Application of laser technique for the calculating the speckle size and object incidence angle

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The electronic speckle interferometry technique used to measure the deformations is based on the subtraction of interference patterns. An object image is first recorded before the deformation of the object, after it receives the reference wave. The difference between two images showing correlation fringes observable in real time directly on the CCD camera. The interpretation of these fringes to determine the disturbance. In this work, we present interferograms from the deformation of a metal plate, selection of optimal parameters for lateral and longitudinal dimensions of speckle grains and the incidence angle in the optical assembly Michelson

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1. Experimental

The experimental configuration is presented in Fig. 1.

FIG 1 the piezoelectric is placed in one arm of a Michelson interferometer. The use of the Michelson interferometer provides a quasi-linear relationship. The terminals of the piezoelectric connected are in a voltage generator which is linked in turn to a millimeter for controlling the applied voltages. Piezoelectric moves when the voltage at its terminals increases. In our experiment, the voltage was varied between 0 and 400 volts in steps of 10 volts.

Knowledge of the number of the pixel corresponding to $2\pi m$ can determine the displacement of the piezoelectric each applied voltage.

The results are given by the following formula, which expresses the displacement versus the applied voltage:

$$Y = -10.20269 + 1.99071 x$$

2. Measurements

a. Size of the speckle grains: Resolution speckle grains by the CCD camera is a very important factor in the formation of fringes in the case of Electronic speckle interferometry (ESPI).

For best results, the average grain diameter must be at least the diameter of the CCD camera pixel. When the speckle diameter is smaller than the pixel, the resulting fringes are less bright and low modulation. In the case where the speckle grains are larger than the
diameter of the pixel, the fringes will be well mixed but disturbed by the visible secondary speckle. The diameter of the speckle depends on the numerical aperture of the lens (formation of subjective speckle). From the following combination of formula [2]:

$$\frac{1}{f} = \frac{1}{d_i} - \frac{1}{d_0}$$  \hspace{1cm} (2)

With: \(d_0\) and \(d_i\) are the object and image distances.

For a distance \(d = 100\) mm and a focal length \(f = 75\) mm, then:

\(d_0 = -300\) mm

The magnification of the obtained lens is equal to:

\[g = \frac{d_i}{d_o} = 0.33\]  \hspace{1cm} (3)

The following formulas allow us to determine the lateral and longitudinal dimensions of subjective speckle.

\[S_l = 1.22 \lambda \frac{d_i}{a} = 1.22 \lambda (1+g) F\]  \hspace{1cm} (4)

\[S_l = 8 \lambda \frac{d_i^2}{a^2} = 8 \lambda (1+g)^2 F^2\]  \hspace{1cm} (5)

Using a camera lens focal length \(f = 75\) mm and aperture number \(F\) which varies between 4.5 to 22, the magnitudes of the objective and subjective speckle are given by the following table:

**Table 1. Quantities of objective and subjective speckle based on the number of openings**

<table>
<thead>
<tr>
<th>(F)</th>
<th>(S_{obj}(\mu m))</th>
<th>(S_{sub}(\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>22.644</td>
<td>4334.16</td>
</tr>
<tr>
<td>16</td>
<td>16,469</td>
<td>2292.45</td>
</tr>
<tr>
<td>11</td>
<td>11,32</td>
<td>1083.54</td>
</tr>
<tr>
<td>8</td>
<td>8,23</td>
<td>573.11</td>
</tr>
<tr>
<td>5.6</td>
<td>5.76</td>
<td>280.82</td>
</tr>
<tr>
<td>4.5</td>
<td>4.63</td>
<td>181.37</td>
</tr>
</tbody>
</table>

**Fig. 2. Representation of variables of the objective and subjective speckle according to number of opening**

During measurement, it is considered that the disruption of the object is less than the dimensions of subjective speckle \(S_{sub}\).

b. The angle of incidence of choice:

The above table shows no correlation between the fringes as a function of the angle incidence \(\theta\), the latter is not related by the following equation [3]:

\[p = \frac{\lambda}{2 \sin \theta}\]  \hspace{1cm} (6)

Avec \(\lambda\) : wavelength of the laser used (\(\lambda = 632.8\) nm).

\(\theta\) : Angle of incidence.

**Table 2: step of correlation fringes for different angles**

<table>
<thead>
<tr>
<th>(\theta(\degree))</th>
<th>(P(\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3.63</td>
</tr>
<tr>
<td>10</td>
<td>1.822</td>
</tr>
<tr>
<td>15</td>
<td>1.222</td>
</tr>
<tr>
<td>20</td>
<td>0.925</td>
</tr>
<tr>
<td>25</td>
<td>0.748</td>
</tr>
<tr>
<td>30</td>
<td>0.632</td>
</tr>
<tr>
<td>35</td>
<td>0.551</td>
</tr>
<tr>
<td>40</td>
<td>0.492</td>
</tr>
<tr>
<td>45</td>
<td>0.447</td>
</tr>
</tbody>
</table>
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3. Results

This application relates to the calculation of the movement out of the plane of a piece of aluminum, which is moved with the aid of a micrometer screw (10 microns). It first starts recording the speckle of the object before deformation, then object is moved one step 5 microns and the speckle pattern is recorded ($S_1$) for different numerical apertures.

Fig. 3: Incidence angle according to different steps

In our work we chose the angle $\theta$ range $[15^\circ, 20^\circ]$ so as not to be less than the average grain size.

Examining the correlograms obtained for different numerical apertures, one opts for the choice of $F = 8$ so that the intensity of the reference wave is twice the intensity of the object wave [4].

In figure, we can simulate a "speckle pattern". To do that, I propagate first a gaussian beam $b(x,y)$ on a certain distance: the propagation of a beam between planes is given by [5]:

$$g(x, y) = b(x, y) \otimes h(x, y)$$  \hspace{1cm} (7)

Where $h(x,y)$ is the Fresnel impulse response.

Fig. 4: Correlograms obtained for different numerical apertures

Fig. 5: Simulation of speckle pattern: a. Gaussian beam b. Gaussian beam after a certain distance

It is noted that as the displacement ‘d’ increases, decreases the fringe. We also see that the visibility of these fringes decreases as the displacement increases and becomes almost zero when the displacement is of the order of magnitude of the diameter of the speckle grains.

4. Conclusions

The Electronic speckle interferometry (ESPI) is a fast and accurate non-destructive technique. It allows qualitative and quantitative measurements of static or dynamic deformation, provided that the deformation does not exceed the speckle grain diameter.
It is also shown that the arithmetic operations such as subtraction interferograms obtained for generating correlation fringes in real time, similar to those obtained by the method of holography.

References


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