

# Control of the deformations of objects by electronic interferometry speckle (ESPI)

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The electronic technique of interferometry speckle, used in the measurement of the deformations of diffusing objects, is based on the process of subtraction of the figures of interferences. A first image of speckle is recorded before the deformation of the object in the RAM of a computer, followed a second after deformation. The square of the difference between the two images gives fringes of correlation in observable real times directly on the monitor. The interpretation of these fringes makes it possible to determine the deformation. In this communication, we have experimental results of deformation out of the plan of two samples out of Aluminium and STAINLESS.

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## 1. Introduction

Speckle interferometry is generally used in the measurement of displacements and the deformations of rough surfaces. In spite of its importance this technique did not see a great adoption by the researchers and industry. Mechanical stability, the photographic need for development and the difficulty of interpretation of the fringes are problems of this method.

For these reasons, it is obvious that the effort of the researchers moves towards the operation of new systems able to replace the holographic media for recording. The idea is to use systems of detection and treatment of the figures of speckles in real time.

These techniques are generally known under the name of electronic interferometry speckle (Electronic speckle pattern interferometry [ESPI]). The major characteristic of the method is that it allows an exposure of the fringes of correlations in real time on the monitor.

The process consists in recording the figures of interferences corresponding to the object before and after deformation by the use of a CCD camera. A video system is used to generate the fringes of correlations which correspond exactly to the movement of the object between the two exposures

In this work, we try to give a very short outline of technique ESPI, to get some experimental results of measurement and to discuss the obtained results.

## 2. Quantitative measurement of the deformations out of the plane

### a) Breadboard construction

Fig. (1) presents the arrangement of the interferometer used in this experiment. The light emitted by a laser source He-Ne (20 mw, 632.8 nm), is widened by a system made

up of an objective of microscope OM and a space filter of 25 micrometers diameter placed at its point focal distance. The laser beam obtained is collimated by a photographic objective OP<sub>1</sub> of 210 mm focal distance and variable numerical opening. This beam is then divided into two equal beams by a separating cube C<sub>1</sub>. The first beam reflected by the mirror M<sub>2</sub> lights an object diffusing under an angle of 45° compared to its normal (called beam object). The second beam transmitted (regarded as reference wave) through the C<sub>1</sub> cube, crosses a second cube C<sub>2</sub> to arrive at the mirror M<sub>1</sub> assembled on a piezoelectric PZT. The difference of the optical way between the beams, object and in reference can be changed by the application of a tension to the piezoelectric element. The mirror M<sub>1</sub> will return the light towards the cube C<sub>2</sub> which will retransmit it towards the cube C<sub>3</sub> and arrives finally at the detecting surface of CCD camera.

A photographic objective OP<sub>2</sub> of 75 mm focal distance and variable numerical opening makes it possible to carry out the image of the surface of the object on the camera, where there will be interference with the wave of reference.

The CCD camera is interfaced with a microcomputer MO to record and store the images. The interface is made via the chart of video-captures acquisition.

The exploitation of the stored images is ensured by the software Image-Pro More (IPP) where all the arithmetic operations are employed on these images to extract the fringes from correlation and to project them on the screen.

To establish the best working conditions, the influence of the following parameters was checked:

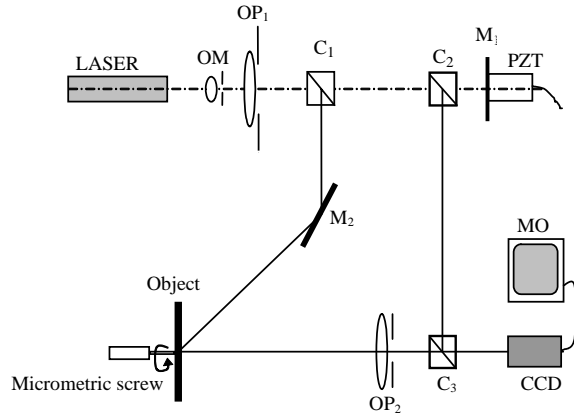
- Influence of numerical opening of the photographic objective

- Influence of  $k$  on the contrast of the fringes

The low intensity diffused by the object, forced us to choose a small numerical opening ( $F=4.5$ ) in order to

capture the maximum of intensity and to obtain a good modulation.

It is noticed in practice that the best fringes are obtained when the value of the intensity of the beam of reference is twice the value of the intensity of the beam object. When the power of the laser source is insufficient, an increase in the ratio  $K$  is necessary to improve the quality of the fringes.



$C_1, C_2, C_3$ : Separating Cubes  
 $M_1, M_2$ : Mirrors  
 OM: Objective of the microscope.  
 $OP_1, OP_2$ : Photographic objectives  
 CCC: CCD CAMERA  
 MO: Microcomputer  
 PZT: Piézoceramics.

Fig. 1. Experimental device for the quantitative measurement of the deformations out of the plane.

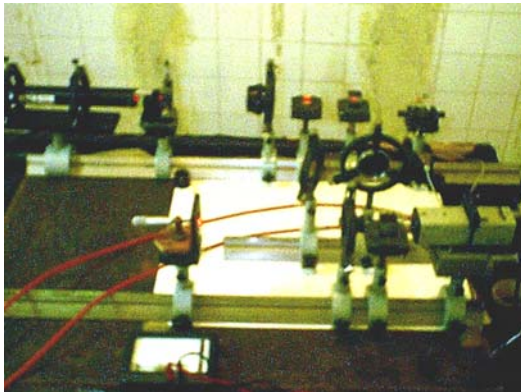


Fig. 2. Image of the experimental device for the measurement of the deformations out of the plane.

### b) Displacements out of the plan

To measure a deformation by method ESPI, a speckle image of the not deformed object is recorded. After deformation, the recorded image is directly withdrawn initial image, and the square of this difference is shown on LE monitor (screen) as fringes of correlations.

Either  $I_1$  and  $I_2$  the distributions of incidental intensities on the face of the camera before and after deformation of the object,  $I_O$  and  $I_R$  are the intensities of the beams object and reference.

$$I_1 = I_O + I_R + 2\sqrt{I_O I_R} \cos \phi \quad (1)$$

$$I_2 = I_O + I_R + 2\sqrt{I_O I_R} \cos (\phi + \Delta \phi) \quad (2)$$

With  $\phi$ : phase shift enters the beams object and of reference, and  $\Delta \phi$  ( $\Delta \phi = (2 \pi / \lambda) \cdot d$ ) phase shift caused by the deformation 'D'.

The first two terms of the equations (1) and (2) are terms of noise, which are necessary to be removed from the final image. The third term represents the term of interference, from where the information of phase concerning the deformation is obtained.

If the signals  $V_1$  and  $V_2$  (on the outlet side of the camera) are proportional to the intensity of the image of entry, then the signal resulting from the subtraction ( $V_S$ ) is given by:

$$V_S = (V_1 - V_2) \propto (I_1 - I_2) = 4\sqrt{I_O I_R} \sin(\phi + \Delta \phi) \cdot \sin \frac{\Delta \phi}{2} \quad (3)$$

This signal has positive and negative values. The negative values are shown as dark surfaces on L' screen of the computer. To avoid this loss of signal and to obtain fringes, the square of the difference  $V_S$  is calculated. Consequently, the average intensity  $B$  in a given point of the image is:

$$B = 8 \langle I \rangle \sin^2 \left( \frac{\Delta \phi}{2} \right) \quad (4)$$

The equation (4) is similar to that obtained in traditional interferometry where the fringes are sinusoidal and are dependent on the phase difference related to deformation.

## 3. Experimental results

### 3.1. Measure deformation of a surface charged in the center

The first application is reserved to the calculation of the deformation out of the plane of an aluminium plate, which is charged in the center by displacement with a thumb screw (10 micrometers).

Fig. 3 represents the speckle figures recorded at the same time before deformation of the object ( $S_0$ ) and after deformation by moving the piezoelectric piece by quantities  $0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}$  ( $S_1, S_2, S_3$  and  $S_4$ ).

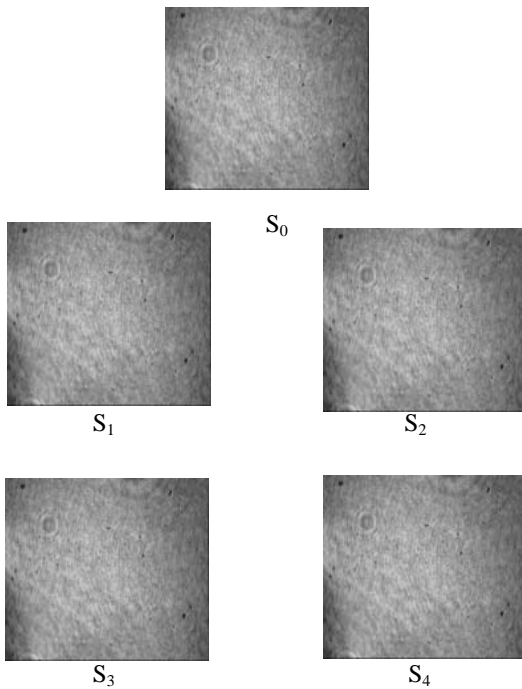


Fig. 3. Interferograms of speckle ( $S_0$ ): Before deformation, ( $S_1 - S_4$ ): After deformation.

The interferograms ( $I_1$  with  $I_4$ ) generated by the calculation of the square of the difference between the figures of speckle before and after deformation, ( $I = 1-4$ ) are shown in Fig. 4.

The various arithmetic operations are executed using the software Image Pro More (IPP) and their analyses were performed by the software Fringe Processor.

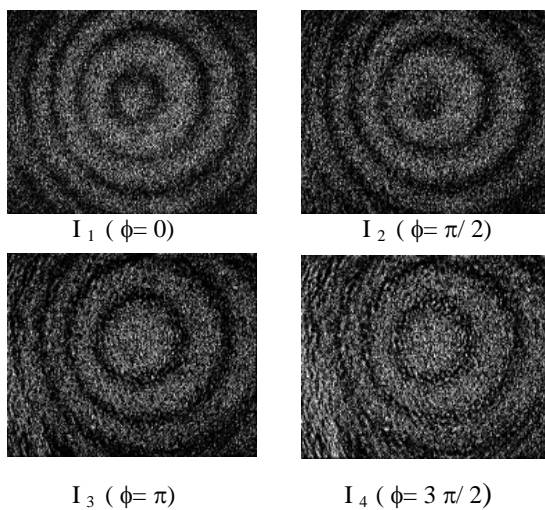


Fig. 4. Interferograms obtained by the technique of shift of phase.

### a) Smoothing of the interferograms

Generally, it is difficult to have a smoothed structure of phase directly starting from the interferograms of the Fig. 4. To reduce the noise in these interferograms, one carries out a low-pass filtering. Fig. 5 shows the result applications of a filter of dimensions  $3 \times 3$ .

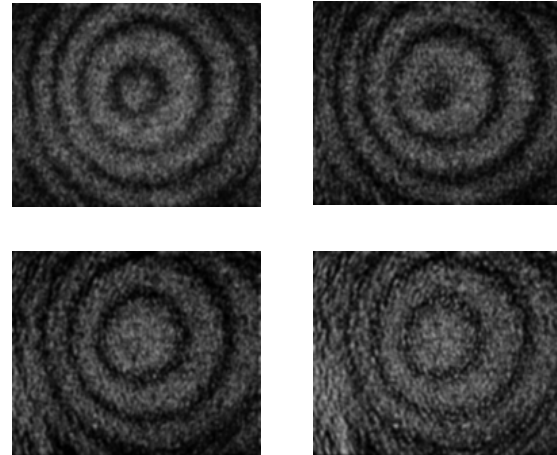


Fig. 5. Low-pass filtering of the interferograms  $I_1 - I_4$ .

### b) Calculation of the phase

To calculate the phase, the program gives access the option sampling in the menu. Some calculation algorithms of phase are posted among which one selected the algorithm with four images. The rolled up phase is presented in the Fig. 6.



Fig. 6. Distribution of the rolled up phase.

### c) Unwrapping of the phase

The correction of the jumps of phase in Fig. 6 is carried out by an unwrapping spiral starting from an unspecified point in the figure of the rolled phase. The result of the process of unwrapping is illustrated on the Fig. 7.

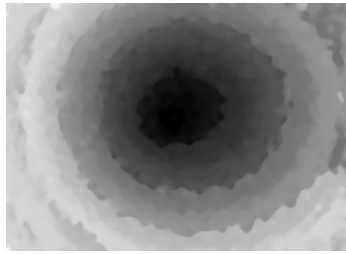


Fig. 7. Unwrapping of the phase.

**d) Filtering of the phase**

To improve the results of unwrapping of the phase, one applies a Median filtering. Fig. 8 is the result of five applications of a Median filter of dimensions 5x5.

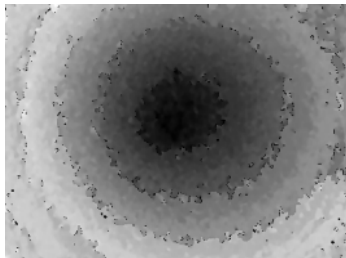
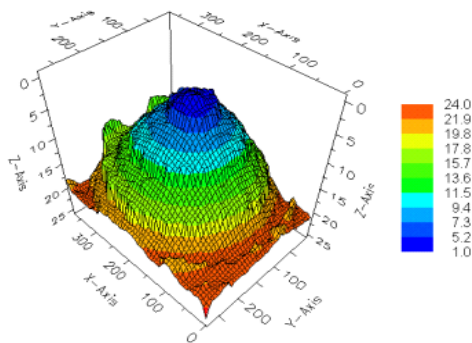


Fig. 8. Median filtering of the unrolled phase.

**e) Exploitation of the phase in three dimensions**

The exploitation of the phase unrolled in three dimensions enables us to know the distribution of the deformation, i.e. the value and the direction of the deformation of surface.



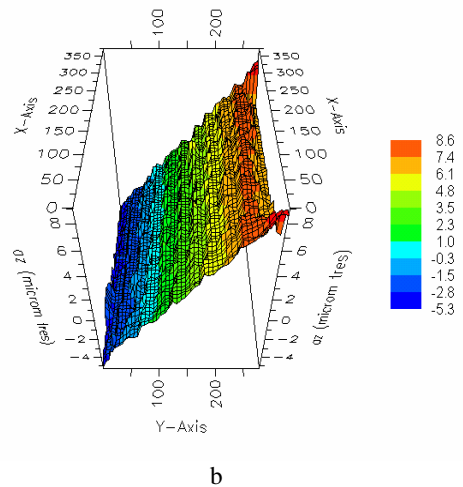
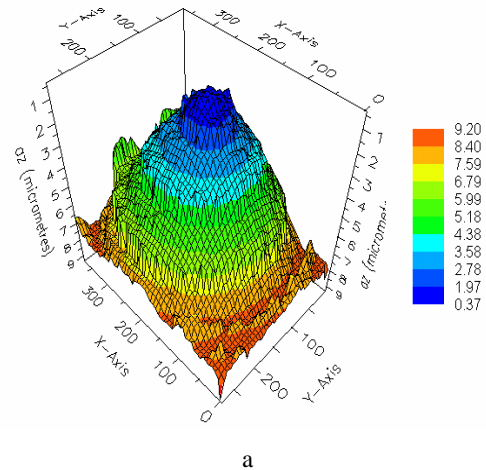
**Fig. 10.** Experimental result of the calculation of the inflection of the Aluminium surface of dimensions  $(80 \times 20 \times 0.5) \text{ mm}^3$ .  
 (a) - Interferogram of speckle.  
 (b) - Correlograms obtained by the technique of shift of phase.  
 (c) - Smoothing of the interferogram by five repetitions of a filter pass-bas  
 (d) - Distribution of the rolled up phase.  
 (e) - Unwrapping of the phase.  
 (f) - Filtering median of the phase.  
 (g) - Exploitation of the phase in three dimensions.

**4. Calculation of the deformation**

Once the phase is given, the corresponding deformation can be calculated starting from the distribution of the unrolled phase. The equation (1) enables us to calculate the deformation out of the plan has  $z$  expressed by:

$$az = \frac{\lambda \delta}{2\pi(1 + \cos \theta)} \tag{5}$$

To establish the distribution of the deformation on the surface of the object, it is enough to divide the distribution of the phase unrolled by the value  $\frac{2\pi(1 + \cos \theta)}{\lambda}$ . Fig. 11 represents the distribution of the deformation for the two preceding cases.



**Fig. 11.** Distribution of the deformation on the surface of the object, a) - Surface  $(42 \times 42 \times 0.5) \text{ mm}^3$  charged in the center (b) - Surface  $(80 \times 20 \times 0.5) \text{ mm}^3$  inflection.

The resulting deformations are almost the same as those carried out by the thumb screw. The difference between the values of the deformations is with the inaccuracy in the displacement of the screw.

It is noticed that as displacement increases, the distance between interference rings decreases. One also sees that the visibility of these fringes decreases when displacement increases and becomes practically zero when this one is of the same order of magnitude with the diameter of the grains of speckle.

The numerical value of the deformation can be evaluated by the techniques of analysis of the fringes (example: technique of the phase shifting) [6-8].

## 5. Conclusion

The electronic technique of speckle interferometry (ESPI) is a nondestructive rapid and precise technique. It makes possible to take qualitative measurements of the static or dynamic deformations at weak frequencies, provided that the deformation does not exceed the diameter of the grain of the speckle.

It was also shown that an arithmetic operation such as the subtraction makes possible to generate fringes of correlation in real time, similar to those obtained holographically.

L has technical interferometry speckle combining with the technique of shift of phase shifting, allows the calculation of the deformation of aluminium charged plate.

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