and systems.

Various techniques have been reported in testing the specimen, non-destructively [1]. Major among them may be categorized as Optical testing, Thermal testing, Radiography (X-ray and Gamma ray), Acoustic (sonic and ultrasonic) testing, Magnetic testing, Electrical and electrostatic, etc. Each of the technique has its area of influence within which it is most useful. The choice of particular technique depends on various factors such as the type of specimen under test, order of accuracy, precision, sensitivity required, the cost effectiveness etc.

Several optical methods have been applied to non-destructive testing (NDT) of object specimens. Major among them may be classified as moiré methods[2], Holographic interferometry[3], speckle interferometry[4], and photo-elastic methods[5]. Holographic interferometric techniques have extended the capability of classical interferometric technology (high sensitivity and resolution) to diffusely reflecting, non-planar surfaces of engineering interest. These have been extensively used for detection of micro-cracks, observation of stress corrosion cracking, study of fluid flow, life cells and tissues, artwork diagnostics, inspection of defects etc. in laminate structure, composite material, cylindrical bore, turbine blade, pneumatic tire and solid propellant rocket [6]. However, the use of holographic techniques is severely affected by ambient conditions. An exhaustive and costly set-up is required to transfer the technology to industrial environment. This restricts its wide utility outside laboratory conditions.

Speckle techniques have been classified under four different categories, namely speckle photography, speckle interferometry, speckle shear interferometry and electronic speckle pattern interferometry and its shear counterpart (digital shearography). These techniques have been used to measure large displacements, deformation, flow fields, temperature, temperature fluctuations [7] etc. However, of all the
above techniques except Speckle shearography, no other technique has been able to earn wide acceptability because of them being susceptible to environmental perturbations. Use of Laser shearography for measurement of displacement, temperature of gaseous flame, deformation, vibration amplitude and tilt of diffused objects has been reported [8]. However, the use of speckle shearography one has to take care of problems such as high signal to noise ratio, poor visibility of fringes etc.

As an alternative to above techniques we propose the use of moiré deflectometry for non-destructive testing and evaluation of circular plates. Moiré deflectometry has several advantages with respect to interferometric techniques discussed above. The most important of it being, the fact that it uses simple and inexpensive components. It is resistant to shock and vibrations, and hence its direct utility in industrial environments. Also, the sensitivity and resolution can be varied as per the requirement.

2. PRINCIPLE

Ever since moiré deflectometry was proposed by Kafri, it has been extensively used for various applications like optical testing, flow visualization, study of transient effects, MTF measurement etc [9]. Moire based deflectometer consists of a collimated light source and a pair of transmission gratings which are rotated mutually in space. The self image of the first grating falls on the second grating. The superposition of the image of the first grating, onto the second grating results in a moiré pattern, which may be observed on a screen or recorded via a CCD camera and observed directly on the Computer. If the two gratings are Ronchi type, the resulting image has a triangular profile. Moire deflectometry is quite similar to Talbot interferometry. The difference being in the fact that in Talbot interferometry the object is introduced between the two gratings whereas in moiré deflectometry it is introduced before the two gratings. This adds to greater design flexibility and other related advantages.

Moire deflectometry is different than interferometry in the sense that the information provided here is the ray deflection map of the light reflected by the object surface. The information obtained is the partial derivative of the object surface in the direction of shear. In case the object is a transparent phase object the information obtained is the ray deflection map of the light passing through the object.

In the present communication we propose the applicability of moiré deflectometry in testing the defects in circular plates. For this purpose the circular plates are bounded along the circumference and loaded at the centre. As per the thin-plate theory [10], the surface slope contours under such conditions are represented by,

$$\frac{\partial w}{\partial x} = 4 w_{\text{max}} \log \left( \frac{x^2 + y^2}{a^2} \right)$$

where, $w_{\text{max}}$ denotes the maximum out-of-plane displacement, $a$ denotes plate radius and $(x,y)$ denote the in-plane coordinates of the circular plate with a central deflection.

3. EXPERIMENTAL SET-UP

Schematic of the experimental arrangement is shown in the Fig.1 Light from He-Ne laser is passed through the spatial filtering arrangement comprising of microscope objective of magnification 60X and a pinhole of 5 µm diameter.
A collimating lens of focal length 250 mm collimates the beam. The collimated beam is incident onto the PMMA plate (used as a test specimen). The PMMA specimen is such that it has a reasonably flat front surface profile. Light is reflected from the front surface of the specimen. To avoid reflection from the back surface, it has been painted black. Under unstressed condition the wavefront reflected from the test specimen is planar. However, when the test specimen is stressed by loading it centrally, the reflected wavefront gets deformed. This wavefront is separated for testing and detection purposes using a beam splitter. A coarse grating G1 is placed in the path of emerging wavefront from the beam splitter. Another grating G2 is placed at certain distance ‘\( \Delta \)’ away from it.

The characteristic moiré fringes are obtained at the image plane beyond the grating G2. Moiré fringes result because of the slope mapping of the test specimen. They arise due to the ray deviations caused because of the slope of the test surface. It maps the gradient of the surface along the direction perpendicular to the grating lines. This pattern is recorded onto the diffused plate and visualized using a CCD camera and computer interfaced with the frame grabber card.

4. RESULTS

In order to test the viability of the technique for defect detection, circular plates of diameter 50mm and thickness 2mm were tested.

Artificial defects were simulated by making holes of approximately 2mm diameter and depth varying from 0.5 to 1mm, at the back surface of the plate. Figure 2 (a) show the results with flawless PMMA plate, when deformed centrally with the transverse displacement of 0.28mm. Next, few defects were incorporated, about 9 mm from the centre of the plate. These defects are not visible with the naked eye from the front surface of the specimen and are well beneath. When these defective plates were clamped and centrally loaded, for a transverse loading of the specimen by 0.28 mm, the effect of defects was very prominent in terms of the change is orientation and spacing of the fringes at the defect site. Fig. 2 (b) corresponds to the slope fringes recorded at the image plane with such a defective plate. The defects have been encircled in the figure. On further transverse loading of the specimen till 0.34 mm, the effect of defects beneath the surface becomes more evident.
To analyse further the effect of defects, the number of defects on the plate were increased in a random fashion. On centrally loading the plate with a deformation of 0.28mm, the slope pattern (Fig. 2 (c)) gets deteriorated at more points near the defects. The defects have been encircled in the figure.

The crack detection in the surface specimen was also attempted. A minor crack was artificially created on the circular sample which was conspicuous over the reflecting front surface. Centrally loading the surface by deformation of 0.28mm via the back side, leads to the change in slope pattern. Fig. 3 (d) corresponds to this test condition. Hence it may is quite evident that the nature of material defect can be detected with the help of slope pattern changes, by applying small out of plane deformation to the specimen.

In nutshell, in this communication we demonstrated the applicability of moiré deflectometry in non destructive testing and defect detection. When the test surface is without defects, a characteristic fringe pattern due to the slope of the surface is obtained. However, if there are areas of stress concentration, the slope around those regions varies in non-isocentric fashion. And hence these areas of defects, etc are visualized, even though they are imbedded deep inside the body of the specimen and have no identification mark on surface. So, based on the change in the slope pattern, the nature of defects and their effect on the stress field of bent plate can easily be predicted.

5. REFERENCES

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