ELECTRONIC HOLOGRAPHY AND SHEAROGRAPHY NDE FOR INSPECTION OF MODERN MATERIALS AND STRUCTURES

J. F. Clarady and M. Summers
Pratt & Whitney
P. O. Box 109600 M/S 707-21
West Palm Beach, FL 33410-9600
(407) 796-6505

INTRODUCTION

Coherent optical techniques such as holography, shearography, and ESPI have been available for inspection applications for years. However, they are still not well known or widely used. In fact, they have sometimes been described as "a solution looking for a problem" and like so many new technologies, they may have been somewhat oversold. These optical NDE methods do, however, offer some impressive advantages over more conventional inspection techniques for the right applications. It is the intent of this paper to provide some basic information on how two of these optical methods, holography and shearography, work discuss capabilities and limitations of both, present the electronic holography and shearography inspection system developed by UTRC/Pratt & Whitney, and provide some examples of successful applications of both.

HOLOGRAPHY AND SHEAROGRAPHY NDE

Holography and shearography NDE are similar in that: 1. both are interferometric techniques that require a coherent light source to illuminate the area to be inspected, 2. both require an external excitation method (such as mechanical or acoustic vibration, pressure, partial vacuum, or thermal) to stress the structure being inspected, and 3. both are capable of inspecting a large area at a rate usually much quicker than more conventional methods. There are, however, distinct differences that result in each having advantages and limitations. Holographic images are formed from the interference of two light wave fronts, one returning from the surface of the structure being tested and a separate reference wave of constant phase. Since holography requires these two separate wave fronts, it is susceptible to environmental disturbances and usually requires the optical system to be mounted on a vibration isolation table. Shearography, on the other hand, forms its images with only the light returning from the surface making shearography less sensitive to environmental noise. As shown in Figure 1, holographic fringes are proportional to the actual displacement of the surface due to the external load applied to the structure whereas shearographic fringes are related to the slope changes of the surface. Holography, therefore, is inherently more sensitive, making it more likely that this method will detect and accurately define the actual size and shape of small flaws. However, for many applications, the required minimum detectable flaw size is large enough that shearography can clearly be used. Finally, shearography is less sensitive to rigid body type motions of the test structure that can sometimes make the flaws difficult to discern with holography.

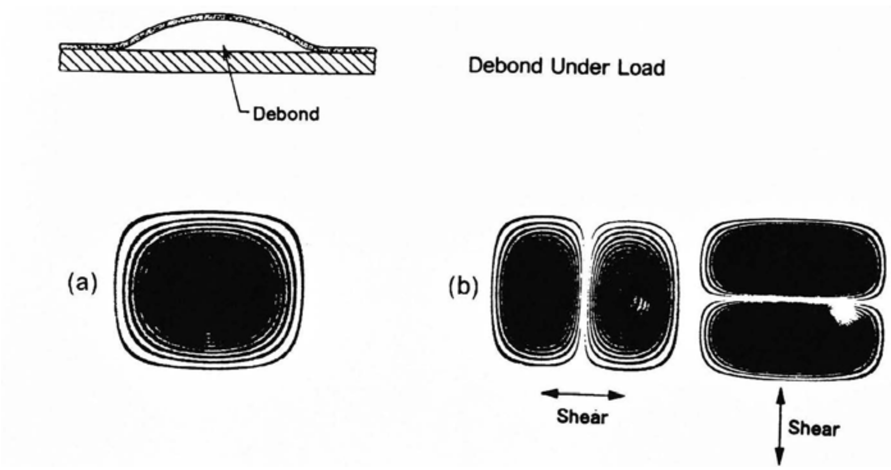


Fig. 1. A debond under static loading would appear as image (a) using holography, where fringe lines are proportional to surface displacement, and image (b) using shearography, where fringe lines are proportional to surface slope.

ELECTRONIC HOLOGRAPHY AND SHEAROGRAPHY INSPECTION SYSTEMS

To permit holography and shearography NDE to be implemented into non-laboratory facilities such as manufacturing plants, overhaul and repair depots, and even field applications, UTRC/Pratt & Whitney has developed an electronic imaging system, shown schematically in Figure 2, capable of performing both NDE methods using a common image processing unit, computer, and software. Images formed by either the holography or shearography interferometer contained within the optical head are viewed by a CCD video camera and fed to the pipe-line image processor. The system can process either time average

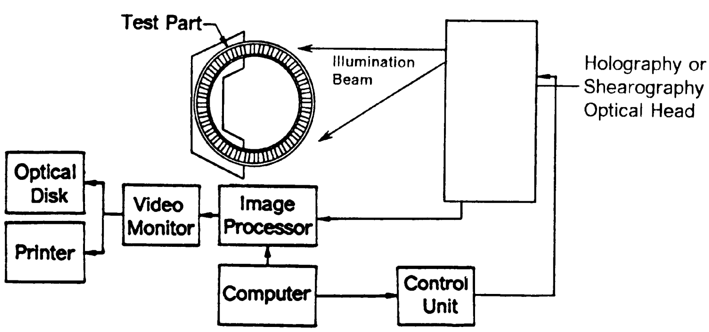


Fig. 2. Schematic diagram of the Pratt & Whitney Electronic Holography/Shearography system. A common imaging system is capable of performing both holography and shearography using the interchangeable optical heads.

holographic or shearographic images required for vibration (mechanical or acoustic) excitation or double exposure images required for steady state loads (pressure, partial vacuum, or thermal).

In the time average mode of operation, the output image viewed on the monitor is derived from four successive video frames A, B, C, and D between which the reference beam in holography or one of the sheared images in shearography is phase stepped by 90°. The processor performs the function:

$$\sqrt{(A-C)^2+(B-D)^2} \quad (1)$$

at every point in the image. The result is a high quality real-time image of the structure with the flaw indications superimposed in red. In the double exposure mode, a set of four phase stepped video frames A, B, C, and D are stored prior to the structure being loaded and a second set A, B, C, and D is saved after the load is applied. The processor then performs the function:

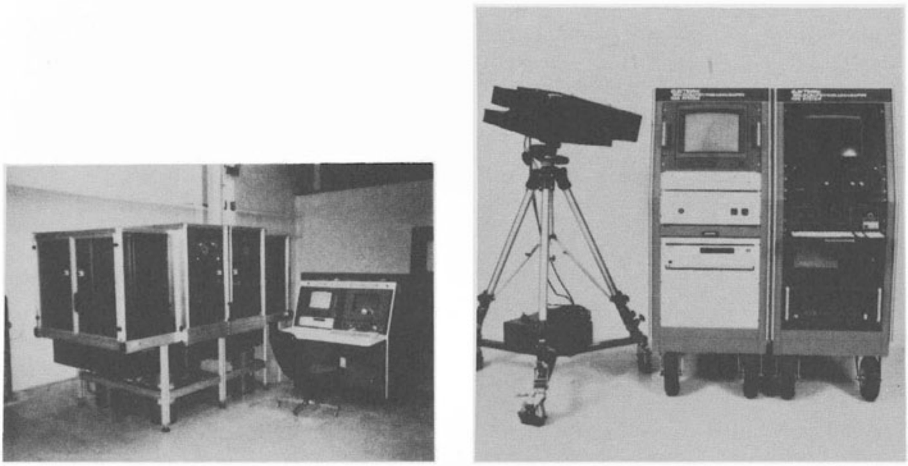
$$\sqrt{\{(A-C)+(A-C)\}^2+\{(B-D)+(B-D)\}^2} \quad (2)$$

at every point in the image. Here again, the resultant image viewed on the monitor is of the surface of structure with the flaws superimposed and highlighted in color. The system can also adjust the amount of phase shift in real-time that results in a fringe scanning across the image viewed on the monitor and causes the flaw indications to "wink". This enhances the visualization of small flaws or ones that could be masked by gross surface movements or rotations.

The flaws may be identified by the operator and their size measured using on-screen calipers or, if desired, the system can automatically identify the flaws, measure them, compare them to a preprogrammed accept/reject criteria, flag any rejectable sized flaws, and provide this information to the operator. A hard copy of the inspection results may be made with a video printer and stored on the computer's hard disk or a mass storage unit such as an optical disk. The operation of the entire system is controlled by a micro-computer that can also control part positioning devices to provide a highly automated system. Such an automated Electronic Holography Inspection System (EHIS), shown in Figure 3a, has been successfully integrated into the Air Force's San Antonio Air Logistics Center. A less automated system, shown in Figure 3b, that is capable of performing both holography and shearography NDE has been installed at NASA's Marshall Space Flight Center in Huntsville, Alabama. This system has two separate optical heads with integral lasers, one for holography and one for shearography, and common image processor computer and software. The system is also completely portable to perform testing at remote locations.

APPLICATIONS

The typical applications for holography and shearography NDE have been to inspect the bond integrity of bonded, composite, or coated structures. Brazed or diffusion bonds, for example, can be inspected for unbonded areas as illustrated in Figure 4. The inspection results shown are of a brazed honeycomb duct with unbonds (highlighted in red) between the honeycomb core and the internal and external face sheets. Composites such as graphite polyimides, carbon-carbon, and metal matrix composites have been inspected to identify internal delaminations. The inspection results of a composite stator vane are shown in Figure 5 with the delaminations highlighted. The stressing method for both of these applications was random frequency vibration excitation which permits the detection of all flaw sizes simultaneously. An example of coating inspected with shearography NDE is shown in Figure 6. This example is of an intentionally created unbond between a Space Shuttle solid rocket booster nose cone and the thermal protection coating that is sprayed onto portions of the boosters. The stressing method used here was a partial vacuum of only 0.5 psi but similar results were also achieved using thermal stressing.



(a) (b)

Fig. 3. (3a) Fully automated Electronic Holography System installed at the USAF San Antonio Air Logistics Center. (3b) Electronic Holography/Shearography system for application development at NASA-Marshall Space and Flight Center.

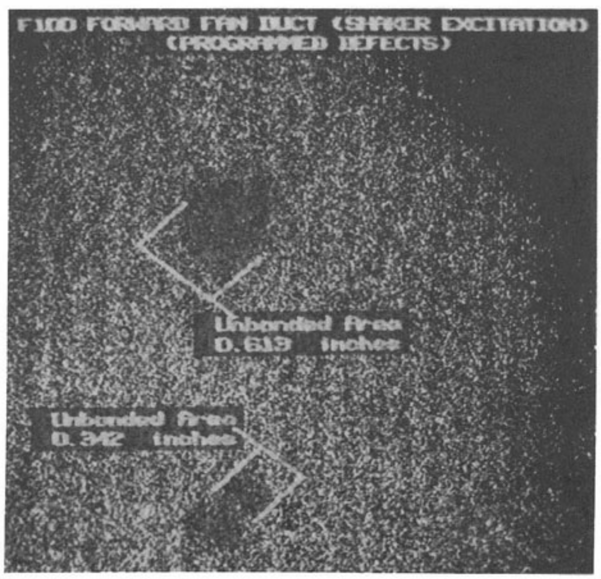


Fig. 4. Electronic Shearography NDE results showing programmed unbonds between the outer facesheet and core of a titanium honeycomb duct. Random vibration was used to stress the duct.

Fig. 5. Electronic Holography NDE results showing delaminations in a graphite/polyimide composite stator. The stator was stressed using random vibration.

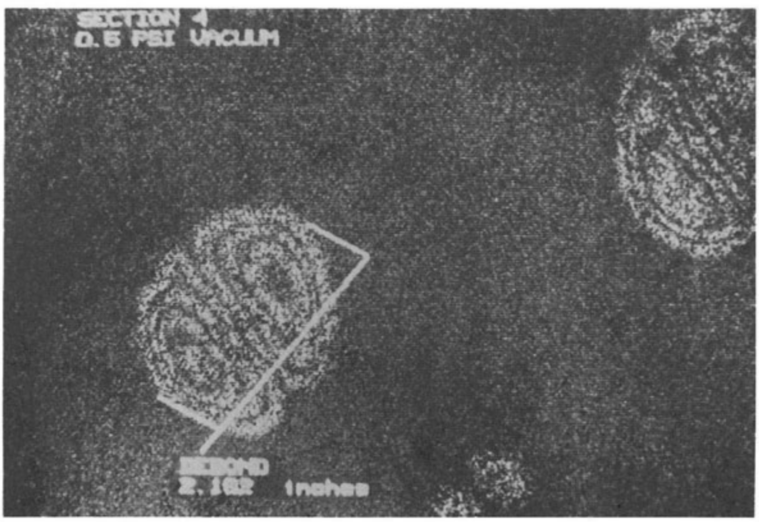


Fig. 6. Electronic Shearography NDE results showing a programmed unbond between the thermal protection coating and aluminum sub-structure of a Space Shuttle Solid Rocket Booster Nose Cap. Pressure reduction loading of 0.5 psi was used to stress the coating.

For the type of applications shown, optical NDE methods not only offer the capability of inspecting large areas very rapidly, but they can also detect "touching" or "kissing" unbonds and delaminations not easily detected by other methods. These methods may also be utilized for other applications in which the flaw significantly weakens the structure. An example of this would be detecting significant internal corrosion on aluminum aircraft structures.

SUMMARY

For the appropriate applications, optical NDE methods such as holography and shearography can be powerful inspection tools. They offer a large field of view, are fast and cost effective, and can inspect certain structures and detect certain types of flaws that would prove difficult, if not impossible, for other NDE methods. They can provide either manual or automated, fixed or portable operation in almost any type of facility.

REFERENCES

1. J. F. Clarady, "Electronic Holographic NDE," Review of Progress in Quantitative Nondestructive Evaluation, 1031-1038, Plenum Press, New York, 1990.
2. T. Bushman, "Development of a Holographic Computing System," Laser Interferometry: Quantitative Analysis of Interferograms, SPIE Vol. 1162, 1989.
3. J. F. Clarady, "Holographic NDT of Composite, Laminated, and Bonded Structures," Technical Digest from VI International Congress on Experimental Mechanics, June 1988, Portland, OR.
4. K. A. Stetson and W. R. Brohinsky, "Electro-optic Holography System for Vibration Analysis and Nondestructive Testing," Optical Eng. 26, 1234-1239 (1987).
5. K. A. Stetson and W. R. Brohinsky, "Electro-optic Holography and Its Application to Hologram Interferometry," Appl. Opt. 24, 3631-3637 (1985).