Comparative Phase-Shifting Digital Speckle Pattern Interferometry Using Single Reference Beam Technique

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This paper reports on the application of phase shifting interferometry to digital speckle interferometry. The method here enables the measurement of phase distributions corresponding to the difference in displacements of two nominally identical specimens subjected to similar common rotation steps. The method is investigated, and its viability is demonstrated by experimental results.

1. Introduction:

One of the most exciting developments of speckle interferometry has been its ability to compare interferometrically the wave fronts originating from a rough object surface in its two states of deformation.[1,2] The resulting fringe map enables one, to obtain a precise measurement of deformations undergone between the two object states. Comparative speckle interferometry owes its development to a growing need in nondestructive testing: an ability to perform interferometrically the comparison of the mechanical responses of two nominally identical specimens subjected to the same common rotation levels.[3-5]. Like deformation variations over the two surfaces mutually cancel each other. The resulting fringes are related directly to the difference in deformations between the objects. The aim of this paper is to present a new comparative interferomtric method that is a modified version of differential digital speckle interferomtry (DDSPI), where the phase-shifting algorithm [6,7] is applied to ensure the highest accuracy for our measurements. This method is another version of the phase-shifting differential digital speckle interferometer (PSDDSPI),[8,9] which uses two reference beam. In our new comparative method we use only one reference beam. To investigate the feature of the new method, a series of measurements were performed. The presented results show the phase map and correlation fringes of the difference in deformations of two stressed objects.

2. Optical arrangement:

The essential elements of the experimental arrangement (Fig.1) are the (MO) and (TO) objects; one reference beam R (from beam expander BE), two holographic plates H_1, H_2 and CCD camera. The light source is an argon ion laser. The objects are illuminated by a divergent beam. The CCD camera is attached to a frame grabber and has no function during the recording of the master holograms. It is used only at the second step, i.e. during the comparison process. Phase shifts needed for automatic fringe analysis can be introduced by a piezoelectric transducer (PZT). The objects to be compared were two nominally identical bars. Their lower parts are clamped rigidly, and the concentrated load is applied at the upper end. The bars can be rotated along the vertical axes.

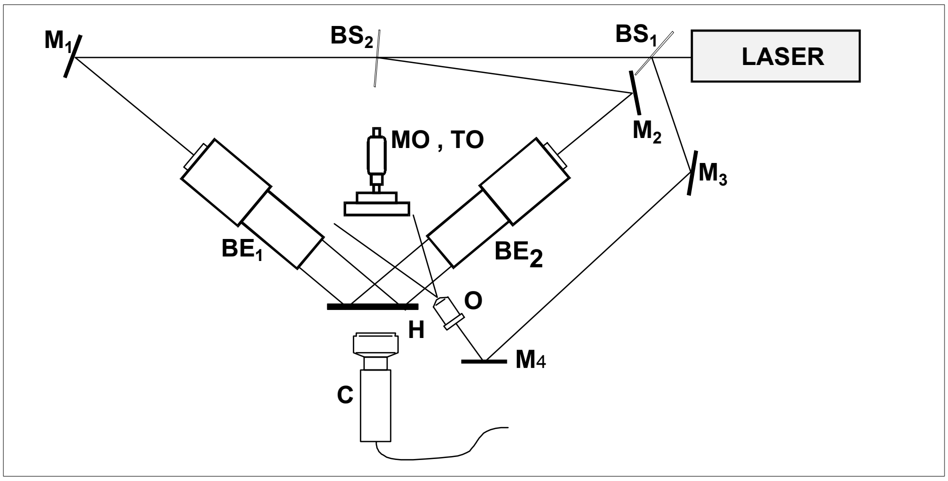

Fig.(1): Optical arrangement for the used setup.

3. Measurement procedure and theory:

The new version of the PSDDSPI method consists of two steps. In the first step, holograms of the master object in unloaded and loaded states are recorded on two different holographic plates. In the second step, four-phase algorithm is applied, and the interferometric speckle patterns of the test object in unloaded and loaded states are recorded by the CCD camera. In this step, the holographically reconstructed master object wave fronts are used as references in the comparison process.

The hologram of the unloaded master object is recorded by the reference beam R on a holographic plate H_1. Then the master object is loaded and the second hologram is recorded on the other holographic plate H_2 by using the same reference beam. Because the holograms of the master object are recorded by the same reference beam on two different holographic plates, the two states of the master object can be reconstructed independently. After development, the holographic plate repositioned using speckle size precision, and in the second step, the master is replaced by the test object. This repositioning does not require interferometric precision. The experimental arrangement used in the second step is the same as that in the first step, with the main difference that now the CCD camera is used. The phase step technique is used only in the second step, for example, by mounting one of the mirrors (the reference beam mirror or the object beam mirror) of the interferometer on a PZT. Accurate calibration is then very important to obtain the desired phase shifts between data frames. In the first measurements the four phase step algorithm was used with a phase shift $\pi/2$ per exposure. First, the wave field scattered by the test object in its initial state and the reconstructed wave field (of the unloaded master object) recorded on the holographic plate H_1 are received by the CCD camera. The resultant wave is stored in the memory of the computer. After loading the test object, the interfering beams are the wave field scattered by the loaded test object and the reconstructed wave field recorded on the holographic plate H_2 (corresponding to the loaded master object).

The interferometric speckle pattern is also stored in the computer memory. Using the two stored speckle patterns the, differential speckle correlograms can be calculated. In the case of the simplest four- frame technique, four phase shifted intensity patterns are produced using the phase-shifting device.

The intensity distribution of the correlograms can be expressed as.

$$I_1 = 4(I_M I_T)^{1/2}\sin(\Delta\varphi + \Delta\varphi'/2)\sin(\Delta\varphi'/2 + \alpha_1) \qquad \text{(1 - a)}$$
$$\text{for} \quad \alpha_1 = 0$$

$$I_2 = 4(I_M I_T)^{1/2}\sin(\Delta\varphi + \Delta\varphi'/2)\sin(\Delta\varphi'/2 + \alpha_2) \qquad \text{(1 - b)}$$
$$\text{for } \alpha_2 = \pi/2$$

$$I_3 = 4(I_M I_T)^{1/2}\sin(\Delta\varphi + \Delta\varphi'/2)\sin(\Delta\varphi'/2 + \alpha_3) \qquad \text{(1 - c)}$$
$$\text{for } \alpha_3 = \pi$$

$$I_4 = 4(I_M I_T)^{1/2}\sin(\Delta\varphi + \Delta\varphi'/2)\sin(\Delta\varphi'/2 + \alpha_4) \qquad \text{(1 - d)}$$
$$\text{for } \alpha_4 = 3\pi/2$$

where I_M is the intensity distribution of the master object I_T is the intensity distribution of the test object, $\Delta\varphi$ is the phase difference between two waves fields before deformation, and $\Delta\varphi'$ is the phase changes introduced by the difference of deformations. The phase difference $\Delta\varphi'$ is obtained from the intensity distributions of Equs. (1a) to (1d) and is given by

$$\Delta\varphi' = \tan^{-1}\frac{I_2 - I_4}{I_1 - I_3}. \qquad (2)$$

The result of measurements made when the two objects (master and test) were subjected to a common rotation changed from 0 to 0.5 degrees. The difference of the rotations due to the difference of the deformation were constantly 0.002 degrees. In the first experiment, differential displacement measurements were done. Intensity and phase maps were recorded simultaneously with increasing the common deformation for the master and test object (Fig. 2 and 3).

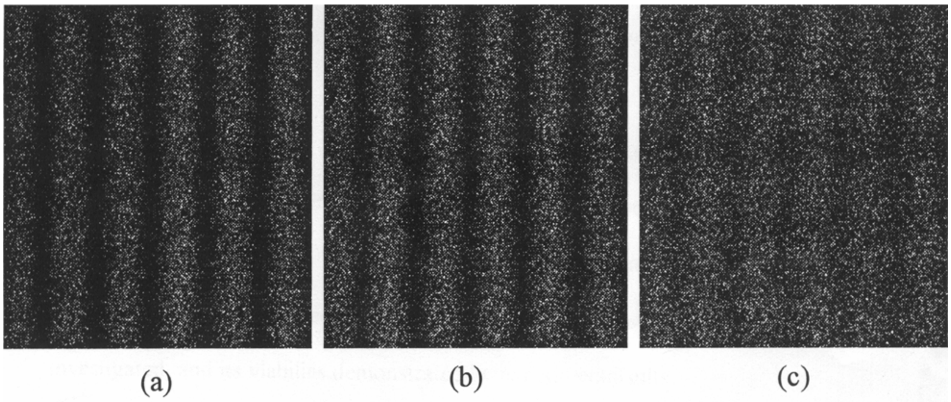

Fig.(2): Correlograms of the differential measurements for the common rotation.

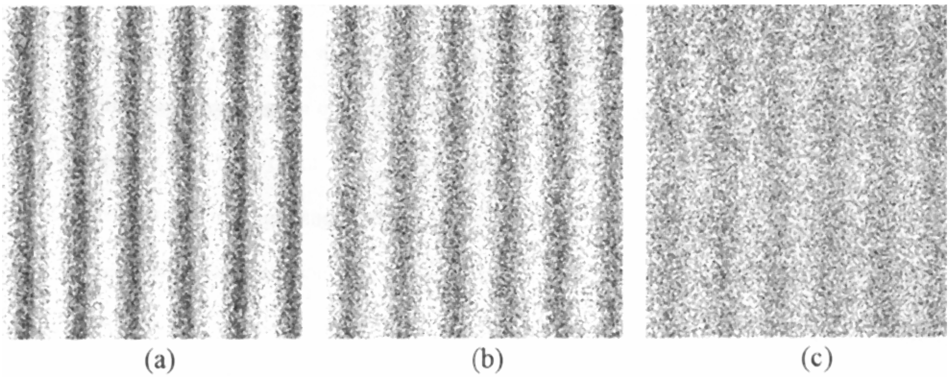

Fig.(2): Phase maps of the differential measurements for the same common rotation as in fig.2.

4. Conclusion:

We have developed an effective digital speckle pattern interferometry. The investigation show that the new version of the PSDDSPI can be considered as a basis for the construction of an effective, easy to use device for comparative measurements, and it can be used successfully even at large deformations. This simple technique may find industrial application as a useful nondestructive testing (NDT) tool.

References

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