

Modal Testing Of A Turbopump Liner Using Time-Average Panoramic Holo-Interferometry

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Abstract

This paper describes the first practical application of a relatively new approach to modal analysis in which time-average holograms are recorded through a panoramic system. When inserted into a cylindrical structure, the system allows a relatively large portion of the surroundings to be illuminated and observed. The approach is applied to study the modal response of a turbopump liner designed for use in the Space Shuttle Main Engine.

Introduction

The time-average holographic recording technique, developed by Stetson and Powell [1], can be used to reveal contours of constant amplitude on the surface of a vibrating object. In this technique, a holo-interferogram is produced by generating a hologram and exposing the recording medium for a period of time during which the test object executes many cycles of steady vibration. In this case, the intensity of the reconstructed image is

$$I \propto J_0^2 \left[\frac{2\pi}{\lambda} (\mathbf{g} \cdot \mathbf{d}) \right] \quad (1)$$

where λ is the wavelength of the coherent light used to record and reconstruct the hologram, \mathbf{d} is the displacement vector of the surface point under consideration, and J_0 is the zero order Bessel function. The sensitivity vector \mathbf{g} is defined by $(\hat{\mathbf{e}}_2 - \hat{\mathbf{e}}_1)$ where $\hat{\mathbf{e}}_1$ and $\hat{\mathbf{e}}_2$ are unit vectors in the directions of illumination and observation, respectively.

Most attempts to record holograms over extended areas in confined spaces have met with limited success, mainly because current holographic systems provide only spot views within the region of interest. This problem can be eased somewhat by employing time-average panoramic holo-interferometry [2].

Time-Average Panoramic Holo-Interferometry

Time average panoramic holo-interferometry relies on the standard time-average holographic method but utilizes two Panoramic Annular Lenses (PALs); one to illuminate and the other to view the inner wall of a cavity.

As shown in Fig. 1, the PAL is a single element imaging block comprised of three spherical optical surfaces, and one flat optical surface. Two of the spherical surfaces are mirrored while the third spherical surface and the flat surface are not. Rays are refracted when they contact the first spherical surface, and they are reflected off the rear mirrored spherical surface. They travel forward in the lens and strike the front mirrored spherical surface. Reflected back, the rays are refracted at the rear flat optical surface and diverge as they exit the lens. The divergent rays leaving the flat optical surface at the back of the PAL can be "back traced" to form a virtual image. The virtual image is captured by a transfer lens to form a flat annular image. Thus, the continuous field of view surrounding the PAL is mapped via a constant aspect ratio polar mapping [3]. The resolution of the PAL varies from the forward viewing edge to the back viewing edge with an average angular resolution of 6 millirads. Even though the PAL is not strictly afocal, objects appear to be in focus from the lens surface to infinity.

The Cartesian (x',y') and polar (r',θ') coordinate systems used to define the annular image are shown superimposed on Fig 1. Figure 2, on the other hand, defines the Cartesian (x,y,z) and cylindrical (r,θ,z) coordinate systems used to describe object space.

Referring to Fig. 2, it is assumed that two opposing collinear PALs are aligned with their optical axes along the z-direction. Coherent light is projected by one PAL from the source point S to a point P located on the wall of a cavity, depicted in the figure as a ring. The image of P is observed by the second PAL at point O. For analysis purposes, unit vectors $\hat{\mathbf{e}}_1$ and $\hat{\mathbf{e}}_2$ are shown in the direction of illumination and in the direction of observation, respectively. The sensitivity vector, \mathbf{g} , described in Eq. (1), lies along the angle bisector of $\hat{\mathbf{e}}_1$ and $\hat{\mathbf{e}}_2$. Figure 3 shows a typical experimental setup for recording panoramic holo-interferograms.

In the center of the illuminated band, \mathbf{g} is perpendicular to the optical axis of the system and only radial displacements are measured. Toward the edges of the band, however, \mathbf{g} becomes inclined. Assuming that the displacement is purely radial, an error is introduced which depends on the spacing between the lenses and the width of the band. For a more complex situation, the displacement component parallel to the optical axis influences the holographic fringe pattern in areas where the sensitivity vector is inclined; whereas, the

circumferential displacement component does not effect the fringe pattern.

Experimental

The method of time-average panoramic holo-interferometry was used to study the modal response of a turbopump liner designed for use in the Space Shuttle Main Engine. The inlet liner was supported by four foam blocks and 27 elastic cords providing a free-free boundary condition. An accelerometer was radially oriented and bonded to the outer surface of the test article. A signal analyzer was used to run a series of acoustically driven 200 Hz band width sine sweep measurements that roughly identified mode frequencies. High resolution 20 Hz zoom band measurements were then acquired to discretely resolve the mode frequencies.

The experimental setup shown in Fig. 3 was used to acquire the mode shape information for each mode identified during the sine sweep tests. Figure 4 shows a typical modal response recorded at 959.1 Hz. The fringes are related to the peak-to-peak radial displacement of the inner surface of the inlet liner. The magnitude of the displacement can be discretely calculated by applying Eq. (1).

References

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3. Lehner, D.L., Richter, A.G., Matthys, D.R., Gilbert, J.A., "Characterization of the panoramic annular lens," to be published in *Experimental Mechanics*.

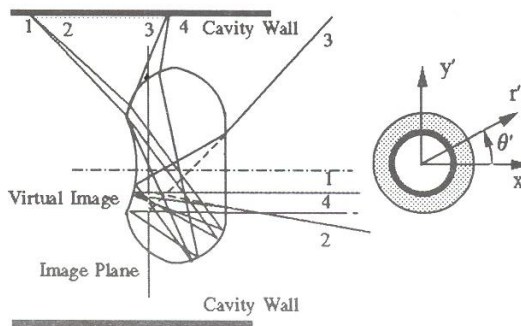


Figure 1. Ray diagram and coordinate systems for the image plane.

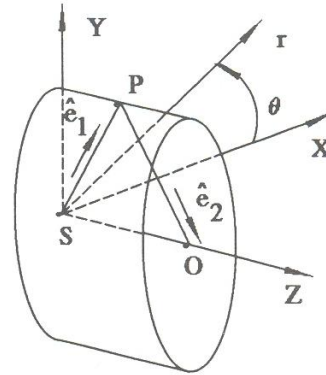


Figure 2. Cartesian and cylindrical systems used to describe object space.

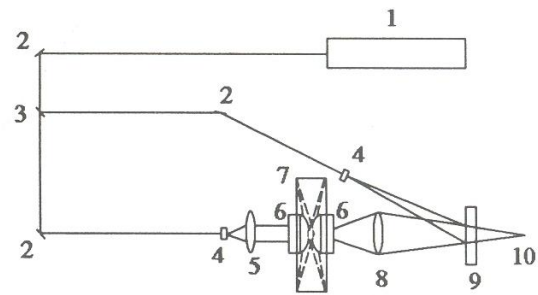


Figure 3. Experimental setup; 1. laser, 2. mirror, 3. beam splitter, 4. spatial filter, 5. collimating lens, 6. PAL, 7. inlet liner, 8. transfer lens, 9. thermoplastic plate, 10. image plane on CCD camera.

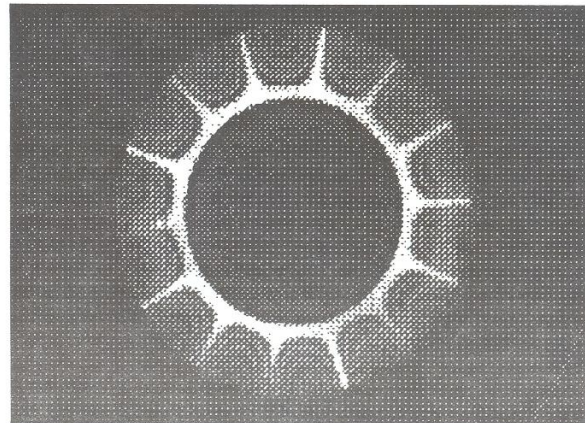


Figure 4. A time-average panoramic holo-interferogram recorded at 959.1 Hz on the inside wall of an inlet liner designed for use in the Space Shuttle Main Engine.