Double Pulse-Electronic Speckle Interferometry (DP-ESPI)

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1. Introduction

For the measurement of vibrations using double-pulse techniques, pulses separations between 1 and 1000 microseconds are necessary. Until now double-pulsed holographic interferometry has been extensively used to measure vibrations. This method has the disadvantage that it needs the recording and the reconstruction of a hologram. For the recording a photographic plate or a thermo-plastic camera is usually used. The hologram is then reconstructed usually with a continuous laser and viewed with a CCD camera. This process is time consuming. Double pulsed ESPI [1] enables to obtain correlation fringes corresponding to the displacement without recourse to any form of photographic processing and plate relocation.

2. Electronic recording of two speckle pattern of a vibrating object

The system used is shown in Fig.1. The beam coming from the ruby laser is splitted into two beams, the object beam and the reference beam. The object beam is enlarged by a diverging lens and it illuminates the object(O). The object is imaged on the CCD camera by the lens L. With the aperture (AP) in front of the lens L it is possible to choose the mean dimension of the speckle in the sensor plane. The CCD-camera records the interference between the light coming from the object and a reference. When the object vibrates the interference pattern changes. We record the first image with the first pulse and the second image with the second pulse. The two images are then subtracted one from the other and correlation fringes corresponding to the object deformation appear. For our experiments we used a ruby laser (wavelength 694 nm), which can emit two high energy pulses separated be few microseconds. The problem is to record two images corresponding to the two pulses by using a CCD-camera. To perform this task we used an interline transfer CCD-camera. This camera consists of an array of photosensors each connected to a tap on a vertical shift register. When illuminated, the photo sensors generate charges that after a period of time are transfered in the shift register which is covered to prevent generation of new charges. The time necessary to transfer the charges from the photosensors to the shift register is short (2 or 3 microseconds for the camera used in our experiment) since it involves only a parallel transfer from each photosensor to the adjacent one. After the charge transfer the photosensors of the camera are ready to capture a new image. For our particular case we recorded the first pulse and we transfered the charges to the shift register, after this transfer we recorded the second pulse. The two images (first image in the shift register and second image in the photosensors) can be read in two normal readout cycles, digitalized and stored into the frame memory. Since the two laser pulses usually do not have the same energy, a normalization of the two recorded speckle images is necessary. The images are the substracted one from the other and the absolute value is taken and stored into the frame grabber. Figure 2 shows the result for a vibrating plate after the subtraction between the two speckle pattern. The puls separation was 100 microseconds. It was even possible to record two separated images using puls separation of 5 microseconds. Since the camera used in our experiment is an interlaced, it is not possible to transfer the charges of all the elements at the same time but only the odd or the even lines, therefore we can use only half of the vertical resolution, but still good results can be obtained.

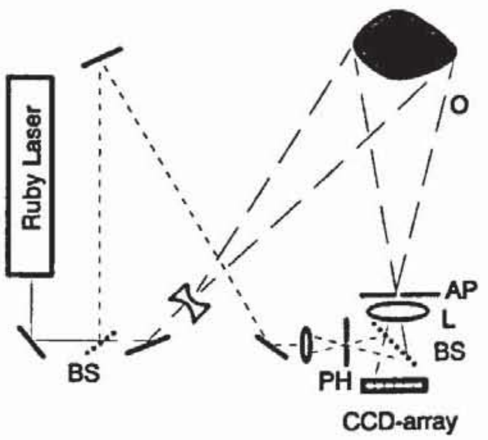


Fig.1. Optical set-up

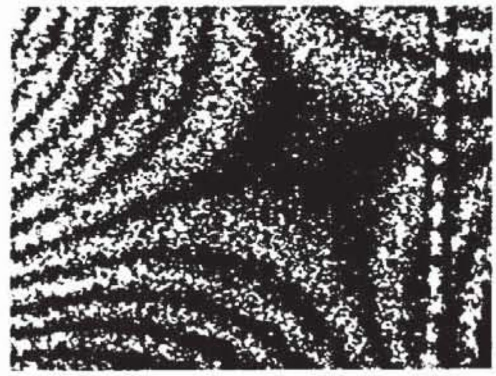


Fig.2. Speckle interferogram of a vibrating plate recorded with puls separation of 100 µsec.

3. Quantitative analysis of the fringes

The spatial-carrier phase-shifting method [1], [2], [3], is particularly well suited to be used for a quantitative analysis in the case of a pulsed laser, since all the information necessary to reduce an interferogram to a phase-map is recorded simultaneously. The reference beam is tilted by an angle θ with respect to the optical axis. In the image plane (where the CCD sensor is located) the speckle image of the object to be tested is then modulated with a carrier frequency having a period $p_M=\lambda/\sin\theta$. The angle θ is chosen so that the phase difference between the reference and object beam changes by a constant α from one pixel of the CCD camera to the other. In order to apply this method it is necessary that the speckle are still correlated after the image-shift of one pixel, this involves that the pixel size should be greater than the period p_M. The first speckle pattern SP1 with the object in position O1 and the second SP2 with the object in position O2 are recorded and stored in the frame grabber. Three phase-shifted fringes-patterns can then be obtained. For the first fringe pattern (phase-shift $-\alpha$) the speckle pattern SP2 is shifted one pixel (Δx) left (digital shift in the frame grabber) with respect to SP1, a subtraction between the pattern is then performed ($SP1(x,y)-SP2(x-\Delta x,y)$). The second fringe pattern (phase-shift 0) is obtained by subtracting the speckle image SP2 from SP1 ($SP1(x,y)-SP2(x,y)$). The third interferogram is obtained by shifting to the right by one pixel SP2 with respect to SP1, by subtracting ($SP1(x,y)-SP2(x+\Delta x,y)$). The three fringe-pattern obtained are then filtered and the phase is calculated. We used the spatial-carrier shift-method to study the vibration of a plate few microseconds after a choc. One result is represented in Figure 3.

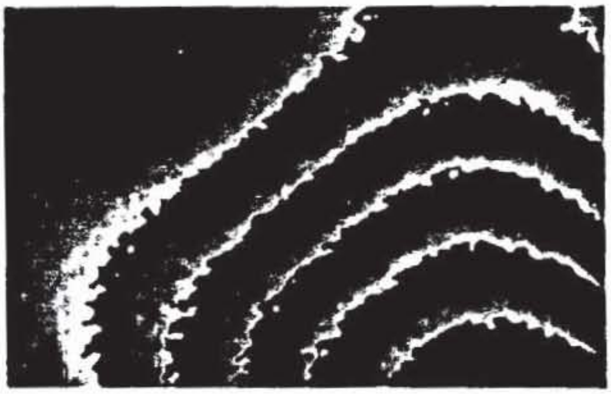
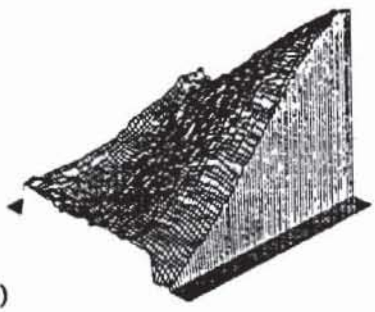
a)  b) 

Fig.3. Deformation of a plate between 150 and 250 microseconds after the impact of a pendulum on the plate. a) Phase-map, b) pseudo 3D representation of the deformation

4. Two and three dimensional measurements

The results presented in sections 2 and 3 are only onedimensional, this means that they give us only the deformation of the object along one sensitivity vector. In some cases a two or three dimensional analysis of the deformation is necessary. More sensitivity vectors can be generated by observing the object from different direction or by illuminating the object from different directions (thre directions of illumination and one direction of observation). We choose the second possibility because it has the advantage that it does not needs rectifications due to the distortion by different observation directions. Figure 4 show the arrangement used for the measurement of two dimensional deformations. The sensitivity vectors are given by the half-angle between illumination and observation directions. The camera 1 records the interference between the reference 1 and the illumination 1, it give also the information of the deformation along the sensitivity vector **e1**, and analogously the camera 2 measure the deformation along the vector **e2**. In order to avoid unwanted interference, the second reference/illumination beam pair is delayed by 5 m (coherence lenght of the ruby laser). For the three dimensional case we use the same principle but with 3 cameras and three illumination directions. Figure 5 shows the results of the measurement of a vibrating cognac-glas. The two dimensional arrangement was used and the figure shows the projection (on a horizontal plane) of the objects deformation along a line at a constant high.

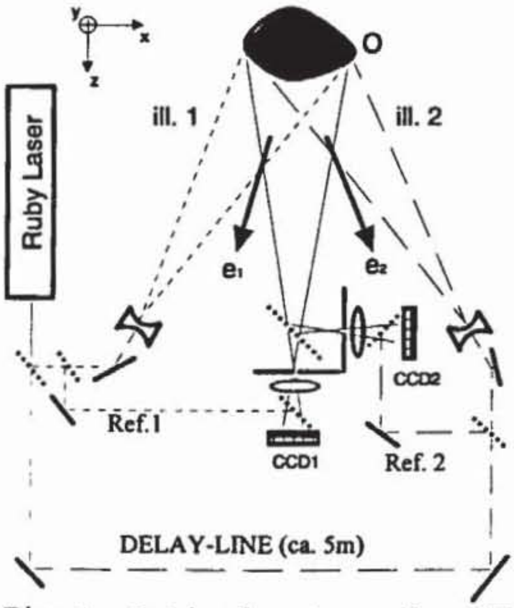


Fig.4. Optical set-up for 2D Speckleinterferometry

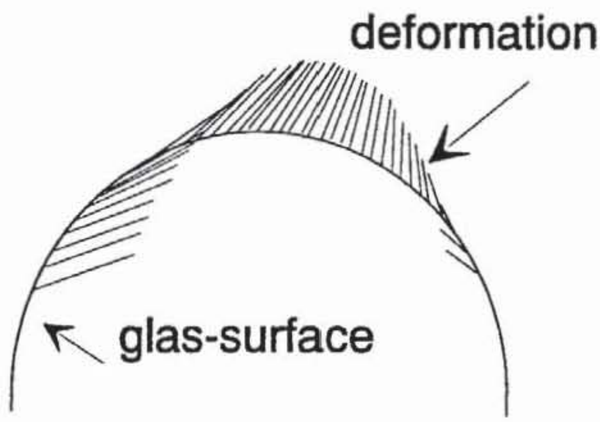


Fig.5. 2D measurement on a cognac-glas. Deformation along a horizontal line.

5.Conclusions

The double-pulsed speckle interferometry method is very much simpler than the double pulse holographic interferometry and allows a quick analysis of the interferograms without the development of films and hologram reconstructions. It is thus well suited to be used in an industrial environment. Using 3 cameras and three illumination directions (in order to have three sensitivity vectors) it is possible to measure 3-D deformations.

References

[1] G.Pedrini, B. Pfister, H. Tiziani, "Double pulse-electronic speckle interferometry", J. of modern Optics, Vol. 40, 89-96 (1993).

[2] B. Pfister, M. Beck and H. J. Tiziani, "Speckleinterferometrie mit alternativen Phasenshiebe-methode an Beispielen aus der Defektanalyse", in Proc. **Laser 91**, (München 1991).

[3] S.Leidenbach, "Die direkte Phasenmessung-ein neues Verfahren zur Berechnung von Phasenbildern aus nur einem Intensitätsbild", in Proc. **Laser 91**, (München 1991).