Averaging double-exposure speckle interferograms

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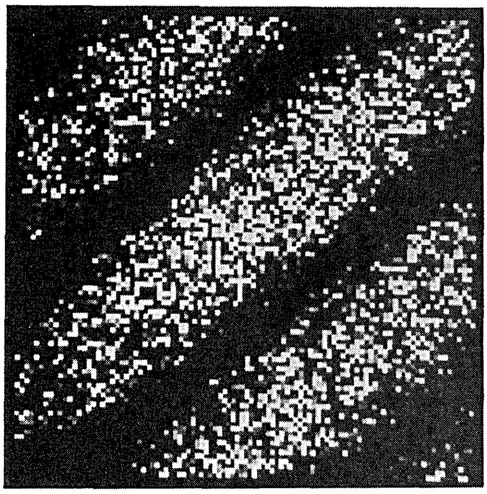
Speckle-fringe quality can be improved by averaging many statistically independent interferograms together, which are generated by shifting the object's illumination angle. A technique applicable to double-exposure speckle interferograms obtained from processing two speckle patterns is described. It utilizes a computer-controlled stepping motor to tilt the object illumination, which is repeatable to λ/100. Results are shown for double-exposure interferograms corresponding to mechanical deformations and vibrations. A significant increase in the fringe visibility is gained.

Speckle interferometry techniques for nondestructive testing have been used for a number of years to study mechanical vibrations and deformations.[1–3] However, the quality of the fringes obtained is not so good as that obtainable using holographic interferometry. This is because speckle fringes are composed of variations in speckle contrast [see Fig. 1(a)]. Speckle fringes show the same functional dependence on object motion as that found in holographic interferometry, but it is difficult to determine fringe centers of speckle fringes and their shapes accurately. Although speckle interferometry has been used to make quantitative measurements,[2] it is a mostly qualitative testing tool. To aid in quantitative measurement, speckle-fringe quality can be improved by averaging many statistically independent sets of speckle fringes.[3]

For speckle interferometry techniques that require a single frame of speckle data (i.e., vibration analysis), averaging fringes together is quite simple.[3] Many sets of statistically independent speckle fringes can be generated by shifting the object illumination between exposures. The averaged patterns will be statistically independent as long as the object illumination is shifted by more than the correlation length of the speckle on the object surface.[4] This corresponds to a lateral movement of one speckle size on the object surface. As more of these frames are added together, the signal-to-noise ratio of the speckle will be increased by the square root of the number of exposures averaged. This is easily done for measurements in electronic speckle-pattern interferometry in which the time-averaged vibration of an object is recorded, high-pass filtered, and then displayed on a television monitor.[2,3]

In double-exposure speckle measurements, two frames of speckle data are processed together to produce the desired fringes. For both of these exposures the object illumination must be from the same direction; otherwise the fringes will be modified by obliquity factors that change orientation and spacing. Averaging can be applied to double-exposure speckle measurements, but it produces a mechanical problem. In order to have equivalent (completely correlated) fringes averaged, the movement of the object illumination has to be repeatable; otherwise fringes that are due to tilt of the object illumination between exposures will wash out the fringes entirely.

The system used to illustrate double-exposure aver-


(a)

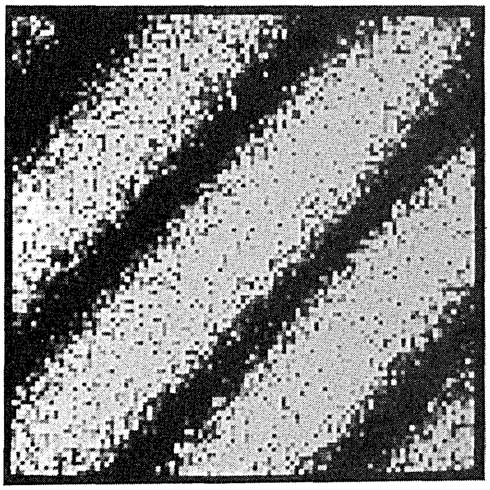

(b)

Fig. 1. Speckle fringes due to the tilt of a flat diffuse object between exposures. All images represent 100 × 100 detector points. (a) Single interferogram. (b) Average of 10 statistically independent interferograms.

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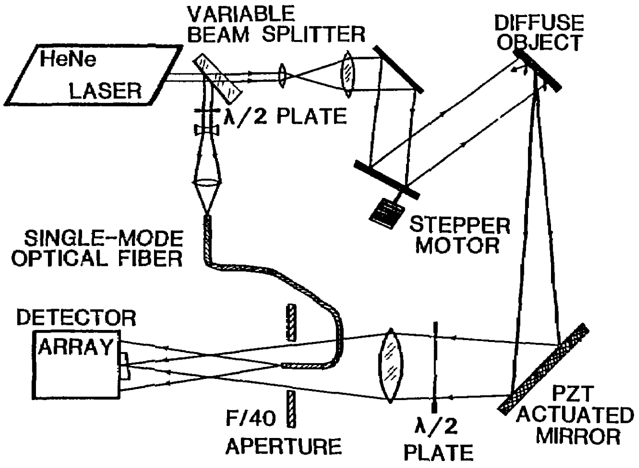
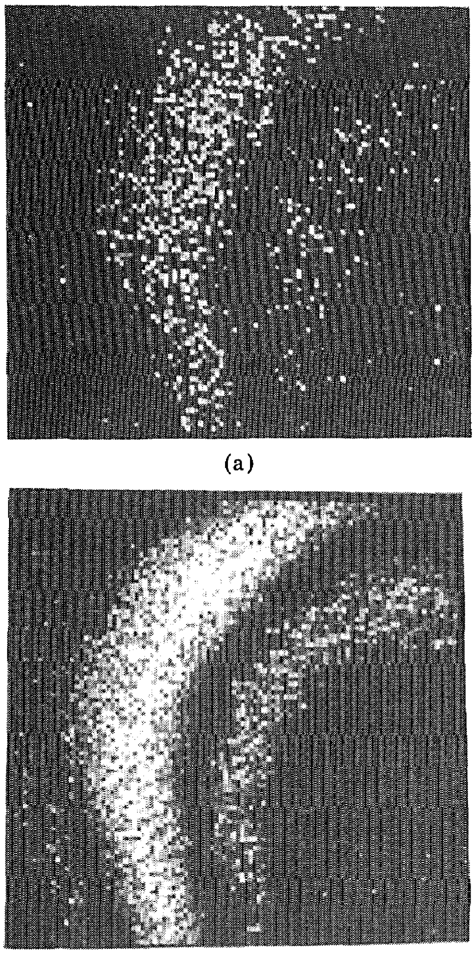


Fig. 2. Interferometric setup. See text for description.

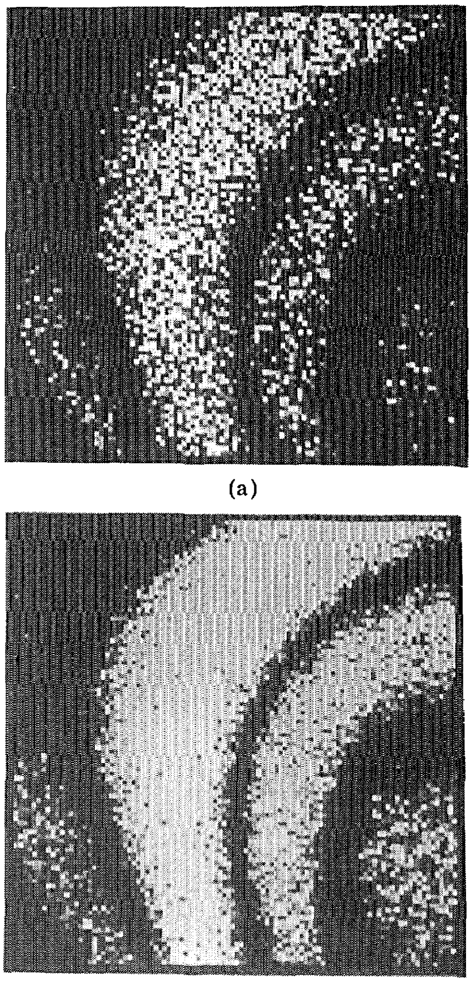

(a)

(b)

Fig. 3. Double-exposure vibration fringes subtracting self-interference terms. Object is a steel plate excited by a PZT. (a) Single interferogram. (b) Average of 10 interferograms.

aging is shown in Fig. 2. It consists of a spherical reference beam produced by a single-mode optical fiber and a collinear object beam consisting of a speckle field. The diffuse object is imaged onto the face of a Reticon 100 × 100 diode array camera, which is interfaced to an HP-9836C desktop computer. The object illumination direction is computer controllable by using a stepping motor. Half-wave plates are present to match polarizations at the detector array. The system is enclosed and mounted on an isolated table to reduce air currents and external vibrations.

The method developed for double-exposure measurements involves recording many frames of the object before deformation with a shift in the object illumination angle between frames. The shift is realized by tilting a mirror using a computer-controlled stepping motor. The amount of illumination tilt is large enough that no correlation fringes are present between the tilted and untilted speckle patterns. Then the object is deformed, the illuminating beam is set back to the starting position, and a second set of frames is recorded again while the object illumination is shifted. The fringes are processed for each pair of data frames before and after deformation. The processed data compose a set of statistically independent realizations of the same fringe pattern that can now be


(a)

(b)

Fig. 4. Double-exposure vibration fringes subtracting two identical frames with a π phase shift between them. Same resonance as Fig. 3. (a) Single interferogram. (b) Average of 10 interferograms.

averaged. As the number of frames averaged increases, the fringe envelope, and hence the fringe contrast, becomes more defined. The fringe contrast for 10 averaged frames in Fig. 1(b) shows a significant improvement. For this technique to work, corresponding pairs of speckle patterns must correlate exactly. The stepping motor repeatably is measured to be $\lambda/100$ when the mirror is tilted and then returned.

Another example of this technique is the application to double-exposure vibration observation. The first double-exposure technique eliminates the self-interference terms by subtracting a reference frame containing these unwanted noise terms rather than by using a high-pass filter as in single-exposure vibration analysis.[5] This permits high-speed digital processing of speckle data without the need for analog electronics. The reference frame is created by vibrating a mirror in the interferometer at a high amplitude when the object is at rest, which destroys the cross interference between the object and reference beams, leaving only self-interference terms. Then data frames of the time-averaged object vibration are subtracted from this reference frame to give the familiar J_0^2 fringes for a sinusoidally vibrating object.[5] This technique produces good-quality fringes, which can be observed in real time while the object vibration frequency is varied. Figure 3 shows the results of averaging this type of speckle fringe. Averaging noticeably enhances higher-order vibration fringes.

The final example shown is another double-exposure vibration observation technique. In this case two frames of the object's time-averaged vibration are subtracted to eliminate the self-interference terms. A π phase shift is introduced in one path of the interferometer between exposures, enabling the cross-interference terms to add.[5] This technique yields high-contrast fringes and is easy to implement on a computer (see Fig. 4); however, the object must be vibrating on resonance since this is not a real-time technique.

In conclusion, a technique for averaging double-exposure speckle interferograms has been described. This technique is easy to implement when some form of digital storage and computation is available. It permits an enhancement of speckle-fringe contrast that is applicable to vibration observation and deformation measurement and is especially useful in digital (or electronic) speckle-pattern interferometry.[2,3,6] The same ideas could be applied to quantitative speckle techniques to yield increased precision for phase measurement of mechanical deformations.

References

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