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# Measurement of the deformations of objects by optical method

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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 possible to determine the deformation.

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## 1. Introduction

Interferometry speckle 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 large adoption by the researchers and industry. Mechanical stability, the photographic need for development and the difficulty of interpretation of the fringes explains this lack of broad use.

For these reasons, it is obvious that the effort of the researchers moves towards the operation of new systems able to replace the holographic recording media. 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 correlation fringes 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 have some experimental results of measurement and to discuss these results.

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

### 2.1 Breadboard construction

Fig. 1 presents the arrangement of the interferometer used in this experiment. The light emitted by a laser source He–Ne (20mw, 632,8nm), is widened by a system made up of an objective of microscope OM and a space filter of 25 micrometers in diameter placed at its point focal distance. The obtained laser beam is collimated by a photographic objective $OP_1$ of 210 mm focal distance and variable numerical aperture. This beam is then divided into two equal beams by a separating cube $C_1$. The first beam reflected by the mirror $M_2$ lights an object diffusing under an angle of $45^0$ compared to its normal (called beam object). The second beam transmitted (regarded as reference wave) through the $C_1$ cube, crosses a second cube $C_2$ to arrive at the mirror $M_1$ assembled on a piezoelectric PZT. The difference of the optical way between the object beams and the reference one can be changed by the application of a tension to the piezoelectric one. The mirror $M_1$ will return the light towards the cube $C_2$ which will retransmit it towards the cube $C_3$ and arrives finally at the detecting surface of CCD camera.

A photographic objective $OP_2$ of 75 mm focal distance and variable numerical aperture makes possible to carry out the image of the surface of the object on the camera, where there will interfere with the reference wave.

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

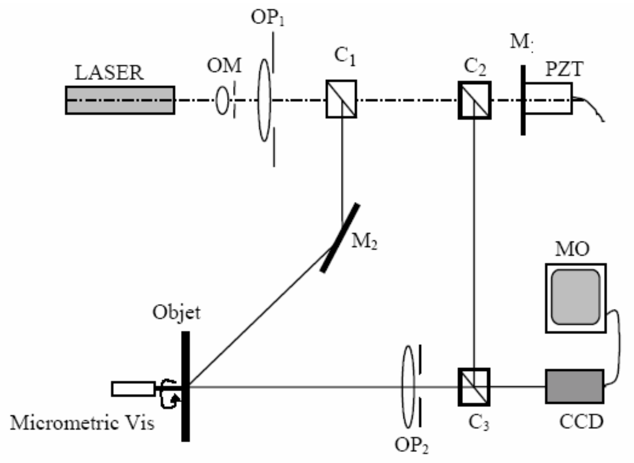
The exploitation of the stored images is ensured by the software Image-Pro Plus (IPP) where all the arithmetic operations are employed on these images to extract the fringes from correlation and to project them on the screen.

To establish better working conditions, the influence of the following parameters is checked:

- Influence of numerical aperture of the photographic objective
- Influence of K on the contrast of the fringes

The low intensity diffused by the object, implies to choose a small numerical aperture (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 microscope.
**OP** $_1$, **OP** $_2$: Photographic objectives
**MO**: Micro computer
**CCD**: Camera CCD
**PZT:** Piezoelectric

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

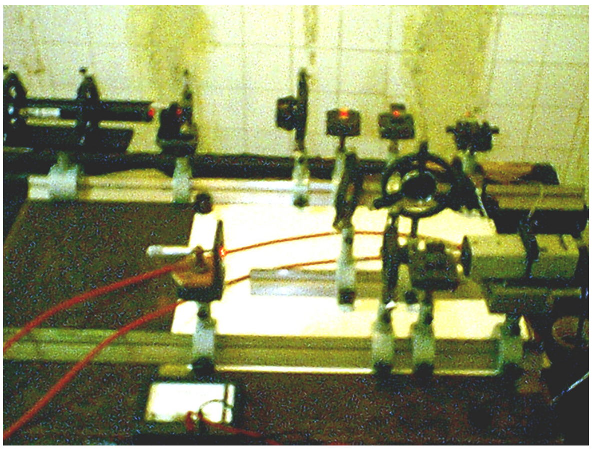


*Fig. 2. Image of the experimental device for the measurement of deformations out of plane.*

**2.2 Displacements out of the plane**

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

Either $I_1$ and $I_2$ the distributions of incident 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.

$$I_1 = I_O + I_R + 2\sqrt{I_O I_R}\cos\phi \tag{1}$$

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

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

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

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:

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

This signal has positive and negative values. The negative values are exposed like obscure surfaces on screen of the computer. To avoid the loss of signal and to obtain fringes, the square of the difference $V_S$ is carried out. Consequently the average intensity B in a point of the image is:

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

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

## 3. Experimental results

### Measurement of the deformation of a surface charged in the center

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

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

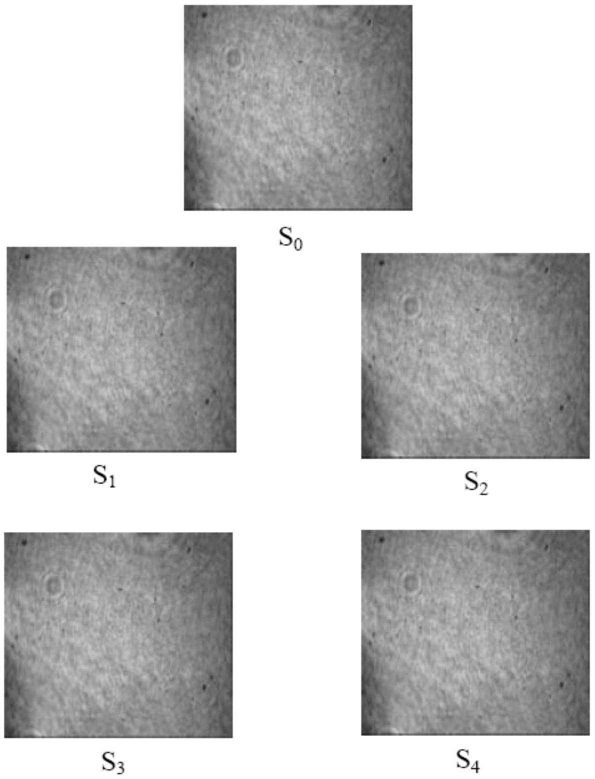



*Fig. 3. Interferograms of speckle ($S_0$): before Deformation, ($S_1$ - $S_4$): after deformation.*

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 performed using the software Image Pro Plus (IPP) and analyses by the software Fringe Processor.

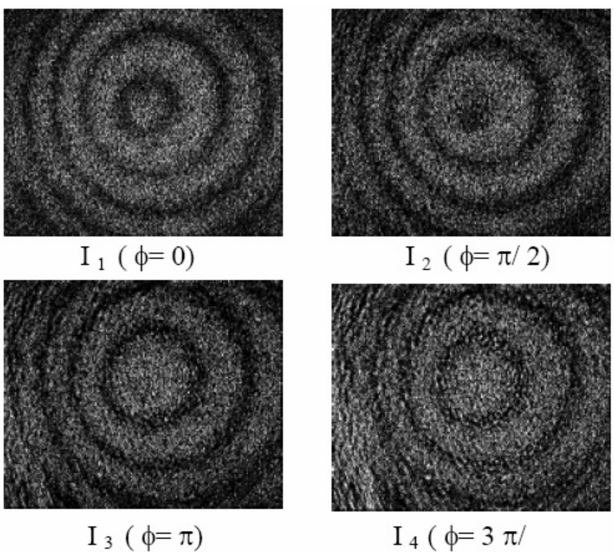



*Fig. 4. Interferograms obtained by the technique of phase shift.*

### 3.2 Smoothing of the interferograms

Generally, it is difficult to have a structure of phase smoothes directly starting from the interferograms of the Fig. 4 To reduce the noise in these interferograms, one uses a low-pass filtering. Fig. 5 shows the resulting applications of a filter of dimensions 3×3.

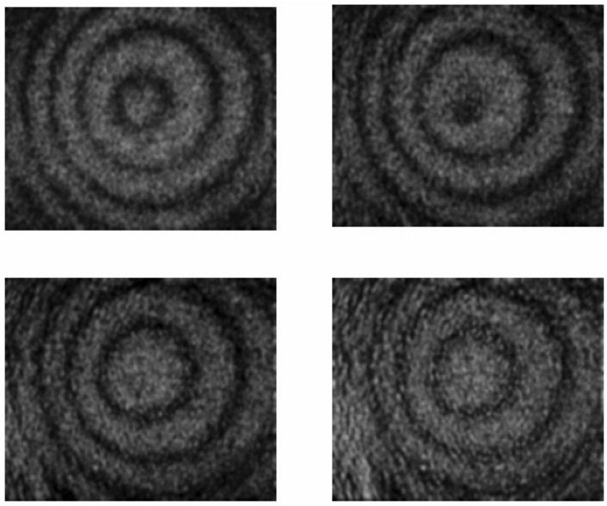


*Fig. 5. Low-pass filtering of the interferograms $I_1$–$I_4$.*

### 3.3 Calculation of the phase

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

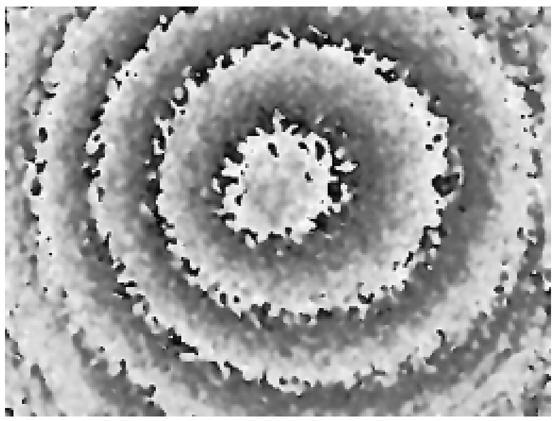


*Fig. 6. Distribution of the rolled up phase.*

### 3.4 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.

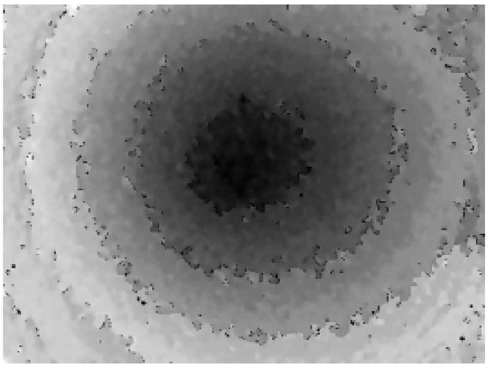


*Fig. 7. Unwrapping of the phase.*

### 3.5 Filtering of the phase

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

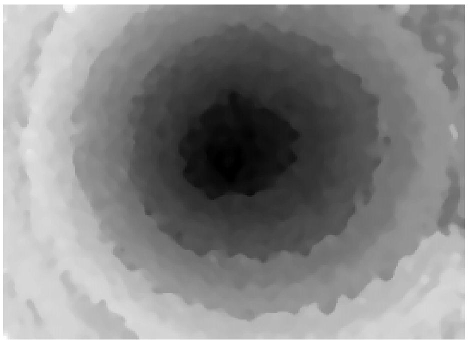


*Fig. 8. Median filtering of the unrolled phase.*

### 3.6 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 surface deformation.

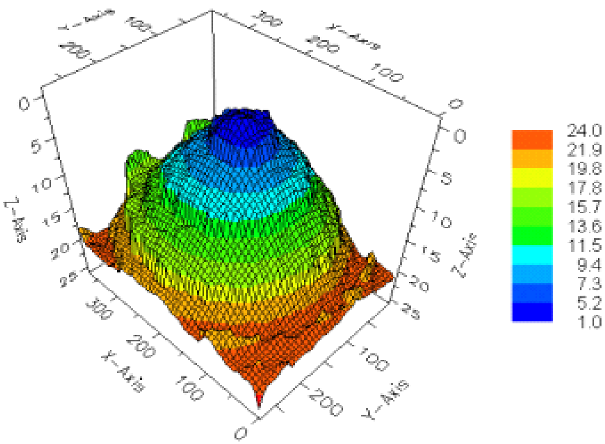
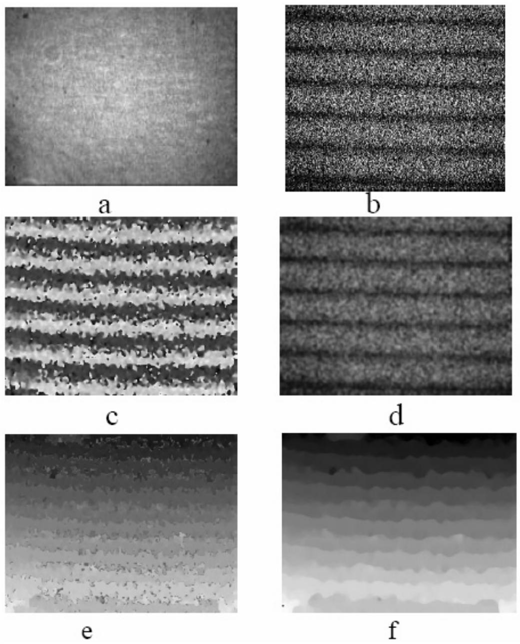
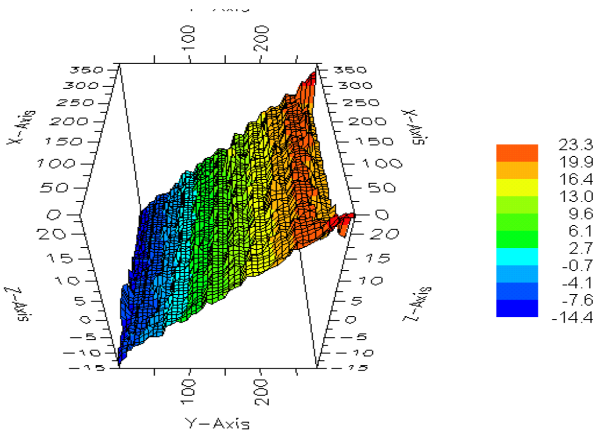



*Fig. 9. Experimental result of the calculation of the inflexion of the Aluminium surface of dimensions $(80\times20\times0.5)\ mm^3$.*

## 4. Measurement of the flexion of a surface

The second application consists in calculating the inflexion of an aluminium surface of rectangular form of dimensions $(80\times20\times0.5)\ mm^3$ stuck by its end lower than a carry-sample. The object is inflected on its higher end by the displacement of a thumb screw (15 micrometers). Distribution of the phase of the deformation is calculated by previous method.




*(g)*

*Fig. 10. Experimental result of the calculation of the inflexion of the Aluminium surface of dimensions $(80\times20\times0.5)\ mm^3$.*

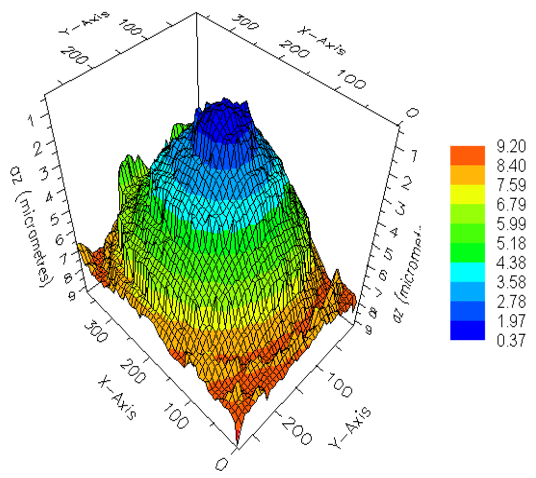
(a) - Interferogram of speckle.
(b) - Correlograms obtained by the technique of shift of phase.
(c) - Smoothing of the interferogram by five repetitions of a filter pass-bas
(d) - Distribution of the rolled up phase.
(e) - Unwrapping of the phase.
(f) - Filtering median of the phase.
(g) - Exploitation of the phase in three dimensions.

## 5. Calculation of the deformation

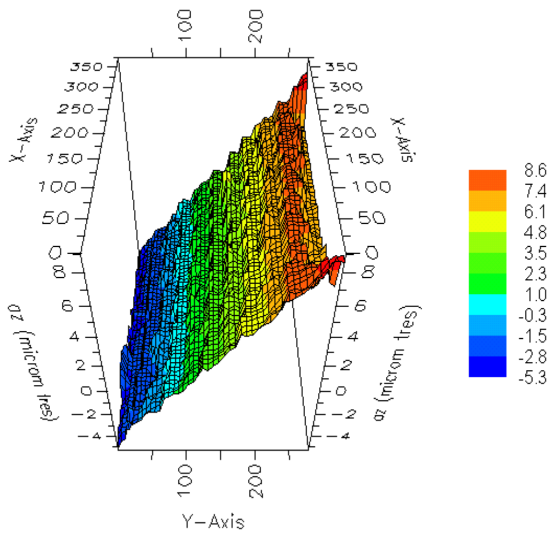
Once the phase is given, the corresponding deformation can be calculated starting from the distribution of the unrolled phase. The equation (1) enables us to calculate the deformation out of the plan has $z$ expressed by:

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

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.




*(a)*




*(b)*

*Fig. 11. Distribution of the deformation on the surface of the object; a) - Surface (42×42×0.5) mm $^3$ charged in the center; b) - Surface (80×20×0.5) mm $^3$.*

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

It is noticed that when displacement increases, the distance between interference rings decreases. It is seen that the visibility of these fringes decreases when displacement increases and becomes practically null when displacement 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 phase shifting) [6-8].

## 6. Conclusions

The electronic technique of interferometry speckle (ESPI) is a technique nondestructive rapid and precise. It makes it 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 speckle.

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

The technical interferometry speckle combined with the technique of phase shifting allows the calculation of the deformation of aluminium plate charged in the center that produces inflexion with the assistance of a thumb screw.

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