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James W. Wagner and Robert E. Green, Jr.

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The objective of this research has been to apply optical holographic techniques coupled with electronic signal and image processing to provide quantitative, full field measurements of acoustic wave disturbances. This program has sought to establish the limits of sensitivity with which surface acoustic waves might be measured and mapped. In addition, heterodyne holographic measurements are being developed to tomographically display acoustic energy flow in optically transparent bulk materials.

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Contract N00014-82-K-0741-P0004
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**FULL FIELD VISUALIZATION OF SURFACE AND BULK ACOUSTIC WAVES
USING HETERODYNE HOLOGRAPHIC INTERFEROMETRY**

James W. Wagner (Principal Investigator)
Robert E. Green, Jr. (Co- Investigator)

The Johns Hopkins University
34th and Charles Streets
Baltimore, Maryland
21218

ABSTRACT

The objective of this research has been to apply optical holographic techniques coupled with electronic signal and image processing to provide quantitative, full field measurements of acoustic wave disturbances. Building on work performed previously at Johns Hopkins and in its second year under the current contract to the Office of Naval Research, this program has sought to establish the limits of sensitivity with which surface acoustic waves might be measured and mapped. Toward this end, the effects film resolution on overall sensitivity have been examined. Also, significant efforts have taken place to extend heterodyne holographic measurements to the examination of acoustic energy flow in optically transparent bulk materials.



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Effects of Film Performance on Heterodyne Holographic Sensitivity

In prior work, heterodyne holographic displacement sensitivities of $1/900$ of an interferometric fringe (or about 3.5 Angstroms sensitivity) had been demonstrated. An effort to establish the degree to which holographic film performance limits displacement sensitivities was completed during the first part of this program year. In short, it was found that, while film performance has a direct effect on sensitivity limits, it is not a limiting factor in determining interferometric sensitivity in most cases.

It is the statistical uncertainty in the measurement of the phase of a heterodyned optical signal which determines the accuracy and sensitivity of heterodyne holographic interferometry. Temporally, the limiting source of uncertainty is detector quantum noise, or "shot" noise. Sensitivity predictions based on shot noise limits alone are several orders of magnitude better than actually observed experimentally. Therefore, it is not temporal sources but rather spatial noise that limits system sensitivity. This spatial uncertainty is directly related to coherent speckle in the output image of the holographic interferometer. In fact estimates for phase uncertainty at any image pixel can be determined from the number of speckles encompassed by the pixel element. The greater the number of speckles per pixel, the greater the certainty of the heterodyne phase measurement. Therefore in order to improve system measurement sensitivity, one may increase the area of the



individual detectors in the image field (and suffer the corresponding loss in spatial resolution) or one may increase the spatial bandwidth (decrease the f/number) of the holographic imaging system producing a corresponding reduction in speckle size.

Currently available holographic films have resolution limits of greater than 2500 lines per millimeter and are readily available in 4" x 5" format. Owing to their high resolution, a well designed holographic camera can be used to record image detail with spatial frequencies of 1000 lines per millimeter or more. In addition, the large clear aperture of the 4" x 5" film format permits the construction of holographic systems with large numerical aperture and correspondingly small f/number . Indeed as a result of this study it was found that it is not the film but rather the more conventional imaging optics used in the holographic system which restrict the system spatial bandwidth, determine the speckle size, and thereby establish the sensitivity of the heterodyne holographic interferometry system.

Holographic Optical Tomography

Significant progress has been made toward the application of heterodyne holographic techniques to the examination of acoustic flow in transparent materials. An optical tomographic scheme is being developed analogous to computed tomography used for radiographic analysis in medical practice. One primary difference, however, is the

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fact that optical phase retardation rather than X-ray absorption is detected as a function of angle and position and used for tomographic image construction. In order to facilitate the collection of data for tomographic construction, multiple beams of collimated light are passed through a single sample volume and redirected to a holographic film plate. To capture the effect of transient acoustic wave propagation through the bulk of the material, a pulsed holographic exposure is made. Upon reconstruction of the recorded hologram, light from each angular pass through the test volume is interfered with the reconstructed image of that same beam. An interference pattern is observed containing information about local phase retardation resulting from variations in acoustic pressure levels in the test material. A detector array may then be swung through each of the reconstructed image angles decoding the phase information using heterodyne interferometric techniques. The data is then digitized and sent to a host computer which applies computed tomography algorithms which construct cross-sectional images of refractive index variation associated with acoustic energy flow.

To date, a holographic recording and readout system has been constructed to collect spatially varying refractive index data on transparent specimens with up to about 1" cross-sectional diameter. A holographic optical element has been developed to produce 5 angularly separated collimated

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laser beams which overlap within the sample volume. High speed pulsed holographic recordings have not yet been made. However, low speed recordings using a continuous wave Argon laser have been made of heat flow in a plexiglas cylinder. Five views have been recorded simultaneously on a single hologram and data collected using a 256-element linear diode array. Image reconstruction was performed by interpolation of data between the 5 collected angles. While considerable artifact is observed when simple back projection algorithms are employed, the reconstructed tomographic image nevertheless results in a mapping of refractive index variation which is consistent with what one would expect based on the temperature distribution within the test sample. These results have been most encouraging and are being used to refine the system for high speed recordings to be made presently.

June 1988

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USING HETERODYNE HOLOGRAPHIC INTERFEROMETRY

NAME(S) OF PRINCIPAL INVESTIGATOR(S) James W. Wagner and Robert E. Green, Jr.

NAME OF ORGANIZATION: The Johns Hopkins University

ADDRESS OF ORGANIZATION: 34th and Charles Streets, Baltimore, Maryland 21218

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PAPERS SUBMITTED TO REFEREED JOURNALS
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Ehrlich MJ, Phillips LC, Wagner JW, Voltage controlled
acoustic optic phase shifter, Submitted to Review
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Wagner JW, Spicer JB, Theoretical noise-limited sensitivity of classical interferometry, J Optical Society of America B 4(8), 1316-1326 (1987).

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Spicer JB, Wagner JW, Absolute calibration of interferometric systems for detection and measurement of surface acoustic waves, Applied Optics 27(16), 3561-2566 (1988).

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INVITED PRESENTATIONS AT TOPICAL OR
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Wagner JW, Laser generation and detection of ultrasound,
Research Colloquium, Lockheed Missiles and Space
Co., Sunnyvale, CA, January 28, 1988.

Wagner JW, Holographic methods in nondestructive testing,
ASNT workshop on NDE in education, Portland,
Oregon, June 23, 1988.

Wagner JW, Deaton JB, Laser generation of narrow band
ultrasound, 1988 Reveiw of Progress in Quantitative
NDE (La Jola, CA), August 1988.

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