

# **Nontraditional Methods of Sensing Stress, Strain, and Damage in Materials and Structures**

***Second Volume***

**George F. Lucas  
Peter C. McKeighan  
Joy S. Ransom**



**STP 1323**

**Editors**

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***Nontraditional Methods of  
Sensing Stress, Strain, and  
Damage in Materials and  
Structures: Second Volume***

*G. F. Lucas, P. C. McKeighan and J. S. Ransom, editors*

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# Foreword

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This publication, *Nontraditional Methods of Sensing Stress, Strain, and Damage in Materials and Structures: Second Volume*, contains papers presented at the symposium of the same name held in Kansas City, Missouri, on 17 November 1999. The symposium was sponsored by ASTM Committee E8 on Fatigue and Fracture. The symposium co-chairpersons were George F. Lucas, MTS Systems Corporation, Peter C. McKeighan, Southwest Research Institute, and Joy S. Ransom, Fatigue Technology Incorporated.

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# Overview

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A mechanical test is of little value without some type of sensor to (a) control the test, (b) provide a measurement of physical behavior or (c) indicate when the test is completed. The most common sensors are those that measure force, displacement and strain. Although many sub-classifications of these devices exist, industrial development of new force, displacement and strain sensors is ongoing, often driven by a new application where the parameters exceed the limits of the currently available sensors. Perhaps a good parallel example of this is the ceramics development that occurred during research concerned with the now defunct high-speed civil transport. Had this aircraft not been envisioned, several of the current high temperature materials would likely not exist.

The focus of this symposium is the development and application of nontraditional sensors. For instance, several novel methods to measure strain in a body are available using non-contacting techniques. In particular, there has been a large amount of work using vision-based sensors to measure the deformation field on a material or structure. Although this is only one example, there are other new, novel methods of measuring parameters that may directly correlate with some form of damage within the material or structure. The purpose of this symposium is to assess the state of the art of these sensing methods and examine their future potential use as standardized tools within the testing communities. Encouraging use of these new sensing methods and extending them into industrial application will presumably be a consequence of the symposium.

This symposium, held in November of 1999 in Kansas City, is the second in a series of symposia concerned with nontraditional methods of sensing stress, strain and damage. The first, STP 1318, was held in May of 1996 in Orlando, Florida and was preceded by two workshops on the same topic in earlier years. These Symposia and Proceeding Workshops were instigated by task group E08.03.03 on Sensors, which is a task group of the committee on Fatigue and Fracture and its subcommittee on Advanced Apparatus. The scope of this task group is to develop standards and encourage technology interchange concerning measurement sensors that are used in determining fatigue and fracture characteristics of materials and structures.

Perhaps one of the major differences between the first and second symposium (a span of three and a half years) was the increase in capability apparent in personal computers. A close examination of all of the papers in this symposium will show that at the heart of all of the systems presented was a computer. As we all know, the speed of the CPU's has been doubling every two years to eighteen months (Moore's Law). However what became apparent during the symposium was not the pivotal role that increased processing speed was playing but rather the enormous impact of infinitely available, low cost RAM and storage space. This is probably most clearly evident for vision-based sensors that manipulate and interpret images. Greater RAM allowed more on-the-fly computations and high-speed storage space (gigabytes plus) implying enhanced flexibility.

The twelve papers included in this STP are very diverse, both from the viewpoint of the applications considered as well as concerning the sensors applied. Four of the papers included in this STP utilize imaging systems to infer deformation fields. Helm, Sutton and Boone use their 3-D system to characterize fatigue crack growth for aluminum panels under tension-torsion loading. Towse *et al.* describe a general purpose, 2-D non-contacting extensometer derived from video images and capable of tracking multiple targets at high speed. Two other

papers, Smith and Bay and Nicollela *et al.* examine strain fields in biological material (bone) using image correlation techniques.

Two papers focused primarily on acoustic emission techniques: McKeighan *et al.* examined crack nucleation and growth from defects in titanium and Ma and Takemoto considered thermal fracture in coatings subjected to cyclic laser irradiation. Two other papers focused on fiber optic methods of measuring strain and deformation. Chen and Sirkis examined the costs and benefits of fiber optic versus conventional electric strain gages. Conversely Tu *et al.* measured long-term creep deformation using quartz optical fiber marking, remote monitoring and image processing.

The remaining four papers examined relatively unique applications and sensors. Suhling and Jaeger present work where the structural reliability of IC chips is measured using piezoresistive sensors bonded to the chip substrate. Morimoto and Fujigaki present work concerning the real-time phase analysis of Moire images to analyze shape, strain and stress. The final two papers concern damage measurement. Ranganathan *et al.* examines methods for quantitative fractography where the fracture surface of a failed specimen can be used to assess loading conditions that led to failure. Finally, Burkhardt and Crouch present a magnetic nonlinear harmonics approach to detect localized plastic deformation in pipelines.

Organizing these papers in some cogent manner is a challenge in view of the diversity of applications, methods, sensors and focus. Nevertheless, the approach adopted is intended to address the focus of the papers. In the first section, *Fracture Mechanics and Structural Integrity*, the papers that talk about cracks (either crack growth or fracture) or general stress-strain behavior are included. The papers that address the damage state of a material are included in the section entitled *Damage Evolution and Measurement* whereas the final section considers *Strain and Displacement Measurement Techniques*.

Following the symposium, a brief panel discussion was held focussing on issues such as where sensor development was going, what was spurring sensor development and what ASTM standardization activities could assist this process. This was a lively discussion and it is succinctly summarized at the conclusion of this book after all of the technical papers. The technical community is clearly faced by some technical challenges—first and foremost being the cost of new sensors and the magnitude of the effort required to develop them. ASTM can play an important role in this process by insuring that the standards are available to assess the performance of sensors once developed. However the breadth of the standards required for this and covering sensor technology not yet even discovered is awe inspiring.

The editors would like to express their sincere appreciation to all of the authors and co-authors responsible for the papers included in this STP and the presentations made during the symposium. Furthermore we would like to recognize the efforts of the reviewers whose high degree of professionalism and timely response ensures the quality of this publication. Finally, the editors would also like to express their sincere gratitude to ASTM planning and editorial staff for their assistance with the symposium as well as their critical input to this special technical publication.

Finally, it should be noted that Tait S. Smith, co-author of the paper “Experimental Measurement of Strains using Digital Volume Correlation” formerly with the University of California, Davis, received the “Best Presented Paper Award” for his excellent presentation at the symposium. This honor was bestowed based upon the critiques of five seasoned professionals in the audience.

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