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FINAL REPORT

NASA GRANT NAG 1-1176

Optical Fiber Sensors for Materials and Structures Characterization

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DISCUSSION OF RESEARCH PROGRESS

This is the final technical report for NASA contract NAG 1-1176 titled, "Optical Fiber Sensors for Materials and Structures Characterization." During the period August 1990 through August 1991, three graduate research assistants and two electrical engineering faculty (Lindner and Claus) within the Fiber & Electro-Optics Research Center at Virginia Tech worked on this research program in three specific technical areas which are described briefly below. Research progress in each of these areas was substantial, as evidenced by the technical publications which are included in this report as appendices.

SAPPHIRE OPTICAL FIBER SENSORS

The first major area of activity on this grant program was the investigation of sapphire fiber-based sensors for the evaluation of material parameters. Sapphire fiber sensors exist commercially but only use sapphire rod waveguides as bulk transmission elements to effectively look inside materials or structural systems. During the past year, our group has developed sapphire fiber-based interferometric systems which allow the very sensitive quantitative measurement of strain, temperature, vibration, displacements and ultrasonic waves at high temperatures. Tests indicate that the sapphire elements are capable of withstanding temperatures in excess of 1700°C, and packaging limitations alone restrict their temperature at this time. We feel that the development of these high temperature fiber interferometers is a major step toward the implementation of highly sensitive fiber sensor systems for the analysis of advanced aerospace materials and combustion processes. Several publications based on NASA sponsored work are listed in the appendices.

VIBRATION ANALYSIS USING TWO-MODE ELLIPTICAL CORE FIBERS AND SENSORS

A second major area of emphasis in this grant program has been the application of "modal domain" optical fiber sensors for vibration analysis. Modal domain sensors were first investigated with NASA funding several years ago, and they have evolved into sensors which

use elliptical core fiber designed to support two propagating modes. These two mode elliptical core fiber sensors have been shown to be particularly advantageous for the monitoring of vibration in structures, and large space structures have been of primary concern here.

This year, we have made two significant steps in this area. First, we have demonstrated that by tapering the geometry of the two mode e-core fibers, we can weight the sensitivity of the fiber sensor along its length. This potentially allows the implementation of a wide range of variable sensitivity sensors for environmental field analysis. We have specifically used these weighted sensors to detect certain vibrational mode shape amplitudes in vibrating structures while suppressing information from other modes. Further, we have written gratings in these fibers and have used weightings in the gratings to also achieve weighted fiber sensor performance.

EXTRINSIC FABRY-PEROT INTERFEROMETER DEVELOPMENT

The third area of emphasis in this program has been the development of extrinsic Fabry-Perot interferometric (EFPI) sensors for the measurement of strain and temperature. Specifically in this area, we have provided to NASA Langley descriptions of these sensors and the required support hardware with the understanding that such sensors may be candidates for measurements on the instrumentation platform to be included in a shuttle test program in 1994. EFPI sensor hardware would be prototyped and flight qualified in the future to support this measurement system requirement.

COATINGS FOR FLORESCENT-BASED SENSOR

Finally, we have worked with Dr. Claudio Eggalon at NASA Langley to attempt to coat optical fiber waveguides with special florescent materials which he has provided to us. The initial tests for this work have not proven to be conclusive and we anticipate additional coating tests on the optical fiber draw tower in the near future.

The following are journal papers and conference papers which relate to work supported directly by the NASA Langley Research Center during the past year. Over the past eleven years, and as part of this

continuing grant program, NASA funds have supported seventeen separate graduate students, fourteen of them U.S. citizens, in the area of optical fiber sensor systems for materials analysis. Further, the Fiber & Electro-Optics Research Center has published more than two hundred related conference and journal papers in this area, most of which have been related in part to work which has been supported by NASA.

2. Journal Papers

"Polarimetric Analysis of Two-Mode, Elliptical-Core Optical Fibers," Optics Letters, Vol. 16, No. 7, April 1, 1991, pp. 464-466, with A.M. Vengsarkar, B.R. Fogg, and K.A. Murphy

"Demodulation Techniques for Two-Mode Elliptical-Core Fiber Sensors," Electronics Letters, Vol. 27, No. 16, August 1, 1991, pp. 1454-1456.

"Quadrature Phase-Shifted, Extrinsic Fabry-Perot Optical Fiber Sensors," Optics Letters, Vol. 16, No. 4, February 1991, pp. 173-275, with K. Murphy, M. Gunther and A. Vengsarkar.

"Elliptical-Core, Dual-Mode Optical Fiber Strain and Vibration Sensors for Composite Material Laminates," J. CompositeTech., Vol. 13, No. 1, Spring 1991, pp. 29-35, with K. Murphy, M. Miller and A. Vengsarkar.

"Fiber Optic Sensors Using High Resolution Optical Time Domain Instrumentation Systems, B. Zimmermann, D. Kapp, R. Claus and K. Murphy, Journal of Lightwave Technology, Vol 8, No. 9, September 1990, pp. 1273-1277.

"Elliptical-Core, Two-Mode, Optical Fiber Sensor Implementation Methods, K. Murphy, W. Miller, A. Vengsarkar, and R.O. Claus, J. Lightwave Technology, Vol. 8, No. 11, November 1990, pp. 1688-1697.

"Direct Numerical Analysis of Dual-Mode Eliptical Core Optical Fiber, K. Shaw, A. Vengsarkar, R. Claus, Optics Letters, Vol. 16, No. 3, February 1991, pp. 135-137.

"Miniaturized Fiber Optic Michelson-Type Interferometric Sensors, K. Murphy, M. Miller, T. Tran, A. Vengsarkar and R. Claus, Applied Optics, Submitted 2/90.

"Stable, Phase-Modulated, Fiber Optic Sensors for Senior EE Laboratory Curricula, A. Vengsarkar, K. Murphy, R. Claus, IEEE Trans. on Education, Submitted 2/90.

"Modal Dependence of the Photoelastic Coefficient in Multimode, Step-Index Optical Fiber Time Domain Systems, A. Vengsarkar, D. Thomas, B. Zimmermann, and R. Claus, IEEE Photon Tech. Ltrs, Vol. 2, No. 11, November 1990, pp. 812-815.

3. Conference Papers

Measurement and Control of Flexible Structures Using Distributed Sensors, D. Lindner, Reichard, Baumann, IEEE Conference on Decision and Control, Honolulu, HI, 1990.

Virginia Tech Fiber Optic Sensor-Based Smart Materials and Structures Overview, R.O. Claus, SPIE (San Jose) September 1990.

Theoretical Analysis of Two-Mode, Elliptical-Core Optical Fiber Sensors, J. Shaw, A. Vengsarkar, and R.O. Claus, SPIE, (San Jose) September 1990.

Fiber Optic Sensor for Simultaneous Measurement of Strain and Temperature, A. Vengsarkar, W. Michie, L. Jankovic, B. Culshaw, R.Claus, SPIE (San Jose) September 1990.

Recent Progress in High Resolution Optical Fiber Time Domain Methods and its Impact on Dynamic Environment Sensing Applications, B. Zimmermann, D. Thomas, R. Claus, SPIE (San Jose) September 1990.

Identification and Control of a Flexible Beam Using Modal Domain Sensor, D. Cox, D. Lindner, C. Furness, S. Bingulac, SPIE, (San Jose), September 1990.

Generation and Detection of Ultrasonic Stress Waves in Materials Using Embedded Optical Fibers, C. Thompson, W. Miller, R. Claus, SPIE (San Jose) September 1990.

High Temperature Sensing Applications of Silica and Sapphire Optical Fibers, K. Murphy, C. Koob, A. Plante, S. Desu, and R. Claus, (San Jose) September 1990.

Vibration Sensing in Flexible Structures Using a Distributed-Effect Modal Domain Optical Fiber Sensor, K.M. Reichard, D.K. Lindner and R.O. Claus, accepted for the SPIE Conference on Structures Sensing and Control/Controls for Optical Systems, Orlando, FL, April, 1991.

Distributed-Effect Optical Fiber Sensors for Plates and Trusses, K.M. Reichard, D.K. Lindner, Proceedings of the SPIE/AIAA Conference on Aerospace Sensors/Sensors and Sensor Integration, Vol. 1480, Orlando, FL., April 1991, pp. 115-126.

Modal Domain Optical Fiber Sensors for Vibration Sensing in Large Flexible Truss Structures, D.K. Lindner, R.O. Claus and H. Cudney, Proceedings of the 4th Annual NASA/DoD Technology Conference, Orlando, FL, November 5-7, 1990, pp. 280-294.