SAVIAC
Shock and Vibration Information Analysis Center
Current Awareness
February 2005

Introduction to Air Blast Measurements

Part V: Alternate Technologies?

Editor's Note: The assessment of the technology presented here is that of the author's and not necessarily SAVIAC's. This is the fifth and final article in a series high-lighting one of the 75th Symposium's featured commercial agencies, PCB Piezotronics.

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If the guidance provided in Parts I-IV is followed, a valid signal representing the air-blast environment will be delivered for subsequent signal conditioning (e.g., digitizing and recording) and analysis. A final question to be addressed is whether there is an alternate technology to piezoelectric ICP® pressure transducers that should be considered for measuring the air-blast environment. The answer is yes; the alternate technology is MEMS ((M)icro(E)lectro(M)echanical (S)ystems)-based transducers.

Like ICP®, silicon-based MEMS (piezoresistive) transducers are often used for air-blast pressure measurements. One reason is that mechanical strain is typically a desired response measurement when structures are loaded by an air-blast. Therefore, strain-gage signal conditioning, i.e., differential amplifiers and power supplies, are usually already in place at the test facility, and these same signal conditioning devices can be applied directly to MEMS pressure transducers. This interoperability, not to mention the ease with which MEMS sensors can be statically calibrated, certainly encourages their utilization.

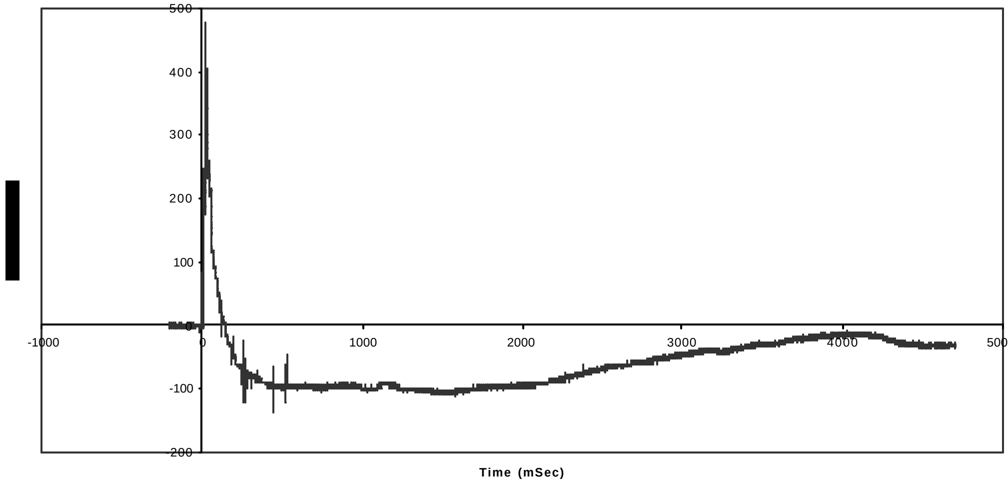

Figure 14 - Erroneous Blast Pressure Data (Notice the -100 psig reading!)

This section attempts to objectively compare strengths and weaknesses of MEMS and ICP® type pressure transducers focused *only* on their applicability to the air-blast environment. The analysis considers erroneous responses to the undesired stimuli that accompany air-blasts, which as previously noted, include as a minimum: thermal transients, light, acceleration/strain, and ionization products of the explosion. In addition, the transducer performance parameters of dynamic range, ruggedness/survivability, frequency response, and self-check are examined. We will deal with these issues one at a time in what this author considers their order of importance.

Thermal transients: Reference 8 discusses challenges encountered due to thermal-transient sensitivity of MEMS pressure transducers. Heat transfer by conduction, convection, and radiation results in the individual strain-elements of the pressure transducer's diaphragm encountering spatially distributed temperatures. These temperatures change with time and are different than that of their supporting structure. In addition, thermally induced distortion (e.g., bending) of the diaphragm can occur. The results of these combined effects are both a zero-shift and a change in sensitivity of the transducer. Figure 14 shows a pressure-time record acquired from a MEMS transducer in a contained explosive environment. This measurement was affected by thermal-transient stimuli.

Methods to mitigate thermal-transient response (as described in reference 8) include (1) a protective or shadowing screen over the diaphragm, (2) opaque grease in front of the diaphragm, and (3) the addition of an opaque material that adheres to the diaphragm such as black tape or RTV. Metallic coatings can also be added to the front of the diaphragm. All of these "fixes" degrade the frequency response (discussed below) of the transducer to some extent as a byproduct of delaying the thermal transient.

References 9 and 10 describe recent advances using MEMS "silicon-on-insulator" (SOI) pressure transducer

Intro Air Blast, con't on Page 2

Free Winter Shock & Vibration Seminar

SAVIAC invites you to attend a FREE seminar on Shock & Vibration. The course will be held on March 2, 2005 at Weidlinger Headquarters in New York in conjunction with the SAVIAC Winter Technical Advisory Group (TAG) Meeting. SAVIAC and the featured experts in their disciplines have organized this seminar to introduce you to the SAVIAC community, while providing a valuable educational experience.

Agenda

7:30 - 7:45	Registration & Continental Breakfast	
7:45 - 8:00	Introduction to SAVIAC	Joel Leifer, SAVIAC
8:00 - 9:00	A Primer On Explosion Effects In the Air, Water, and Soil	Dr. Charles Robert Welch, US Army Engineer Research and Development Center
9:00 - 10:00	Oklahoma City Bombing - Lessons Learned	Dr. Paul Mlakar, US Army Engineer Research and Development Center
10:00 - 11:00	Blast Analysis and Damage Visualization of Buildings	Dr. David K. Vaughan, Weidlinger Associates
11:00 - 12:00	Introduction to Vulnerability Assessment Software: BEEM, SBEDS, and HAZL	Patrick Lindsey, US Army Corps of Engineers Protective Design Center
12:00 - 1:00	Lunch	Hosted by NTS
1:00 - 1:30	Aluminized Explosive Modeling	Dr. Eric Rinehart, Defense Threat Reduction Agency
1:30 - 2:00	An Analytic Approach to Airblast and it's Effects using a coupled Eulerian.Lengrangian FEM Approach	Bart McPheeters, MSC. Software
2:00 - 2:30	Zero offsets in Accelerometer data: Causes and Corrections	Tim Edwards, Sandia National Labs
2:30 - 3:00	Overview of Mechanical Vibration & Shock Standards Development	Susan Blaeser, Acoustical Society of America
3:00 - 3:30	Navy Hydrocode Development Efforts for Underwater Explosion Effects	Greg Harris, NSWC/IH
3:30 - 4:00	Lithium Battery Environmental Testing	Allen Parkes, NSWC/Crane
4:00 - 4:30	Overview of Hazard Assessment Testing (HAT) per MIL-STD-2105	Jamie Howell, NSWC/Dahlgren
4:30 - 5:00	Shock Isolation	Dr. Chris Merrill, CMA Engineering
5:00 - 5:15	Wrap-up & Questions	All

Please forward this invitation to anyone you know who may be interested in attending this program.

The seminar is free, but you must register to attend as space is limited. Please RSVP to Lauren Yancey, (703) 892-0060 or lauren.yancey@saviac.org to assure your space and note packet. SAVIAC reserves the right to substitute topics and/or instructors when necessary. This schedule is subject to change. For more information about SAVIAC please visit our website at www.saviac.org.

Intro Air Blast, con't from Page 1

technology. This technology enables steady-state operation at temperatures to greater than 1000^{o} F, while also enhancing transducer performance in thermal-transient environments.

The initial effect of transient temperature on quartz ICP® pressure transducers is to cause internal component dimensional changes (see Fig. 5), which ultimately result in a partial release of the preload within the stack of quartz plates. The release of this preload results in an error in the pressure transducer output and a false indication of a positive pressure after the pressure event is over. A RTV coating is usually placed on the diaphragm of the transducer to provide a barrier to thermal transients. Coatings, placed on either MEMS or ICP® transducers, typically delay the thermal transient for no more than a few 10's of milliseconds.

Light: Reference 8 also discusses light-sensitivity of silicon transducers. This is of interest because light-intensity increases with proximity to the airblast. Silicon-diaphragm pressure transducers absorb short-wavelength electromagnetic radiation in the wavelength range between 3,000 to 10,000A, most of which is in the visible spectrum. The temporary results are photoconduction as well as a photo diode effect in the junction isolation between the gages and the bulk material. Reference 8 concludes, "flash sensitivities of silicon diaphragms vary widely from unit to unit, and it is rather easy to obtain a full-scale output from a flash of light."

Again, since the publication of Reference 8, more recent SOI technology[9,10] used by select manufacturers, has greatly minimized transducer response attributable to light. By comparison, quartz ICP® technology has no sensitivity to light.

Frequency response: MEMS pressure transducers typically possess a maximum resonant frequency of 100 to 200 KHz at pressures under 100 psi extending to a 1 MHz resonance at 1,000 psi. Quartz ICP® transducers possess resonant frequencies of 300 to 400 KHz over this same pressure range. Frequency tailoring (mentioned previously in this article) extends the useable frequency response of quartz ICP® transducers. In addition, they do not require screens and are not influenced by the addition of coatings or RTVs to their diaphragms. MEMS

Intro Air Blast, con't on Page 4

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Intro Air Blast, con't from Page 2

transducers, in ranges less than 100 psi, typically find their frequency response degraded by the addition of thermal protective coatings to their diaphragms. This occurs due to the low density of silicon and the thinner diaphragms necessitated at the lower pressure-ranges. All quartz ICP® pressure transducers are extremely rigid, so as to be virtually unaffected by coatings.

Acceleration (strain): As noted earlier, blast loading of the housing of a structure in which a pressure transducer is mounted creates motion of the structure and, additionally, induces mechanical strain into it. The lower profile of the MEMS silicon diaphragm assembly (< 0.015" thick), along with the low modulus/density ratio of silicon (approximately 1/3 that of steel), minimizes the acceleration response of MEMS pressure transducers. In addition, some MEMS SOI technology, analogous to ICP® technology, incorporates a 2nd transducer for acceleration compensation. When acceleration compensation is provided, the acceleration sensitivity of ICP® transducers is also very small; however, the larger, more complex structure of their sensing element (Fig. 5) makes them more sensitive to strain coupling.

Ruggedness (survivability): MEMS pressure transducers are specified with ranges to 30,000 psi, and, historically, with stated over-range capabilities of 2 or 3 times full-scale, without damage. Currently, select MEMS transducers[9] are being fabricated with mechanical over-range stops to increase this capability. Quartz ICP® transducers are specified with ranges to 200,000 psi, with over-range capability in some instances of 200 times full-scale.

Dynamic range: MEMS pressure transducers typically provide an output signal of 100 to 200 millivolts without amplification. The basic piezoelectric sensing element in ICP® transducers typically has a dynamic range of 100 to 120 dB. Quartz ICP® pressure transducers can readily provide a 5-volt full-scale output without amplification. Measuring a 100-psi blast-pressure wave with a 500-psi MEMS pressure transducer that has a 100 mV full-scale output would result in 20 mV of signal before amplification. The comparable measurement with a 500-psi ICP® transducer could result in 1000 mV of signal before amplification. This typical 50:1 signal ratio greatly reduces the number of ranges of ICP® transducers that have to be inventoried at a test facility.

Evaluation Parameter	ICP®	SOI	Silicon p-n
Thermal transients	+		
Light	+	*X*	
Frequency Response	+	+	+
Acceleration (strain)	*X*	+	*X*
Ruggedness (survivability)	+	+	
Dynamic range	+		
Self-check	+	+	+
Ionization Products	+	+	+

(+) is best or highest performance
(X) is lesser but still highly competitive performance

Table I: Technical Comparison of ICP7 vs. MEMS Transducers for the Air-Blast Application

Self-check: End-to-end checks of the integrity on the measurement system can be performed both with MEMS and ICP® transducers. With MEMS transducers one can shunt calibrate the system by paralleling a resistor across one arm of the bridge to produce a known voltage change. Calibration is somewhat of a misnomer, since the values of the transducer's bridge-resistors have some dependency on ambient temperature. Nevertheless, the signal indicates continuity and provides some measure of gain through the circuit, which is important information when long runs of cables are involved. The equivalent check for the ICP® transducer is the monitoring of the bias voltage associated with the MOSFET inside the transducer. This bias voltage serves as a continuity check.

Ionization products: The MEMS and ICP® transducers can both be mounted with the transducer housing either grounded or ungrounded to a mounting plate. Both devices have low-impedance outputs, and various cable shielding options can be provided. Any relative advantage between the two technologies would have to be associated with the dynamic range of the ICP® transducer, which was credited above under "dynamic range".

Transducer cost has not been considered in the preceding discussion. The cost of lost test data is often priceless. If multiple channels of acceptable strain-gage signal conditioning are in place, the MEMS transducer is the most economical solution. If these existing and available channels are not in place, per channel costs favor the ICP® solution.

Table I recaps the preceding comparison. A (+) indicates the best or highest performance and a *(X)* lesser but still highly competitive performance. It should again be noted that the MEMS SOI pressure-transducer technology is currently emerging, and is only available from select manufacturers. The more significant observations include the ICP® sensors' greater tolerance to thermal-transient protection barriers (e.g., RTVs), as well as their much greater dynamic range, compared to the lower acceleration or strain response associated with MEMS SOI sensors. In many air-blast environments both MEMS and ICP® pressure transducers currently operate successfully. However, focusing only on this air-blast application, the ICP® pressure transducers are seen to have some advantage.

Conclusion (Parts I - V): After briefly describing the air-blast environment, some of the historical challenges associated with its measurement were presented. Problems associated with interfacing a pressure transducer to the air-blast environment were next described, and analysis procedures were provided to calculate the effects of any transducer-mounting compromises. Tools for validation of data were then discussed, and methods to minimize any documented environment-induced noise, if present, were provided. The frequency limitations attributable to long cables runs used in air-blast testing were then described, and some computational tools were identified. Last, a comparison of differ

Intro Air Blast, con't on Page 7

Announcement for International Short Course on

Response of Marine Structures to Underwater Explosions

March 22-25, 2005
Monterey Beach Hotel
2600 Sand Dunes Drive, Monterey California 93940

Course Lecturers:

Professor Thomas L. Geers
Dept. of Mechanical Engineering
University of Colorado
Boulder, Colorado 80309

Dr. Young S. Shin
Shock and Vibration Research
Monterey, California 93940

Course Objective & Overview

Course Objective: The purpose of this course is to provide engineers, scientists, and naval architects a discriminating review of underwater explosion phenomena, structural response analysis, fluid-structure interaction, shock spectrum concept, and shock-induced vibration analysis of shipboard equipment.

Course Overview:

1. UNDERWATER EXPLOSION PHENOMENA: Sequence of Underwater Explosion Events, Hydrodynamic Relations, Underwater Acoustic Waves, Air-Water Interface, Shock Wave Parameters, Bubble Behavior and Bubble-Pulse Loading, Bulk and Local Cavitation, Scaling
2. ELEMENTS OF STRUCTURAL DYNAMICS: Analytical Dynamics, Classical Linear Oscillator, Two-Degree-of-Freedom System, Finite Element Discretization and Modelling, Finite Difference Time Integration
3. FLUID-STRUCTURE INTERACTION: Athwartship Response of Submarine, Vertical Response of Surface Ship, Submerged Plate Oscillator
4. DAA-BASED ANALYSIS: Submerged Spherical Shell, FE/BE Fluid-Structure Interaction, USA-DYNA, USA-NASTRAN, etc.
5. FLUID VOLUME DISCRETIZATION: Fluid Cavitation, Validation of Computer Codes
6. MODELLING AND SHOCK SIMULATION: Three Dimensional Ship Shock Analysis, Modeling and Approaches
7. SHOCK QUALIFICATION OF SHIPBOARD EQUIPMENT BY DESIGN ANALYSIS: Shock Spectra, Normal Mode Analysis, Response of a Multi-DOF System to Shock Motion
8. DYNAMIC DESIGN ANALYSIS WORKSHOP: Dynamic Design Analysis Method (DDAM), DDAM Step-by-step Analysis Procedure, Design Criteria of Shipboard Equipment Using DDAM
9. APPLICATION TO SHIPBOARD EQUIPMENT USING DESIGN ANALYSIS: Application Problems

Course Organization

REGISTRATION FEE

The following registration fee includes the cost of all sessions, coffee breaks, and the course notes.
$ 1,620 --- if paid by February 22, 2005.
$ 1,800 --- if paid after that date.

ACCOMMODATION

A block of rooms has been reserved at special rates for short course attendees at the Monterey Beach Hotel (Rates $75 single & 95 double). To qualify for these special rates, you must mention that you are attending the "Shock 05 Seminar". Attendees should contact the hotel directly to make reservations. The rooms at the special rates will only be held until February 22, 2005.

COURSE LOCATION

The course will be conducted in Monterey, California, USA;

Monterey Beach Hotel
2600 Sand Dunes Drive, Monterey, California 93940
Phone: (800) 242-8627 or (831) 394-3321
Fax: (831) 393-1912
Email: montereybeachresort.com

FOR FURTHER INFORMATION, CONTACT:

Shock and Vibration Research
10150 Blue Larkspur Lane
Monterey, California 93940, USA
Phone/Fax (831) 375-4999, Cell: (831) 277-7117
Email: undex05@sbcglobal.net

Announcement for International Short Course on

APPLICATIONS OF LS-DYNA/USA CODE TO SHIP- SHOCK MODELING AND SIMULATION

March 28 - 30, 2005
Monterey Beach Hotel
2600 Sand Dunes Drive, Monterey California 93940

Course Lecturers:

Dr. John A. DeRuntz, Jr.
Unique Software Applications
Colorado Springs, CO 80906

Dr. Young S. Shin
Shock and Vibration Research
Monterey, California 93940

Course Objective & Overview

Course Objective: The purpose of this course is to provide engineers the applications of coupled LS-DYNA/USA code to ship-shock modeling and simulation.

Course Overview:

1. THE PHYSICS OF UNDERWATER SHOCK
2. FLUID-STRUCTURE INTERACTION: Exact Formulations, Doubly Asymptotic Approximations, Interaction Equations, Augmentation For Unconditional Stability
3. FLUID MASS MATRIX DEVELOPMENT: Potential Flow Boundary Element Method, Model Symmetries And Fluid Boundaries, Bottom Effects Model, Surface Of Revolution Models, Fluid Boundary Modes, Rigid Body Added Mass And Rotational Inertia Coefficients
4. CAVITATING FLUID ANALYSIS
5. OVERVIEW OF THE UNDERWATER SHOCK ANALYSIS CODE
6. USING THE USA CODE: Processor Functions, Structural Modeling Preliminaries, Wet Surface Mesh from Structural Model, User Options
7. USING THE USA-CFA CODE: External and/or Internal Fluid Problems, Radiation Boundary Options, LS-DYNA Usage, Fluid Volume Modeling and Stability, Transient Response Analysis and Stability
8. INCIDENT SHOCK WAVE SPECIFICATION: Scaling Laws, Tabular Inputs, Exponential Waves And Double Decay, Built In Explosives, Features
9. BUBBLE PULSE SPECIFICATION: Physical Basis, Hicks Bubble Model, Theory, Units, Options, Features
10. COMBINED SHOCK-BUBBLE SPECIFICATION: Physical Basis, Geers-Hunter Bubble Model
11. Using USA/LS-DYNA: USA/LS-DYNA Processors, Execution of USA/LS-DYNA, Wet-Surface Modeling, LS-DYNA Time Step Control, Hydrostatics, Damping, Resilient Mounts, LS-DYNA Fluid Volume Elements, USA/LS-DYNA Sample Problems
12. OTHER TOPICS: Problem Areas Where More Work Is Needed, Selected USA/LS-DYNA Sample Problems
13. LS-DYNA CODE FOR SHIP SHOCK MODELING: Capabilities, Features and Limitations, Software Organization, Ship Structure and Surrounding Fluid Modeling, Radiation Fluid Boundary, Ship System Damping Modeling & Error Correlation Factors
14. LS-DYNA AND USA INPUT DECK SETUP: Ship Structures and Surrounding Fluid, Ship System Damping, Radiation Boundary and Shock Analysis Geometry
15. SHIP SHOCK MODELING & SIMULATION PROBLEMS: 1D, 2D and 3D Model and Analysis

Course Organization

REGISTRATION FEE

The registration fee is $1,250 which includes the cost of all sessions, coffee breaks, and the course notes. Early registration is suggested because enrollment is limited. Please send us email or phone call requesting registration form.

ACCOMMODATION

A block of rooms has been reserved at special rates for short course attendees at the Monterey Beach Hotel (Rates $75 garden side). To qualify for these special rates, you must mention that you are attending the "Shock-05 Seminar". Attendees should contact the hotel directly to make reservations. The rooms at the special rates will only be held until 4 weeks before class starts.

COURSE LOCATION

The course will be conducted in Monterey, California, USA;

Monterey Beach Hotel (email: montereybeachresort.com)
2600 Sand Dunes Drive, Monterey, California 93940
Phone: (800) 242-8627 or (831) 394-3321
Fax: (831) 393-1912

FOR FURTHER INFORMATION, CONTACT:

Shock and Vibration Research
10150 Blue Larkspur Lane
Monterey, California 93940, USA
Phone/Fax (831) 375-4999, Cell: (831) 277-7117
Email: undex05@sbcglobal.net

Conference & Short Course Announcements

27th World Conference on Boundary Elements and other Mesh Reduction Methods

Wessex Institute of Techonology

March 15 - 17, 2005
Orlando, Florida, USA

The World Conference on Boundary Elements and other Mesh Reduction Methods, now in its 27th year is the internationally recognised Forum for the dissemination and the latest advances on Mesh Reduction techniques and their applications in sciences and engineering. BEM/MRM 27 aims to disseminate the latest research and applications in the field of Mesh Reduction techniques. The range of topics covered are listed on the website below. Papers of a more theoretical nature, as well as case studies, will also be welcome, including those dealing with computational issues and software development. For more information about this conference please visit http://www.wessex.ac.uk/conferences/2005/bem05/index.html.

Aerospace Testing Seminar

The Aerospace Corporation

March 22-24, 2005
Manhattan Beach, CA

The Aerospace Testing Seminar provides a forum to communicate and exchange knowledge about the improvement and implementation of aerospace testing technology that will benefit current and future space programs. Topics will include the need for effective testing in a challenging project environment with constrained budgets, increasing complexity of space systems, and more stringent design requirements. For more information about this conference please visit http://www.aero.org/conferences/ats/.

SAE 2005 World Congress

April 11-14, 2005
Detroit, MI, USA

The SAE World Congress is about the future direction of the automotive engineering technology, the opportunity to connect with the people influencing this industry and its products, and the contact with prospects and customers from the entire global automotive supply chain. Each year, for five days, 35,000+ of most influential professionals from the OE and supplier community assemble at the SAE World Congress. Join them, at SAE 2005, which will commemorate the Society's 100th Anniversary and a century worth of transportation events, people, and technological advancements that have helped to shape the automotive world. For more information about this event, please visit http://www.sae.org/congress/index.htm.

INDUSTRY NEWS

Peak Monitoring System Combines Amplifier and Peak Meter

Depew, NY - New Model 400B20 Peak Pressure Monitoring System from the Pressure Division of PCB Piezotronics, Inc., combines a dual mode amplifier module, a peak voltage monitoring module, and an AC power supply module into one integrated device. The unit connects directly with an ICP® or charge output piezoelectric sensor, normalizes sensor sensitivity, and displays peak transient measurement signals in voltage or pressure units. Ballistic testing applications include gun barrel chamber pressure testing and lot testing of ammunition. Alternate version is also available for force, vibration, shock, and impact applications.

The dual mode amplifier features continuous gain, and resetting or zeroing may be accomplished manually or remotely. Peak voltage monitoring module features dual set points that provide the ability to establish acceptable threshold levels. Alternative version for ballistic testing (Model 444A52) incorporates only the peak voltage monitoring module and AC power supply module. Model 444A52 provides ICP® signal conditioning, and may also be connected to an existing charge amplifier for use with charge output sensors. For additional information, contact the Pressure Division of PCB Piezotronics, Inc., toll-free at 888-684-0011, Email: pressure@pcb.com, Fax 716-686-9129, or visit www.pcb.com.

Intro Air Blast, con't from Page 4

ent transducer technologies was performed.

Measurement of air-blast phenomena is a challenging task for the test engineer or technician. Hopefully this work will provide comprehensive guidance where a lack of it now exists.

8. Whittier, Robert M., Reducing Transient Thermal Sensitivity of Silicon Diaphragm Pressure Transducers, Eleventh Transducer Workshop, Seattle, WA, available Secretariat Range Commander's Council, White Sands Missile Range, NM, pp. 292-301, June 2-4, 1981.

9. Kurtz, A. D., Ainsworth, R. W., Thorpe, S. J., Ned, A., Further Work on Acceleration Insensitive Semiconductor Pressure Sensors for High Bandwidth Measurements on Rotating Turbine Blades, NASA 2003 Propulsion Measurement Sensor Development Workshop, Huntsville, Alabama, May 13-15, 2003.

10. Kurtz, A. D., Ned, A. A., Epstein, A. H., Improved Ruggedized SOI Transducers Operational Above 600oC, Twenty-First Transducer Workshop, Lexington Park, MD, June 22-23, 2004.

A number of additional reference sources were consulted for this work. A few of the more valuable are noted below:

Hilten, John S., Vezzetti, Carol F., Mayo-Wells, J. Franklin, and Lederer, Paul S., Experimental Investigation of Means for Reducing the Response of Pressure Transducers to Thermal Transients, NBS Technical Note 961, National Bureau of Standards, Washington, DC, January 1978.

Hilten, John S., Vezzetti, Carol F., Mayo-Wells, J. Franklin, and Lederer, Paul S., A Test Method for Determining the Effect of Thermal Transients on Pressure-Transducer Response, NBS Technical Note 905, National Bureau of Standards, Washington, DC, January 1976.

Sachs, Donald C., Cole, Eldine, Air Blast Measurement Technology, Report Defense Nuclear Agency #DNA 4115F, work performed by Kaman Sciences Corp. (K-76-38U(R), Colorado Springs, CO, September 1976.

Guide for the Dynamic Calibration of Pressure Transducers, ISA-37.16.01-2002, Nov. 21, 2002.

For a complete set of the series, visit the Sound and Vibration website, www.sandv.com/home.htm

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Industry News

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