VIBRATION ANALYSIS WITH YOUNG'S FRINGES MODULATED SPECKLE

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A new method for vibrational analysis is proposed. It is based on the deblurring of time-averaged Young's fringes inside speckle grains in the image of a vibrational object. A spatial filtered image of the recording of those speckles, modulated by Young's fringes, shows the loci of points of equal vibratory amplitude.

1. Introduction

Several methods for vibration analysis employing holographic or speckle techniques have been proposed in the last few years [1–5].

There are many differences between all these techniques. In the case of the holographic methods, the recording of the vibrational diagrams shows a good definition between nodal and ventral lines. However, one of its principal disadvantages is the short range of vibration amplitudes to be recorded. On the other hand, the experimental arrangement of the speckle methods does not need to be as stable as the holographic ones, and, in general, they are applicable to a larger range of vibration amplitudes. But, one of its main shortcomings is that ventral lines are poorly defined.

Recently Chiang and Lin [6] developed a method using moiré that gives the contours of slope, but it can only be applied to objects whose surfaces have a mirror finishing. In this case the contour lines are better defined than those obtained by a similar method employing speckle [7].

Our purpose is to report a new method that retains the advantages of the speckle methods, but whose sensitivity is greater. This new method is based on the Young's fringes modulated speckle (Y.F.M.S.) that appear when the image of a laser illuminated object is formed by an optical system whose pupil consists of two identical holes [8]. If the photographic record of that image is Fourier transformed in a conventional way [9], Young's fringes act as a carrier frequency, and two diffracted orders appear in the Fourier plane symmetrically located to the zero order. Using spatial filtering techniques in order to select only one diffracted order, and this one being again Fourier transformed, an image of the object can be reconstructed.

When the object vibrates, the speckle grains in the regions of the nodal lines will remain at rest with high contrast, while the speckle pattern of the moving areas will blurr out. If the directions of illumination and viewing are assumed to be almost normal to the surface, so that the speckle oscillation has a component perpendicular to the direction of Young's fringes, the time averaged intensity in the photographic plate will produce a blurring in the fringes. Then, the contrast of the fringes in the speckle grains will depend on its vibratory state, and so will do the intensity proportion transmitted to the image in the filtering operation. In this way, steady vibrational states of diffusing objects can be analyzed by this method, where nodal and ventral lines are defined as a variation of the contrast of the Young's fringes in the speckle grains, instead of a variation of the contrast of the speckle pattern itself.

2. Discussion of the method

A laser beam illuminates the diffusing surface S of the vibrating object, as illustrated in fig. 1. A lens L images the surface S in the plane of the recording plate H. The optical axis of the lens makes an angle θ with the normal to the surface S. If a mask M with two identical holes is placed near the lens, Young's fringes appear in the speckles of the image of S. The spacing and orientation of the fringes are given by the separation between the holes and their orientation, for a given magnification of the optical system. Because the viewing is not normal to the surface S but makes an angle θ with it, the speckle oscillation will have a component in the (x, y) plane. If the speckle movement is sinusoidal, the intensity of Young's fringes in the speckle grains of the image can be described as:

$$I(t) = I_0 \cos^2[px + pA_x \cos(\omega t) + \phi] \ ,$$

where p is the spatial frequency of the fringes in the x-direction, A_x is the amplitude of the speckle vibration in the x-direction, ω is its angular frequency, and I_0 and ϕ are constants.

Then, the local exposure of the speckle grain in the photographic plate will be:

$$E = \int_0^T I(t)\,\mathrm{d}t = \tfrac{1}{2} I_0 T + \tfrac{1}{2} I_0 \int_0^T \cos[2px + 2pA_x \cos(\omega t) + 2\phi]\,\mathrm{d}t \ , \qquad (1)$$

where T is the exposure time.

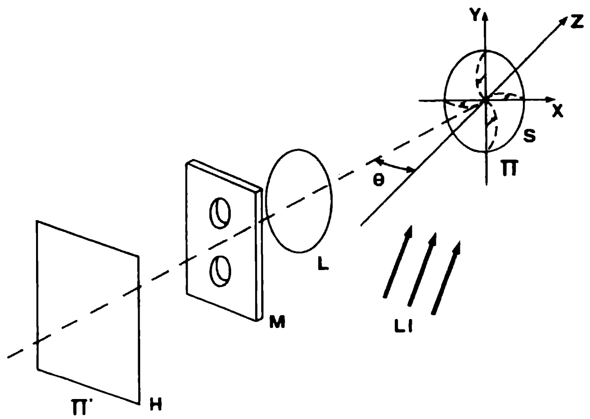

Fig. 1.

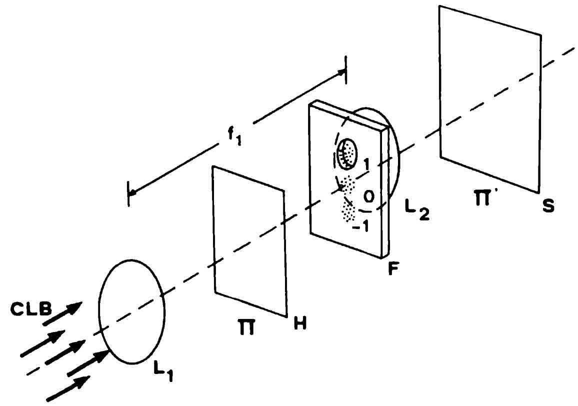

Fig. 2.

Rewriting (1) in the form

$$E = \tfrac{1}{2} I_0 T + \tfrac{1}{2} I_0 \,\mathrm{Re}\left\{ \int_0^{2\pi n/\omega} \mathrm{d}t \times \exp\{-\mathrm{i}[2px + 2pA_x \cos(\omega t) + 2\phi]\} \right\} ,$$

where Re{ } indicates the real part of the integral, the following expression for the local exposure is obtained:

$$E = \tfrac{1}{2} I_0 T [1 + J_0(2A_x p) \cos(2px + 2\phi)] \ ;$$

that is, Young's fringes of the speckles of the image are themselves modulated by the zero order Bessel's function of the first kind.

If the recording is done in the linear region of the t-E curve of the photographic plate, the transmittance of the developed plate will be:

$$t = t_0 - \beta E.$$

Then, if the transmittance t is Fourier transformed as indicated in fig. 2, the intensity in the filtered image will be:

$$I = C|J_0(2A_x p)|^2 \ ,$$

where C is a constant which involves β, I_0, and T.

This result means that nodal lines will be depicted as very bright zones, and information of the amplitude of vibration can be extracted from the location of the J_0^2 maxima and minima.

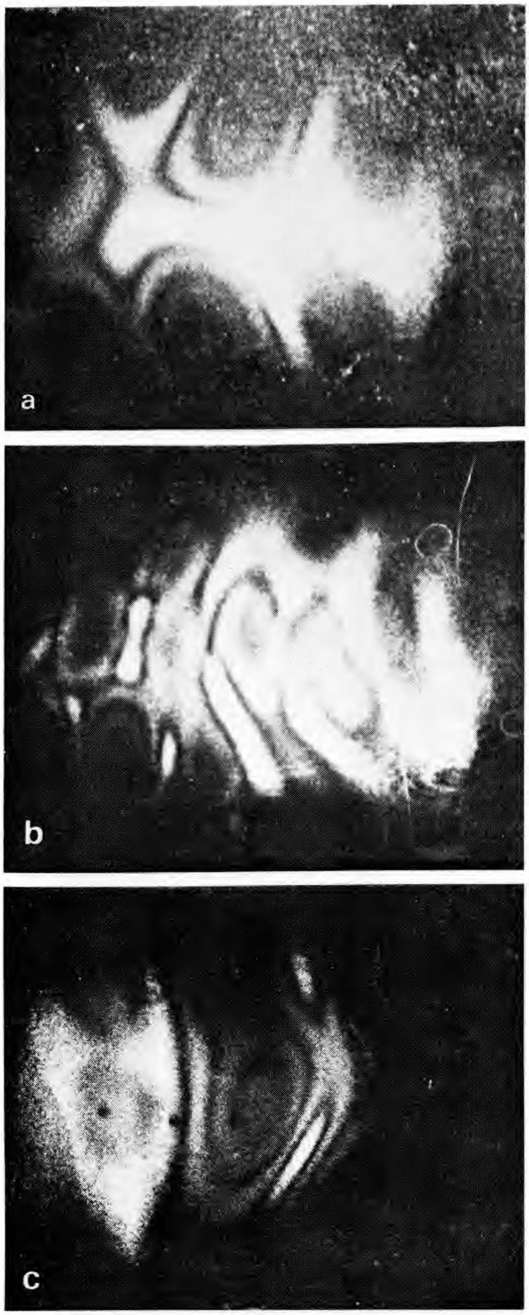

Fig. 3.

3. Results and conclusions

For our work we employed an argon ion laser, 200 mW, $\lambda = 514$ nm. Apertures in the mask were 25 mm apart, and the value of the angle θ was 20°. The vibrating surface S consisted of a sanded mylar sheet and the recording material was a Kodak 649F film. Fig. 3 shows positive reproduction of the vibrating membrane at three different states.

Some information on the amplitude of vibration can be extracted from these results.

Taking into account that the amplitude of vibration A is related with its components A_x by relation $A_x = A$ sen θ, and analyzing the nulls of $J_0^2(2A_x p)$, we arrived to values of A of 10 μm.

No special mechanical stability requirements were needed.

The method we present here seems to have some advantages with respect to other speckle methods. One of its principal shortcomings, that is, the spatial filtering step, is practically immaterial if the spatial frequency of the Young's fringes is high. In this case, the two diffracted orders are far away, allowing their visualization without using a filter. Images of high quality could also be observed with polychromatic partially coherent light, and up to three secondary maxima were obtained. For those reasons the method seems to be intermediate between time averaged holography and other speckle methods.

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