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IN-PLANE STRAIN ANALYSIS BY MEANS OF REFLECTION HOLOGRAPHY

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Abstract

Application of reflection holography to numerical inplane strain measurement is presented. The corner transition of hydraulic press is investigated in order to pointing out critical points on the transition. The method makes possible examining small areas of large structures despite of large motions of the overall object. The recording set-up is very simple: the stability requirements for recording are drastically reduced and allow omiting of vibration-isolation equipment. The values of strain are obtained by derivating displacement vector field and compared with strain gauge measurement.

Introduction

Holographic interferometry has provided the engineer with powerful tool for nondestructive testing, as well as with an aid for engineering design and analysis. In typical off-axis holographic interferometry the separation of investigated object from measuring system causes, that the fringe patterns are not characteristic only of effects of structural deformation but contain also rigid body motions, which should be cancelled out in optical-mechanical [5], [6] or numerical way.

If there are small localized distorsions of interest associated with large structural motions the problems with interferogram evaluating are very similar to mentioned above. Neumann and Penn [2] gave at first description of a method which overcomes the drawback of extrem sensitivity to vibration and is largely independent of the relative motion of the object and laser source. The main idea is to attach a transparent holographic plate to the object illuminating it directly through the plate. By double-exposure method, each of the exposures blong to one state of loading, the fringe pattern relating to the deformation can be obtained.

Requirements of the technique

To investigate the in-plane displacements a plateholder with a plate without antihalation backing should be kinematically mounted to the object to be investigated in order to assure relation between object real deformation and fringe pattern. It is preferable to know the character of deformation before attaching the holder to the object; otherwise the fringe pattern obtained by double exposure method can be characteristic of any relative motion between object surface and hologram plate that has occured between two exposures, including rigid body motion too, beeing not characteristic of object deformation.

The stability requirements are described in [1], [2]. The most important of them are that an interferogram good quality depends only on the stability of the distance between the object and emulsion during exposure and is independent of changes in the distance from the illuminating source.

Reconstruction of interferograms takes place in collimated white light, although reconstruction in laser light can be naturally also applied.

The model

The model of a framework of the hydraulic press for chipboards was prepared ensuring strict mechanical conditions. In interest of that not only the characteristics of material but geometrical similarity have also been ensured. Mechanical stress acting in the real press and that of the model must be the same. Thus the reduction ratio of length measurement is $l_v = 0.1892$, $v_m = 11.35$ mm, $v_0 = 60$ mm, where v_m is the thickness of the model's plate and v_0 is the thickness of the real object's plate. The reduction ratio of loading force is $F_v = 0.03359$ (the total loading of the model is $F_m = 34527$ nN and loading of the object $F_0 = 96 \cdot 10^5$ N).

The symmetry of loading was checked by four strain gauges placed on the arms (nr. 1, 5, 9, 19). Strain gauges (KYOWA KFC 2-C1-11 type with measuring base of 2 mm) were cemented in the internal edges of the frame as it is shown on Fig. 1. The range of loading was 0 - 45 MPa. Fig. 2 shows strain values obtained from strain gauge measurement in range 0 - 30 MPa. Because of symmetry the values measured in the upper left and in upper right corner transition are put onto the same diagram a (Fig. 2).

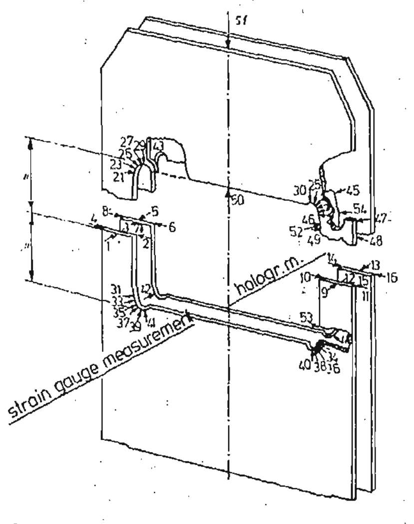

Fig. 1. The scheme of the hydraulic press model and setting of the strain gauges

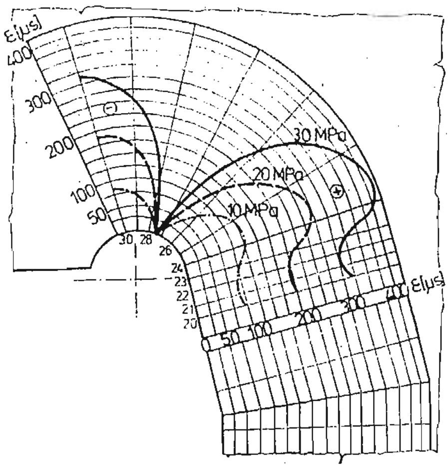

Fig. 2. The strain values obtained from strain-gauges measurement

Experiment

There was used a cw He-Ne laser with output of 7 mW. The laser was mounted on a tripod standing on the floor of workshop at distance of about 2 m from the object. It illuminated the model from the opposite side to that beeing under strain-gauge measurement. Using collimator with external lens of 100 mm diameter and set of two flat mirrors a collimated plane wave was directed through the holographic plate normally to the surface (Fig. 3).

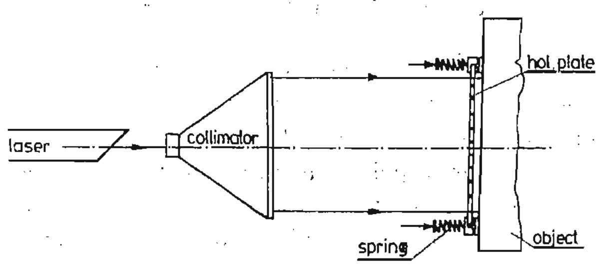

Fig. 3. The set-up for recording the holograms

The light reflected back forms the signal beam and interfers with incident light [8]. The object was painted white with diffusely reflecting paint in order to allow a large variation of the angle of view at reconstruction.

The plateholder mounting to the object is shown schematically on Fig. 4. As it was mentioned, the plateholder must be mounted kinematically to the object as it is shown on Fig. 4. The fix clamping point (*P2*) is placed in the zero strain zone (dotted-dashed line) to avoid noncharacteristic of object deformation-rigid body motion between plate and the object. On Fig. 4a the balls are fixed on to the upper side of the object.

Explanation:

A-A: the ball rest on a flat surface to slide freely in any horizontal direction.
B-B: the ball defines the position of the hologram holder
C-C: the ball rest in a slot in the form of a trench with triangular cross-section.
Two springs (*R1*, *R2*) press the plateholder to the object.

The model of press was initially loaded by pressure of 10 MPa and pressure belonging to the second exposure was 21 MPa.

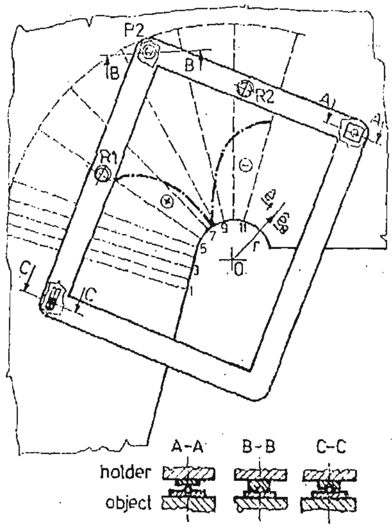

Fig. 4. The plateholder mounting to the object

Reconstruction of the interferograms

Since the fringe pattern at reconstruction is not influenced by the reconstruction wavelength [1] the reconstruction of the interferograms is realized in collimated white light, which incidents normally to the hologram plate.

The investigated interferogram point was placed in the middle of a circle table with precise angle scale. Instead of varying observation directions, the whole circle table with interferogram lying on it was rotated round the verical axe. The fringe patterns were

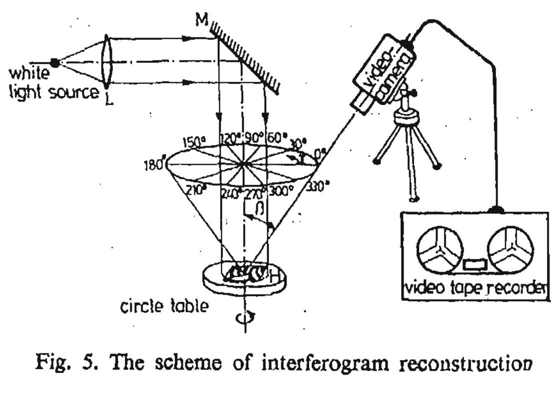

Fig. 5. The scheme of interferogram reconstruction

viewed by TV camera (SONY DXC 1800 P-type) under β angle normal to the surface of the plate (Fig. 5). Because of very fast changing of fringe patterns during varying of angle, the whole observation was recorded on Video taperecorder (SONY U-matic, VO-5630 type) to precise reconstruction of fringe pattern variation.

Evaluation of the interferograms

Generally for evaluating displacement vector components there is a need for at least three different fringe patterns associated with different sensitivity vectors. In this case the fringe orders for each of investigated points were determined from twelve different observation angles ($\gamma = 0°, 30°, \ldots, 330°$) (Fig. 5) to get an overdetermined set of equations for increasing the accuracy of the measurement.

Fringe counting was carried out in following way: order of a fringe passing the investigated point was chosen arbitrarily. Counterclockwise direction along tangent to given point was chosen as positive. The fringe pattern moving in opposite direction decreased it. The correctness of fringe counting was checked after rotating the interferogram about 360 degrees. In this case the fringe pattern formed a closed loop and it resulted in total number of fringes adding up to zero.

As it is seen from Fig. 4 the points from 11 to 5 were evaluated in polar coordinates, where:

$$\mathbf{u} = u\hat{\mathbf{e}}_r + v\hat{\mathbf{e}}_\theta \tag{1}$$

where $\mathbf{u}$ denotes plane displacement vector.
The plane strain components are:

$$\varepsilon_{\alpha\beta} = \frac{1}{2}(u_{\alpha,\beta}+u_{\beta,\alpha}) \tag{2}$$

namely:

$$\varepsilon_{rr} = \frac{\partial u}{\partial r},$$

$$\varepsilon_{\theta\theta} = \frac{1\partial v}{r\partial\theta}+\frac{u}{r},$$

$$\varepsilon_{r\theta} = \frac{1}{2}\left(\frac{\partial u}{\partial\theta}+\frac{\partial v}{\partial r}-\frac{v}{r}\right).$$

The points 4, 3, 2, 1 were evaluated in local rectangular Cartesian coordinates, for which

$$\varepsilon_{xx} = \frac{\partial u}{\partial x},$$

$$\varepsilon_{yy} = \frac{\partial v}{\partial y},$$

$$\varepsilon_{xy} = \frac{1}{2}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right).$$

The strain measured by strain gauges corresponds to $\varepsilon_{\theta\theta}$ or ε_{xx} respectively.

For evaluation of displacement vector components there was applied the „Fringe — counting" method [4] described by equation:

$$K \cdot \mathbf{L} = \lambda \Delta \mathbf{N} \tag{3}$$

where K is a matrix, which consists of differences of observation unit vectors, $\Delta\mathbf{N}$ is a fringe order vector consisting of fringe order differences, λ denotes the wavelength of laser source, $\mathbf{L}$ is a displacement vector.

The fringe order number was digitized with aid of drawing digitizer connected with microcomputer. Thus, for fringe values differed from each other of half order there were fitted smoothed cubic spline functions and the fringe orders in given points were interpolated. The fringe order evaluation of point x was evaluated in four neigbourhood points of x: $(x-2\Delta, x-\Delta, x+\Delta, x+2\Delta)$. Δx, chosen experimentally, satisfied eq. $\Delta x = 2.50$ mm on drawing digitizer. Since the photographs of each fringe pattern ($\gamma = 0°, 30°, \ldots, 330°$) were magnified 2 times comparing with real model, the ratio 1/2 was applied. In case of well defined fringe pattern the accuracy was better than 0.05 fringe order, in case of complicated fringe pattern (change of sign, fringe pattern with low spatial frequency) the accuracy was better than 0.1 fringe order.

The eq. 3 was solved by the least-square method [9]; in this way one can obtain displacement vector components of five points lying in given interval in tangent direction. Next these values of displacement vector components were fitted once more by smoothed cubic spline functions. The derivative is equal ot component $\left(\frac{1}{r}\frac{\partial v}{\partial \theta}\right)$; in Cartesian rectangular coordinates it is equal to $\frac{\partial u}{\partial x}$. The second component of $\varepsilon_{\theta\theta}$ in polar coordinates $\left(\frac{u}{r}\right)$ is to be evaluated directly from displacement vector field. Fig. 6 compares the in-plane strains evaluated from interferogram and measured by strain — gauges.

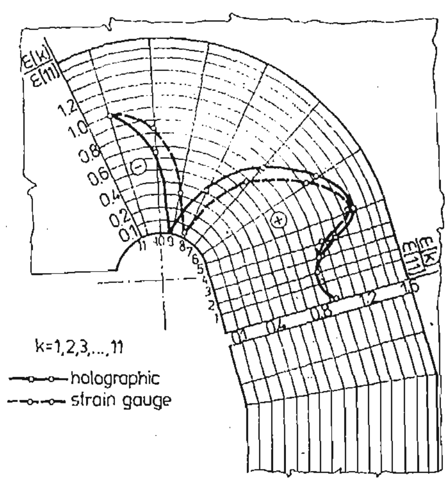

Fig. 6. Comparison of the strain values obtained from strain-gauge and holographic measurement

Comment to the results

The measurement with aid of strain gauges was realized, as it is seen on Fig. 1, on front side of the press model and the holographic experiment was conduced on the opposite side of the model. Thus, although the symmetry adjustment on each of four press arms was controlled very carefully, the results of strain-gauge measurement and these of holographic evaluation must be assumed as beeing obtained not exactly upon the same experimental basis. The precise regulation of the manometer presented difficulties. As the two measurements were conduced not in the same time — the results were compared in relative scale and the strain value of point nr 11 was taken as minus unity (because of negative strain value).

Conclusions

The comparison of results presented on Fig. 6 shows great similarity for values of both kinds of strain. Reflection holography in the way presented in this paper is time-consuming method, but its great advantages are simplicity of recording and reconstruction and non-destructive character of the method.

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Резюме

АНАЛИЗ ДЕФОРМАЦИИ В ПЛОСКОСТИ МЕТОДОМ ИНТЕРФЕРОМЕТРИИ В ОТРАЖЕННОМ СВЕТЕ

В работе представлено метод колическтвенных исследований деформации при помощи голографической интерферометрии в отраженном свете и непосредственном креплении голографической плиты на испытываемом обьекте. Метод делает возможным исследование фрагментов больших конструкций при исключении влияния перемещений целого обьекта.

Состав аппаратуры для создания голограмм очень несложный, кроме этого значительно ограничены требования касающиеся виброизоляции системы.

В представленном примере деформации, определены на основе векторов перемещений точек, согласны с измеренемы методом опорных дошчиков.

Streszczenie

ANALIZA ODKSZTAŁCEŃ W PŁASZCZYŹNIE PRZY UŻYCIU INTERFEROMETRII W ŚWIETLE ODBITYM

W pracy zaprezentowano metodę ilościowych badań odkształcenia przy pomocy interferometrii holograficznej w świetle odbitym z bezpośrednim mocowaniem płyty holograficznej na badanym obiekcie. Metoda umożliwia badanie fragmentów dużych konstrukcji eliminując wpływ przemieszczenia obiektu jako całości.

Zestaw aparatury do formowania hologramów jest bardzo prosty, a ponadto zostały znacznie ograniczone wymagnia odnośnie wibroizolacji układu. W przedstawionym przykładzie, odkształcenia wyznaczone na podstawie wektorów przemieszczeń punktów są zgodne z mierzonymi metodą tensometrów oporowych.

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