THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47th St., New York, N.Y. 10017

97-AA-63

FLAW DETECTION AND CHARACTERIZATION USING SHEAROGRAPHY

BREAK

Siew-Lok Toh, Fook-Siong Chau
Dept of Mechanical & Production Engineering
National University of Singapore
10 Kent Ridge Crescent
Singapore 11920

ABSTRACT

Shearography is a laser interferometric method developed originally for full field observation of surface strains of components. Since flaws usually induce strain concentrations around them, shearography can be employed to detect the flaws. Conventional shearography involves exposing high resolution films before and after the components are loaded. The exposed films are developed and then viewed via a high-pass filtering optical setup. Though the images obtained are good, this method is time-consuming. With the advent of high-speed computers, associated sophisticated imaging hardware and software, the Digital Speckle Shearing Interferometry (DSSI) method which employs a CCD (charged-coupled device) camera and computer image processing to produce the interferometric fringe patterns has been developed. In contrast with the conventional shearography, the electronic version does not require any film and is faster. The techniques are used to detect and characterise (a) flaws simulating delaminations in composites and (b) thinning in pipes.

Keywords: Digital speckle shearing interferometery, shearography, phase shifting, PZT, image processing, non-destructive testing.

INTRODUCTION

Shearography is a speckle interferometric technique which gives a full-field observation of displacement gradients of components under study [1,2]. As object rigid movement does not result in interferometric fringes, the method is well-suited for revealing localised strain concentrations [3]. Since flaws in structures usually create strain concentrations, they manifest themselves by showing up as the fringe anomalies over the affected areas. This method utilises a speckle-shearing camera which has a lens, half of which is covered by a thin glass wedge. The object under study is illuminated by laser light, and is imaged by the speckle-shearing camera (see Fig. 1). This camera produces two sheared images which interfere with each other producing a random interference pattern known as a speckle pattern.

When the object is deformed, this speckle pattern changes. By exposing a photographic film twice, one before and one after the object is deformed, the two speckle patterns will interfere to produce a fringe pattern which

Presented at the ASME ASIA '97 Congress & Exhibition
Singapore – September 30–October 2, 1997

depicts the surface displacement gradient of the deformed object. The fringe pattern is only visible using a high-pass Fourier filtering technique as shown in Fig. 2.

In contrast, instead of using high-resolution films and Fourier filtering, DSSI employs a CCD camera and computer image processing software to capture and process the interferometric fringe patterns [4, 5]. The optical arrangement for DSSI makes use of the Michelson interferometric principle as the shearing device as shown in Fig. 3. The ease with which the shearing value and direction can be adjusted - by altering the orientation of one of the two mirrors - makes this arrangement a preferred choice over other methods of producing image-shearing [6]. To improve on the quality of the fringe patterns, various image processing routines are often incorporated. Phase shifting [7] is a technique used to determine phase distribution in an interferometric fringe pattern. This is done by attaching a mirror M1 to a piezoelectric translator (PZT) (see Fig. 3). By applying the technique to the fringe patterns obtained in DSSI, values of the displacement derivative can be determined quantitatively.

In the experiments, a four-map, two-step phase shift method is used. The theoretical background is given below.

When an object is illuminated with coherent light, the two sheared images interfere with each other producing a resultant image with intensity distribution I, described by [1]:

$$I = I_o (1 + \cos\Phi) \qquad (1)$$

where I_o is the object image and Φ is a random phase angle.

When the object is deformed, the intensity distribution of the speckle pattern is slightly altered, and is described by:

$$I' = I_o(1+\cos (\Phi + \Delta)) \qquad (2)$$

where I' is the intensity distribution after deformation, and Δ is the relative phase change of two neighbouring points separated by δx, the amount of shearing in the x-direction . As derived in Ref 7,

$$\Delta = \frac{2\pi}{\lambda}\left(A\frac{\partial u}{\partial x} + B\frac{\partial v}{\partial x} + C\frac{\partial w}{\partial x}\right)\delta x \qquad (3)$$

The derivatives in Eq. (3) become the displacement derivatives with respect to y if the shearing direction is parallel to the y-direction.

A fringe pattern is produced by subtracting I from I', i.e.

$$I_s = I' - I = I_o (\cos (\Phi + \Delta) - \cos\Phi) \qquad (4)$$

Since in DSSI, only positive values are stored and displayed, Eq. (4) can be re-written in the following form:

$$|I_s| = \left|2I_o\left\{\sin\left(\Phi+\frac{\Delta}{2}\right)\sin\left(\frac{\Delta}{2}\right)\right\}\right| \qquad (5)$$

A four-image method is used to determine the phase distribution. In this, three speckle pattern images of the object before deformation, each with a different phase shift are obtained. Then after deforming the object, the fourth image is captured. By subtracting the first three images from the fourth image, three fringe patterns I_1, I_2, I_3 corresponding to phase shifts of 0, $2\pi/3$, $4\pi/3$ respectively are obtained. The phase distribution Δ can be determined by:

$$\Delta = arctg\frac{\sqrt{3}\left(I_3^2 - I_2^2\right)}{\left(2I_1^2 - I_2^2 - I_3^2\right)} \qquad (6)$$

EXPERIMENTAL WORK

For the composite plate with debonds, a woven roving glass reinforced polyester (GRP) flat plate of about 270 mm by 250 mm was fabricated using the wet lay-up technique. To simulate the overlapping of the debonds in a four-ply GRP plate, two square flaws, made of melinex sheets of sides 25 mm taped together, were positioned below the first ply and the second ply of the plate to give a 10 mm overlap. The first ply here refers to the one nearer to the illumination surface. The glass reinforced plastic plate was placed in a specially constructed vacuum chamber. Double exposure shearography was performed, one before and one after a vacuum pressure was applied.

To illustrate the use of shearography in the detection of internal thinning in pipes, a

315 mm long mild steel pipe of mean diameter 127 mm and 6.5 mm thick was used. A 15 mm square defect was machined (using electro-discharge machining) to a depth of 3mm on the inside of the pipe. An internal pressure of 3.4 MPa was applied to the pipe via a hydraulic pump.

In conventional shearography, a 15 mW HeNe laser was used as the light source. The image shearing camera used was a Mamiya RB67 Pro-S with a specially ground wedge of about 1° included angle, placed in the iris plane of the lens. High resolution Agfa Holotest type 10E75 holographic films were used as a recording medium. A double exposure technique was adopted whereby the film was exposed before and after the loads were applied. The double exposed films were then developed after which the shearograms were viewed using the high- pass filter as shown in Fig. 2.

In DSSI, a 10 mW HeNe laser was used as the light source. The resolution of the image processing system is $512 \times 512 \times 8$ bit. Before applying the pressure, three images of the speckle patterns of the pipe were obtained by the CCD camera; each image with a different phase shift. Then after applying the pressure, the fourth image was captured. In the system, real time subtraction using a pipeline image processor was implemented to obtain the fringe patterns of the test specimen when loaded. The resultant image was displayed at a rate of 25 frames per second.

RESULTS AND DISCUSSION

Debonds in GRP plates

Figure 4 shows the fringe patterns of the overlap flaws detected by conventional shearography. Flaw 1 is below the first ply and flaw 2 is below the second ply and it is noted that the fringes of flaw 1 are much denser than flaw 2. This is because, being closer to the illuminated surface, flaw 1 will deform more under vacuum loading. It can also be seen that there is an interaction of the fringes of the two flaws, the zero order (outermost) fringe of flaw 1 joins that of flaw 2. This indicates that the displacement of the left edge of flaw 1 is not zero. The results show that the two overlapping flaws tend to produce two sets of fringes with different fringe densities. The outline of the fringe pattern gives the sizes of the flaws which, in this case, differs from the actual sizes by about 5%.

Flaws in pipes

Figure 5 shows the fringe pattern of a square flaw in the pipe under an internal pressure of 3.4 MPa. The outline shows the shape of the flaw clearly but because of the shearing effect, it appears elongated.

From the Fig.6, it can be seen that the defect is clearly revealed in the phase map. The figures show the phase patterns corresponding to the out-of-plane displacement derivatives of the deformed pipe with shearing along the longitudinal axis of the pipe.

Since fringe patterns produced by DSSI are inherently noisy, a smoothing operation performed in a 9×9 pixel window is carried out after subtraction. The computational time to produce one phase map is approximately 10 seconds using a real-time image processing board (Imaging Technology MVC 150/40-PCI board) installed in a Pentium running at 133 Mhz.

CONCLUSION

The paper demonstrates that defects in structures can be detected by using shearography. However, one must determine an effective means of stressing which will reveal the damage in the structure. For damage viz delaminations or debonds, shearography employing vacuum stressing has proven to be a very effective method for detection. This technique has the advantages of being non-contacting, fast in response and full field.

The main advantage of digital speckle shearing interferometer (DSSI) is the ease and speed with which fringe patterns can be obtained. By using a simple yet effective optical set-up coupled to a powerful image processing system, a useful and on-line NDT apparatus for industrial application is realised. By using the phase shift technique, numerical values of displacement derivative at all points on the surface of the specimen may be obtained, allowing the rapid determination of the location, size, and shape of a defect.

ACKNOWLEDGEMENT

The above work is part of a project funded by the National Science and Technology Board through the Process Analysis and Optimisation Enterprise, National University of Singapore.

REFERENCES

1. Hung, Y.Y., 1974, "A Speckle Shearing Interferometer," Opt. Com. Vol. 11, pp. 723.
2. Leendertz, J.A. and Butters, J. N., 1973, "An image-shearing speckle-pattern interferometer for measuring bending moments," J. Phys. E., Sci.Inst. Vol. 6, pp. 1107-1110.
3. Hung, Y.Y., 1986, "Shearography Versus Holography in Non-destructive Evaluation," Proc. Soc. Photo-Opt. Instrum. Eng. Vol. 604, pp. 18-29.
4. Chau, F. S. and Ng, T. W., 1992, "A real-time digital shearing speckle interferometer," Meas. Sci. Technol. Vol. 3, pp. 381.
5. Xie, L., Chau, F S and Toh, S. L., 1996, "Non-destructive testing and evaluation using phase shifting electronic shearography," SPIE Proceedings of the International Conference on Experimental Mechanics: Advances & Applications, edited by F S Chau & C T Lim, Singapore, vol. 2921, pp 597-602
6. Krishna Murthy, R., Sirohi, R. S. and Kothiyal, M.P., 1982, "Speckle shearing interferometry: a new method," App. Opt. Vol. 21, No. 16, 2865.
7. Owner-Petersen, M, 1991, "Digital speckle pattern shearing interferometry: limitations and prospects," App. Opt. Vol. 30, No. 19.
8. Hung, Y. Y., 1982, "Shearography: A New Optical Method for Strain Measurement and Non-destructive Testing," Opt. Eng., 391.

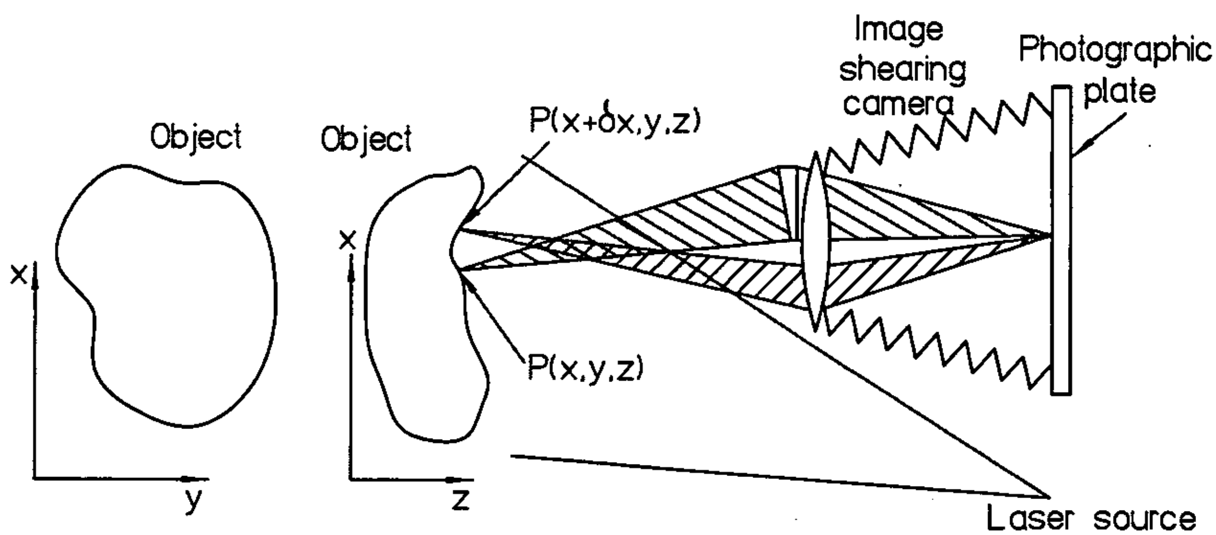


Figure 1: Basic set up for conventional shearography

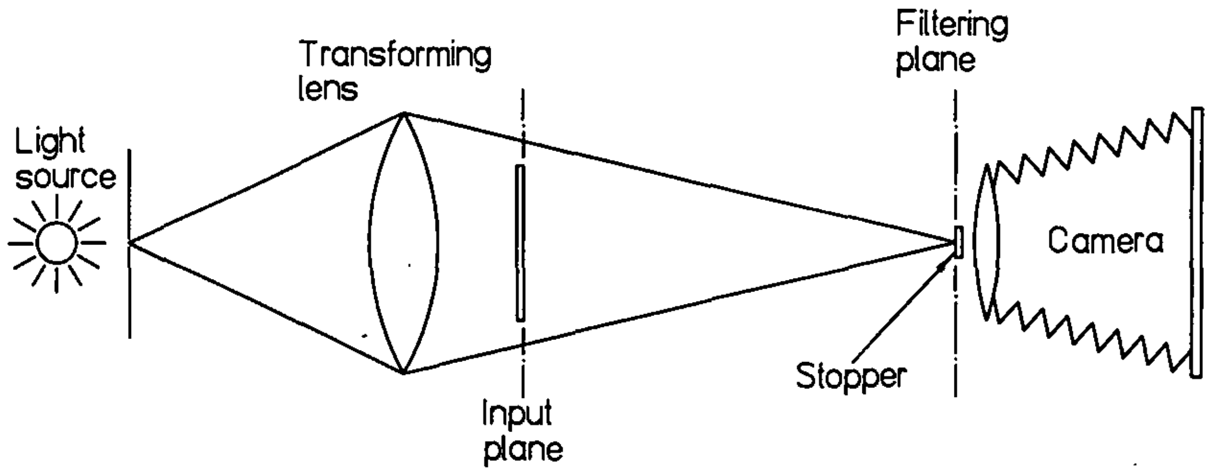


Figure 2: Reconstruction of shearogram using a high-pass filter

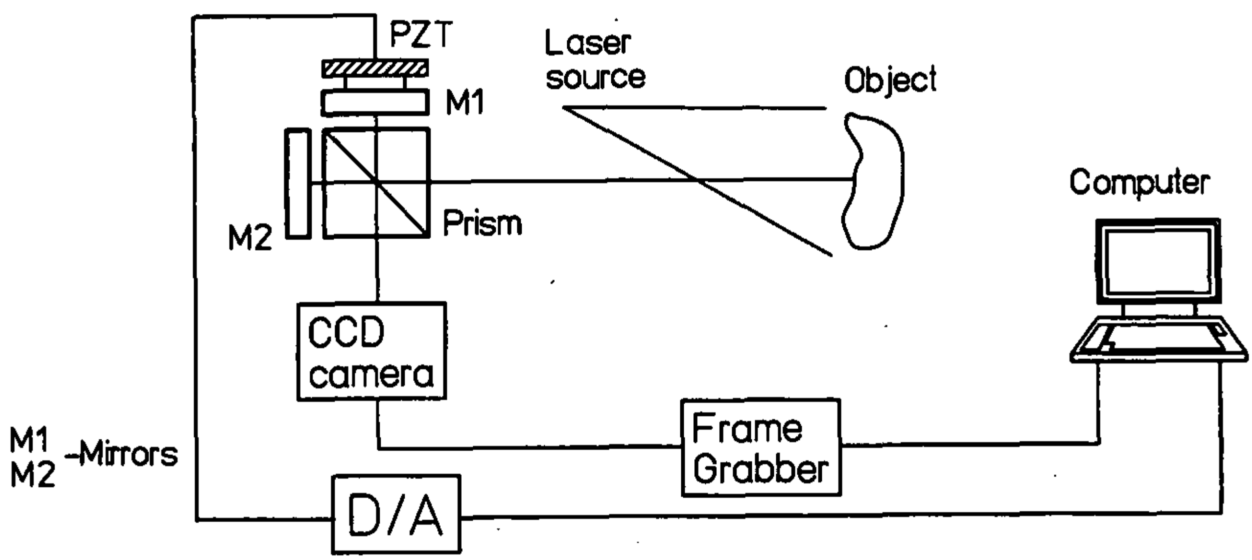


Figure 3: Schematic diagram of the digital speckle shearing interferometer

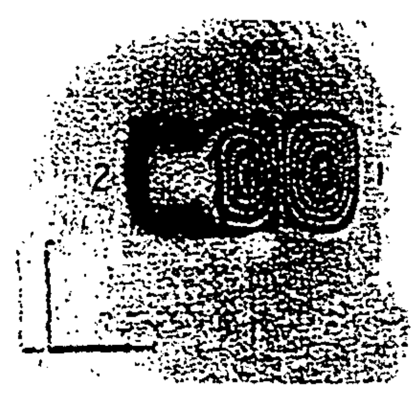
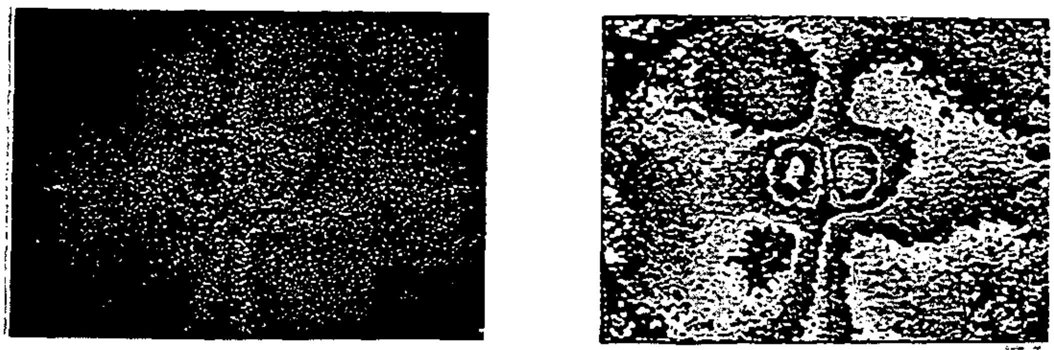


Figure 4: Fringe patterns of overlapping debonds in GRP plate

Figure 5: Fringe pattern of a pipe with 15 mm square by 3 mm deep flaw using conventional shearography



(a) Fringe pattern of pipe (b) Phase map of fringes

Figure 6: Fringe pattern of a pipe with 15 mm square by 3 mm deep flaw using DSSI