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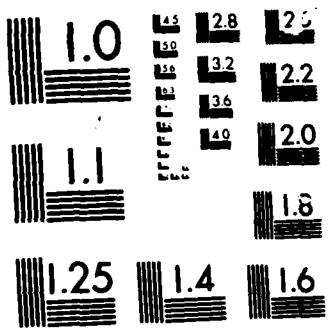

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The overall aim of the work was to design and test self-contained, automated, fiber-based optical systems to measure displacement in production-related or dynamic testing applications. To this end, stability requirements imposed on fibers and optical elements required for remote holographic interferometric analysis have been evaluated for continuous wave laser systems, and techniques were developed to record interferograms on non-isolated and submerged test objects. Thermoplastics have been incorporated into fiber-based systems to

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20. ABSTRACT CONTINUED

record time-average and real-time holograms, and holographic/fiber-iptic systems have been practically applied to evaluated the thermal deformation response of microcircuit modules. Keywords:

ARO 21671.5-EG

DEVELOPMENT OF FIBER OPTIC SYSTEMS FOR RECORDING AND TRANSMITTING HOLOGRAPHIC INFORMATION

FINAL REPORT

by

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FORWARD

The aim of the research conducted under ARO Contract No. DAAG 29-84-K-0183 was to design and test self-contained, automated, fiber-based, optical systems to measure displacement in production-related or dynamic-testing applications where currently existing holographic/fiber optic techniques would be difficult or impossible to apply. The original three-year contract (awarded for the period October 1, 1984 through September 31, 1987) called for 6 phases of research consisting of 22 separate tasks. A letter was submitted to ARO on September 17, 1985 formally requesting that the first year award for the contract be extended through December 1, 1985, at no additional cost to the agency. This action was taken to allow the work and objectives proposed for that period to be completed while the principal investigator transferred his research efforts from the University of Wisconsin-Milwaukee (UWM) to the University of Alabama in Huntsville (UAH). The second year award to UWM was refused and a new proposal was submitted to the ARO for continuation of the project at UAH. This two-year request was subsequently funded for the period December 1, 1985 through November 30, 1987 under ARO Contract No. DAAL 03-86-K-0014. This final report covers research performed under DAAG 29-84-K-0183 during the period October 1, 1984 through December 1, 1985.

We have addressed all, and met mostly all, of the research objectives scheduled for the first year of research in our original three-year proposal. Most of that work has been documented. We continuously recieve reprint requests from investigators throughout the United States, and have replied to

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inqueries from organizations in sixteen different countries. University, and university/industry interaction has been significant (with Marquette and Iowa State Universities; and with AT&T Bell Laboratories, American Cystoscope, Allen Bradley Company, Rexnord Corporation, A.O. Smith, SMD, etc.) and we have successfully piloted additional research directions under the contract (as described later in the final report). Several students have benefited from the funds made available through ARO under Contract No. DAAG 29-84-K-0183. Five of these have graduated with M.S. degrees. One of those was awarded a fellowship for Ph.D. work in remote sensing at MIT; the other four transferred with the principal investigator and are currently working on their Ph.D.'s in applied optics at the University of Alabama in Huntsville.

In short, the work conducted under this research contract has allowed the principal investigator to develop a very strong research program in engineering mechanics and applied optics at the University of Alabama in Huntsville. Special thanks are extended to Dr. E. Saibel and Dr. R. Singleton of the Army Research Office in Research Triangle Park for their invaluable guidance and cooperation throughout the contract period.

John A. Gilbert, Ph.D.
Principal Investigator

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STATEMENT OF THE PROBLEM STUDIED

Over the last decade, the work of various investigators has demonstrated the practical uses of fiber optic elements for holography [ref. nos. 1-7] and holographic interferometry [ref. nos. 8-19]. Experience has established that individual single mode fibers provide convenient, highly stable illuminators for holographic interferometry, [ref. no. 10] while lensed fiber optic bundles may be used to transmit holographic "images" for recording and analysis at locations remote from the actual test object [ref. no. 9]. Moreover, unlensed fiber optic bundles may be used as flexible illuminators for pulsed laser holography [ref. no.7]. Individual optical fibers and coherent fiber optic bundles may be used in both local and remote holographic systems, including double exposure, [ref. no. 12] time average, [ref. no. 16] and real time [ref. no. 18] holographic interferometry. Procedures for recording both image plane ("white light") and Fraunhofer holograms through fiber optics have now been developed, as well as a method for greatly suppressing the inherent instability of commercially available multimode fiber optic image bundles through the use of an "ultra low spatial frequency" (ULF) holographic technique [ref. no. 14].

Although these holographic/fiber optic techniques have been of interest to the stress analyst for many years, industry has been somewhat reluctant to imploy holographic interferometry to any significant extent. One of the major factors inhibiting full exploitation of the technique is the difficulty of getting numerical results out of the interferograms. Indeed, the interferogram does not contain sufficient information to determine the sign of the surface displacement component being measured. However, the real root of the problem is that interference patterns obtained in practical cases are frequently so complex that even if the sign of the displacements were known, a skilled analyst could obtain numerical results only with great difficulty. Therefore, if holography is to be commonly used as a measurement tool, some method of simplifying the recording and analysis of interferograms must be developed. Some of the work conducted under ARO Contract No. DAAG 29-84-K-0183 shows that this simplification can be attained through a combination of fiber optics, image processing, and computer analysis.

Numerical algorithms and correlation routines developed in conjunction with that automated holographic/fiber optic research have led to a number of new research avenues. For example, a hybrid approach to stress analysis, and a technique called shadow speckle metrology have been developed.

A summary of the most important results of our work begins on page 9. Further details can be found in the publications and presentations listed following the summary.

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SUMMARY OF THE MOST IMPORTANT RESULTS

Prior research conducted under ARO Contracts DAAG 29-80-K-0028 and DAAG 29-84-G-0045 has demonstrated that fiber optics provide convenience and simplicity when used in holographic applications. Individual single mode fibers may be used to provide object beam illumination for the test subject and/or reference beam illumination for the hologram itself. Fiber optic components may also be used to transmit the reflected wavefront back from the test subject to the hologram. Adding these links facilitates access to test surfaces that may otherwise be optically inaccessible or physically remote from the laser bench or test station where the hologram is recorded.

The overall aim of the work conducted under DAAG 29-84-K-0183 was to design and test self-contained, automated, fiber-based optical systems to measure displacement in production-related or dynamic testing applications. To this end, stability requirements imposed on fibers and optical elements required for remote holographic interferometric analysis have been evaluated for continuous wave laser systems, and techniques were developed to record interferograms on non-isolated and submerged test objects [see pub. no. 1; pres. no. 1]. Thermoplastics have been incorporated into fiber-based systems to record time-average [pub. no. 2] and real-time [pub. no. 3] holograms, and holographic/fiber-optic systems have been practically applied to evaluate the thermal deformation response of microcircuit modules [pub. no. 5; pres. nos. 2 and 3].

The feasibility of recording holograms using high energy pulses transmitted through fiber cables was demonstrated [pres.

no. 4]. Some of that work has been incorporated into DoD short term innovative research contract DAAG 29-85-K-0178. Tests conducted at AT&T Bell Laboratories by T. D. Dudderar of Bell Labs, C. P. Burger of Iowa State, and the author, have shown feasibility for a new method of nondestructive testing called thermal-acousto-optics [pres. no. 5]. Details are avilable in the final report for that project.

A computer based vidicon camera system has been demonstrated with the capacity to digitize, store and accurately analyze high speed photographs of real-time holo-interferometric fringe fields [pres. no. 6]. Key to this approach is the use of a superimposed carrier fringe pattern to remove intrinsic ambiguities, and the recording of reference or "background" intensity distributions [pres. no. 7]. Early work was concerned with the evaluation of a simple out-of-plane static deformation on a two-dimensional planar surface [pub. no. 5]. This relatively simple study confirmed, in principal, a fundamental approach to the eventual development of automated holo-interferometric systems for the efficient, quantitative evaluation of complex, multidimensional, dynamic displacement fields. A more advanced study will be presented in June, 1986 [pres. no. 8], in which the relatively complex surface displacements of printed circuit boards due to thermal loading by VLSI chip carriers are holographically mapped and automatically processed.

Numerical correlation routines were developed to register high-speed photographs taken of holographic interferograms [pres. no 9]. This research led to a number of new avenues including the development of an objective speckle measurement system that uses fiber optics and photoelectronic-numerical processing [ref. no. 6], and a new technique called shadow speckle metrology [ref. no 7]. This new method has been applied to evaluate the flecture of thin plates, for contouring, and in studying buckling phenomenon of large structural components [pres. nos. 10 and 11].

Real-time holographic/fiber optic recording systems were incorporated into a high frequency moire recording system [pres. no. 12]. The displacements measured using this technique were combined with finite element analysis to develop a hybrid approach to stress analysis [ref. no. 8; pres. no. 13]. Here the basic idea is to combine finite element analysis and experimental measurements in order to better characterize the behavior of an existing prototype. Hybrid analysis was also initiated using displacements measured by digital correlation of speckle patterns [ref. no. 9; pres. no. 14]. The hybrid approach will eventually applied in cases where displacements are holographically recorded through automated fiber optic systems.

Additional information on the historical development of ARO supported holographic/fiber optic research can be found in reference 10.

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PARTICIPATING SCIENTIFIC PERSONNEL

The students listed below were partially or fully funded under Contract No. DAAG 29-84-K-0183. All research was conducted under the direct supervision of the principal investigator.

Name: Chern, J. H.
Remarks: Mr. Chern worked with the principal investigator in the capacity of research assistant and graduated with an M.S. in 1985. He was awarded a fellowship at MIT and is currently working on his Ph.D. at that institution. See pres. nos. 6 and 7.

Name: Johnson, H.S.
Remarks: Ms. Johnson worked with the principal investigator in the capacity of research assistant and graduated with her M.S. in 1985. She is currently working with the principal investigator on her Ph.D. at the University of Alabama in Huntsville. See pub. nos. 8 and 9; pres. nos. 12-14.

Name: Lehner, D.L.
Remarks: Mr. Lehner joined our team as a research assistant in late 1985, and is currently working on his Ph.D. with the principal investigator at the University of Alabama in Huntsville.

Name: Peters, B.R.
Remarks: Mr. Peters worked with the principal investigator in the capacity of research assistant and graduated with his M.S. in 1985. He is currently working with the principal investigator on his Ph.D. at the University of Alabama in Huntsville. See pres. nos. 4 and 5.

Name: Petersen, M.E.
Remarks: Mr. Petersen worked with the principal investigator as an undergraduate research assistant. He transferred to the University of Alabama with the principal investigator and has been awarded a scholarship to continue his undergraduate work. See pub. no. 7; pres. nos. 10 and 11.

Name: Taher, M.A.
Remarks: Mr. Taher worked with the principal investigator in the capacity of research assistant and graduated with an M.S. in 1985. He is currently working with the principal investigator on his Ph.D. at the University of Alabama in Huntsville. See pub. nos. 6, 7 and 9; pres. nos. 9-11, 14.

Note: J.H. Bennewitz [pub. no 6], R.A. Franzel [pub. nos. 2 and 8], A. Nose [pub. no. 1], and J.H. Schamell [pub. no. 2] worked with the principal investigator as research assistants. These students contributed to the project but were funded from other sources. They have all completed their advanced degrees and are currently employed at AT&T Bell Laboratories, General Electric Medical Systems Division, Yamaha, and Beloit Corporation, respectively.

Note: T.D. Dudderar [pub. nos. 1-6, 8, 9; pres. nos. 1-9, 12-14], and P.M. Hall [pub. no. 4; pres. nos. 2 and 3] are Members of the Technical Staff at AT&T Bell Laboratories in Murray Hill, N.J.

Note: D.R. Matthys [pub. nos. 5, 7-9; pres. nos. 3, 4, 6-14] is an Associate Professor of Physics at Marquette University in Milwaukee, Wisconsin. He worked with the principal investigator at the University of Wisconsin-Milwaukee as a Visiting Associate Professor.

Note: C.P. Burger [pres. no. 5] is a Professor of Engineering Mechanics at Iowa State; J. A. Smith [pres. no. 5] and B. Raj [pres. no. 5] are students working with Professor Burger.

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