BRITISH ACOUSTICAL SOCIETY.

Meeting on Thursday 22nd March, 1973 at National Physical Laboratory, Teddington, Middx.

"COHERENT LIGHT METHODS FOR THE STUDY OF MECHANICAL VIBRATIONS".

Paper No: 73/14

Vibration Mode Visualization using Holography.

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1. Introduction

Vibrations in aero engine compressor and turbine blades and discs are usually analysed by using either sand patterns or a piezo-electric contact probe. These methods are not always accurate or possible with complex shapes and are slow; for example, a traced sand pattern takes 30 minutes and a probe pattern an hour. These disadvantages can be overcome by holographic techniques which in addition provides vibrational amplitude information.

2. Application of Time Averaged Holography

The time averaged holographic process has been found the most appropriate technique for use as a general vibration visualization system in this engineering environment, ref. 1, and has been applied to a number of aero engine components. The principal advantage of holography over conventional methods is speed and the ability to present the information in a concise pictorial form. The amplitude information provides strain concentration measurements and locations for strain gauges for dynamic tests. The system is most effective for observing the vibrational modes of complex assemblies such as a turbine disc and blades where the interaction between the disc vibration and the blades can be seen. Heavy rigid components, which are difficult to excite with sufficient amplitude to enable the use of standard techniques, can be analysed by holography as only a few micro inches amplitude is required,for example a rigid turbine stub shaft.

A holographic unit has been developed for vibration analysis of components and now a number of these are in use on a routine basis. The unit is completely self-contained and can be blacked out for use in a normal laboratory environment. It is a box-like structure with the laser on the top plate and the object placed flat on the base plate. The main optical arrangement is permanently set and minimal adjustment is required to accommodate objects from 1 to 24 inches diameter.

3. Large Amplitude Vibration Visualization

In many industrial applications vibrational amplitudes of 0.2 mm and above are required to induce realistically high stress levels into the component to simulate what occurs during normal service, whereas time averaged holography is limited to approximately 50 microns. To increase the amplitude range of time averaged holography a reference beam phase modulation technique has been developed, ref. 2. This enables contours of equal vibrational amplitude to be generated on the image of the object at intervals of 5 to 50 microns, the contour intervals being a function of the degree of phase modulation.

3.1 Phase Modulation

The phase modulation technique uses the standard optical arrangement for time averaged holography with the addition of a small mirror in the reference beam that can be vibrated at the same frequency and phase as the object. During the hologram exposure the reference beam mirror is vibrated at the same frequency, phase and amplitude as one particular part of the object, to keep the optical path length of the reference beam the same as that of the object beam from that point. Hence the light scattered from this point on the object, as viewed at the hologram, will always be in phase with the reference beam. So as far as the hologram is concerned this point on the object will appear stationary, resulting in a bright fringe on the image.

The resultant intensity distribution of the point (x_1,y_1) on the reconstructed image will be of the form

$$I(x_1,y_1) = J_o^2\left[\frac{2\pi}{\lambda}\left(k\ a(x_o,y_o) - k'b\right)\right]\ S_o^2\,A_o^2$$

where S_o, and A_o are the light amplitudes from the object's surface and reference beam respectively, $a(x_o,y_o)$ is the maximum vibrational amplitude of the point (x_o,y_o) on the object, k is a constant dependent upon the cosines of the object's illuminating and observing angles, b is maximum amplitude of the reference beam phase modulating mirror, k' is the incident and reflected light angle constant and λ is the wavelength of light used.

The phase modulation term k'b effectively subtracts an amplitude proportional to b from the object vibration level to form the centre of the Bessel function at the point where $ka(x_o,y_o)=k'b$. This produces the bright fringe at that point, enhancing this and its surrounding fringes.

If a number of holograms are recorded on the same photographic plate ("multiplexing") in each of which the mirror amplitude has a value nb, where n is an integer increasing from 0 to m, a series of enhanced fringes will be produced on the reconstructed image. The number of steps will depend on the total amplitude of the component's vibration and the amplitude interval set for each enhanced contour. For large amplitudes and intervals between the bright contours the fringes between the enhanced regions will not be discernable, thus reducing the information to a series of known amplitude contours to ease the analysis.

3.2 Experimental Results

The experimental results show that it is possible to obtain good fringe enhancement even when using relatively unsophisticated phase modulation equipment such as a small mirror mounted on an electromagnetic vibrator. This system was limited to the enhancement of the 50th fringe by mechanical instability of the reference beam mirror. A microdensitometer trace of the resultant images showed that the enhanced fringes had an intensity of 50% of that of the nodal regions.

4. Conclusions

Holography has been found to be a valuable measuring tool for vibration analysis in an industrial environment. The increased amplitude range produced by reference beam phase modulation enables measurements to be made with applied stresses nearer to normal operating conditions.

5. References

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