Abstracts

Review of Progress in Quantitative NDE

KI Convention Center – Green Bay, Wisconsin
July 27 – August 1, 2003

Organized by:

Center for Nondestructive Evaluation
Iowa State University

In cooperation with:

American Society for Nondestructive Testing

Ames Laboratory - U.S. Department of Energy

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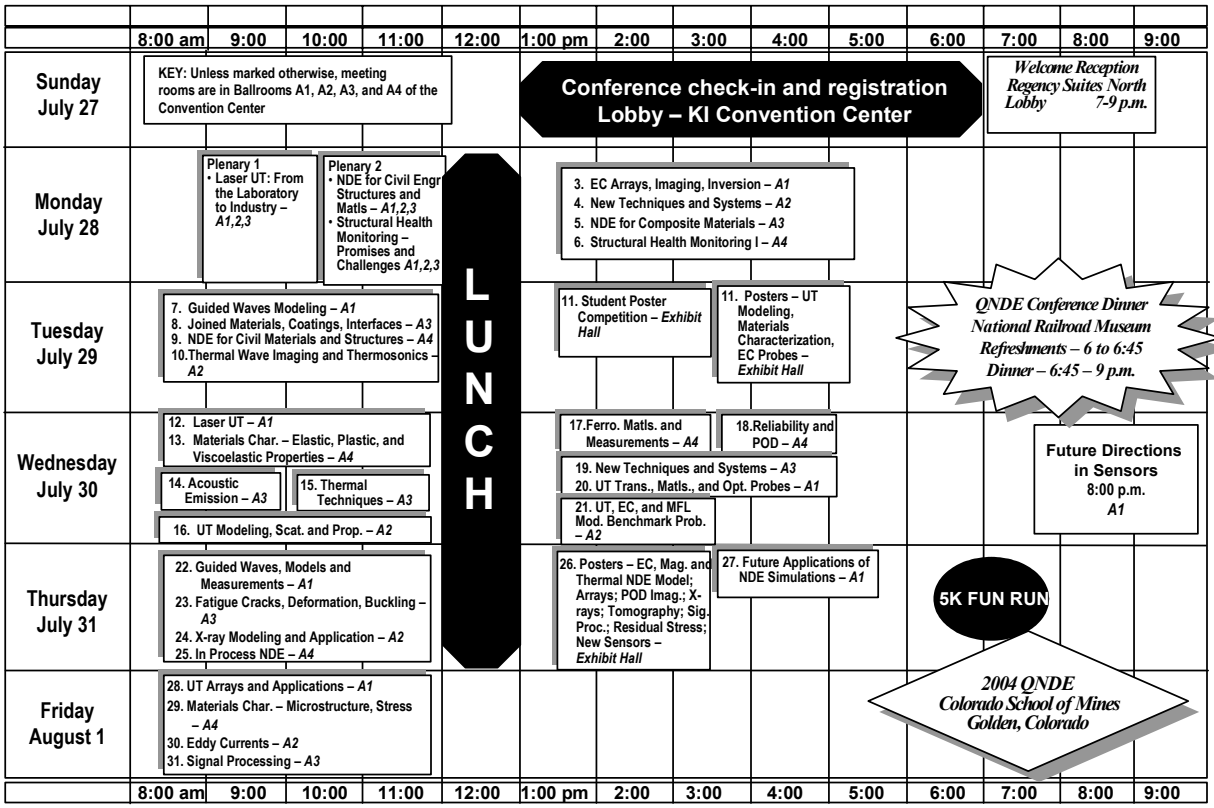
2003 Review of Progress in Quantitative NDE Program Summary



REVIEW OF PROGRESS IN QUANTITATIVE NDE

KI Convention Center
Green Bay, Wisconsin

July 27-August 1, 2003

PRELIMINARY PROGRAM

Monday, July 28, 2003

PLENARY SESSION 1

REVIEW OF LASER ULTRASONICS

R. B. Thompson, Chairperson

BR A1, 2, 3

9:00 AM ***Opening Remarks***

9:15 AM **Laser Ultrasonics: From the Laboratory to Industry**
---J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Quebec, J4B 6Y4, Canada

10:10 AM ***Coffee Break***

PLENARY SESSION 2

RENEWED AND EMERGENT NDE INTERESTS

D. E. Chimenti, Chairperson

BR A1, 2, 3

10:30 AM **Nondestructive Evaluation for Civil Engineering Structures and Materials**
---J. S. Popovics, The University of Illinois at Urbana-Champaign, 205 N. Mathews Avenue, MC 250, Urbana, IL 61801

11:20 AM **Structural Health Monitoring – Promises and Challenges**
---F.-K. Chang, Stanford University, Department of Aeronautics & Astronautics, School of Engineering, Durand Building, 496 Lomita Mall, Stanford, CA 94305-4035

12:10 PM ***Lunch***

Laser Ultrasonics: From the Laboratory to Industry

---Jean-Pierre Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Quebec, J4B 6Y4, Canada

---In this presentation, a broad overview of the field of laser-ultrasonics will be presented. This overview will draw from accomplishments and results obtained at the National Research Council of Canada as well as elsewhere. The principles of generation and detection will first be outlined, stressing a few key characteristics of laser-ultrasonics: the material is actually the emitting transducer and transduction is made by light, thus eliminating any contact. These features carry both advantages and limitations that will be explained. Another feature, which has been an impediment, is actually the complexity of the “laser-ultrasonic transducer”, but in spite of this complexity, it will be explained that it could be made very reliable for use in severe industrial environments. It also can be made very cost effective for a number of applications. Two applications that have reached some maturity for industrial usage, the inspection of polymer matrix composites used in aerospace and the thickness gauging of hot steel tubing in production will be presented. Perspectives for improving the laser-ultrasonic sensor, for making it even more cost effective and affordable and several potential applications will be reviewed.

Nondestructive Evaluation for Civil Engineering Structures and Materials

---John S. Popovics, The University of Illinois at Urbana-Champaign, 205 N. Mathews Avenue, MC 250, Urbana, IL 61801

---This paper describes the challenges associated with the application of non-destructive evaluation techniques for the civil engineering infrastructure. Significant inspection tasks and structural defects tasks are first defined. Theoretical bases and experimental requirements of several current NDE techniques are then described, where case studies of application of the described techniques to specific structures are highlighted. Limitations of the current technology in achieving the inspection goals are identified. Finally, discussion about the future direction of civil structure NDE, in terms of newly developed and promising NDE techniques, is presented.

Structural Health Monitoring: Promises and Challenges

---F.-K. Chang, Stanford University, Department of Aeronautics & Astronautics, School of Engineering, Durand Building, 496 Lomita Mall, Stanford CA 94305-4035

---Reliability, performance, and life cycle costs are the primary concerns for almost all in-service structures such as transportation systems, civil infrastructures, and medical devices, etc. It is envisioned that future structures will be made of multi-functional materials integrated with sensors, actuators, electronics, and intelligence software to perform multiple functions. With smart sensing and intelligent diagnostics, structural conditions can be monitored and residual life can be predicted while the structures are in service. Optimal structural performance could be achieved in operation because the actual structural conditions are better known in real time and because the structures are better designed to account for uncertainties. These structures shall only be maintained when needed, thus significantly reducing maintenance costs.

Recent advancement in materials, sensors, computations, informatics, and electronics has led significant progress in structural health monitoring (SHM) technology development. Although SHM has demonstrated promising applications in many engineering fields, many technical challenges exist because of the complexity of the systems and because of the technical barriers, which involve multidisciplinary engineering fields. This presentation will highlight recent progress in SHM technologies at Stanford University and also focus on technical challenges in three areas: Sensor devices, System integration/manufacturing, and Intelligence algorithms/software.

SESSION 3

EDDY CURRENT ARRAYS, IMAGING, AND INVERSION

J. Bowler, Chairperson

BR A1

1:30 PM **Deep Crack Detection Around Fastener Holes in Airplane Multi-Layered Structures Using GMR-Based Eddy Current Probes**
---T. Dogaru, Albany Instruments Inc., Charlotte, NC 28223; S. T. Smith, Center for Precision Metrology, UNC Charlotte, Charlotte, NC; C. H. Smith and R. W. Schneider, NVE Corporation, Eden Prairie, MN

1:55 PM **Eddy-Current Testing with GMR Magnetic Sensor Arrays**
---C. H. Smith and R. W. Schneider, Advanced Technology, NVE Corporation, Eden Prairie, MN; T. Dogaru, Albany Instruments, Inc., Charlotte, NC; S. T. Smith, Cameron Center for Precision Metrology, University of North Carolina at Charlotte, Charlotte, NC

2:20 PM **Absolute Property Imaging and Monitoring, Using MWM-Array Eddy Current Sensors**
---N. Goldfine, I. Shay, A. Washabaugh, D. Schlicker, and R. Lyons, JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013

2:45 PM **Flaw Imaging Using the Massively Multiplexed Eddy Current Technique**
---C. M. Hils, D. J. Brown, and J. Kyle, Zetec, Inc., 1370 N.W. Mall Street, Issaquah, WA 98027

3:10 PM ***Coffee Break***

3:30 PM **Inverse Methodology for Eddy Current Testing Using Multiple Transmitter-Receiver Coil Probes**
---F. Kojima, N. Goto, and N. Kawai, Graduate School of Science and Technology, Kobe University, 1-1, Rokkodai, Nada-ku, Kobe, Hyougo 657-8501

3:55 PM **A Multi-Frequency Eddy Current Inversion Method for Characterizing Water Jet Peened Aluminum Alloys**
---V. Sundararaghavan, K. Balasubramaniam, and R. Babu, Centre for Non-Destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Chennai, India

4:20 PM **System for Automatic Determination Coordinates of NDT Performer**
---S. Mayevskyy and K. Syeryy, National Technical University, Kiyv, Ukraine

4:55 PM **Inspection of Bare Printed Circuit Board Using Planar Type ECT Probe**
---S. Yamada and M. Iwahara, Institute of Nature and Environmental Engineering, Kazazawa University; T. Taniguchi, Faculty of Electrical and Communication Engineering, The University of Electro-Communications; H. Wakiwaka, Faculty of Engineering, Shinshu University

Deep Crack Detection Around Fastener Holes in Airplane Multi-Layered Structures Using GMR-Based Eddy Current Probes

---Teodor Dogaru, Albany Instruments Inc., Charlotte, NC 28223; Stuart T. Smith, Center for Precision Metrology, UNC Charlotte, Charlotte, NC; Carl H. Smith and Robert W. Schneider, NVE Corporation, Eden Prairie, MN

---Within aircraft industry there is an increasing need to inspect for cracks and flaws emanating from fastener holes located on the wing multi-layered structures of the airplanes. Presently lower-layer cracks are not found until the aircraft has been removed from service and some disassemble done. These cracks and flaws are causing troubleshooting and repair, which significantly add maintenance costs. Both rotational and linearly scanned eddy current probes based on giant magnetoresisitve (GMR) sensors have been developed to address this difficult problem. The high sensitivity of these magnetic sensors extends to the low frequencies required for deep penetration by the eddy currents. A portable eddy current system prototype has been successfully tested for real-time monitoring of this type of defects. Corner cracks of 0.1 inches in length were detected around holes at the bottom of a 0.5 inches thick two-layer structure. Results from specimens of thickness 0.45 inches having rows of fasteners and containing second-layer, real cracks are also presented in this paper.---This work has been supported by the US Air Force/WPAFB under contract numbers F33615-01-C-5207 and F33615-01-M-5219.

Eddy-Current Testing with GMR Magnetic Sensor Arrays

---Carl H. Smith and Robert W. Schneider, Advanced Technology, NVE Corporation, Eden Prairie, MN; Teodor Dogaru, Albany Instruments, Inc., Charlotte, NC; Stuart T. Smith, Cameron Center for Precision Metrology, University of North Carolina at Charlotte, Charlotte, NC

---The advent of GMR magnetic sensors and GMR sensor arrays with frequency-independent sensitivity offers improvements in speed, depth, and resolution in eddy-current testing. Arrays of GMR magnetic sensors allow rapid scanning of an area for defects in a single pass. The small size and low power consumption of these solid-state magnetic sensors enable the fabrication of compact arrays of sensors on circuit boards and even on-chip sensor arrays. Arrays have been fabricated with sensor spacing as small as 5 micrometers when fine resolution is required. Matrixed arrays of 30 micrometer elements have been constructed with 128 elements covering 4 mm. GMR sensor elements can be deposited on active silicon substrates facilitating on-chip signal processing and multiplexing. This integration simplifies the sensor/signal-processing interface, minimizes the number of leads, and can reduce the effect of noise. This paper will discuss the technology of fabricating arrays on GMR sensors, especially on-chip arrays. Integrated sensor arrays with on-chip signal processing and multiplexing will be described. Finally, some applications of arrays to crack and corrosion detection will be discussed.---This work supported by the Department of the Air Force/WPAFB under contract numbers: F33615-01-C-5207, F33615-01-M-5219, and F33615-00-C-5510 and by the National Science Foundation under contract number DMI-0216200.

Absolute Property Imaging and Monitoring, Using MWM-Array Eddy Current Sensors

---Neil Goldfine, Ian Shay, Andrew Washabaugh, Darrell Schlicker, and Robert Lyons, JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013

---This paper focuses on the use of model-based methods with MWM-Array eddy current sensors to provide C-scan images and local monitoring of absolute properties (i.e., conductivity, permeability, layer thickness). Precomputed data bases of sensor responses, called Measurement Grids, Lattices, or Hypercubes,
are used to provide property images for two, three, or more unknowns. Specific examples are provided for (1) magnetic permeability imaging for precrack fatigue damage in steels, (2) material loss images to map hidden corrosion in lap joints, (3) imaging and detection of surface and subsurface cracks, and (4) embedded sensors arrays for monitoring usage and fatigue. This paper will specifically address the value of absolute property estimation, using model based methods.

Flaw Imaging Using the Massively Multiplexed Eddy Current Technique

---Chris M. Hils, David J. Brown, and Jeff Kyle, Zetec, Inc. 1370 NW Mall Street, Issaquah, WA 98027

---The characterization of discontinuities in metallic structures using Eddy Current Testing presents a major challenge to the nondestructive testing community. Many attempts have been made at the deconvolution of Eddy Current test data to reproduce the mechanical dimensions of a discontinuity. This paper presents a new tool for this effort, using an Eddy Current instrument capable of multiplexing a very large number of frequencies. This technique, herein referred to as Massively Multiplexed Eddy Current, allows frequency or time domain display of Eddy Current data. A basic attempt is made at using this data to determine distance from the Eddy Current sensor to the discontinuity and thereby allow imaging of that discontinuity.

Inverse Methodology for Eddy Current Testing Using Multiple Transmitter-Receiver Coil Probes

---Fumio Kojima, Nanaka Goto, and Nobuhiro Kawai, Kobe University, Graduate School of Science and Technology, 1-1, Rokkodai, Nada-ku, Kobe, Hyougo 657-8501

---Detection of multiple cracks on the subsurface of SUS304 component is a critical issue for safety operation of power plants. We have developed the inverse methodologies for recovering a stress corrosion crack (SCC) on steam generator tubes using the single transmitter-receiver probe. Evolutionary programming has been successfully tested for JSAEM benchmark problem. In this paper, the idea is extended to the identification of multiple cracks on the subsurface of SUS304 test sample. The set of multiple coil probes works as a single transmitter coil and multiple magnetic sensors. Effective scanning strategies are discussed to detect multiplicity of cracks and its orientation of each crack. These procedures make it possible to set up the admissible parameter class of inverse problems to be solved. The simple forward model driven by the admissible set of cracks is developed from the conventional eddy current model. The output least square error problem is formulated for identifying multiple cracks. The optimization scheme using virus evolutionary genetic algorithm (VEGA) is proposed. The effectiveness and validity of the proposed algorithm will be demonstrated in the presentation.

A Multi-Frequency Eddy Current Inversion Method for Characterizing Water Jet Peened Aluminum Alloys

---Veeraraghavan Sundararaghavan, Krishnan Balasubramaniam, and Ramesh Babu, Centre for Non-Destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Chennai, India

---This paper describes a multi-frequency eddy current inversion procedure for characterizing specimens that are water jet peened. Multi frequency inductance data was obtained using well characterized eddy current probes. The inversion uses a multilayer axi-symmetric FEM model; the conductivity of each layer is obtained through interpolation of the inductance-frequency data generated by this model. Skin depth approximation was used to isolate the integral effects of the conductivity variation on the inductance signal. Inverted conductivity profiles of water jet peened specimens closely resemble the predicted profiles. Information regarding the depth of reversal of residual stresses and relative intensities of peening were inferred from the conductivity profiles.

System for Automatic Determination Coordinates of NDT Performer

---S. Mayevskyy and K. Syeryy, National Technical University, Kiyv, Ukraine

---The basic lack of many NDT instruments with manual scanning is subjectivity of an estimation of result of the testing. For elimination of this lack it is necessary automatic registration as trajectories of scanning, and coordinates of position of the found out defects and their sizes. Such system is capable not only to exclude subjectivity at realization, but also to carry out monitoring for the defects. We develop the system for automatic determination of position of the Eddy Current performer in three-dimensional testing area of objects with a non-plane surface. Determination of coordinates of the performer during manual scanning is carried out by measurement of angular coordinates of two photo diodes on an axis of this performer concerning three optical receivers of radiations and the subsequent calculation of coordinates the active part of the performer as a point on direct line. Receivers of optical radiations are established on the ends of some base what limited width of the testing area. Accuracy of system for determination of coordinates is equal 0,1 mm at speed of scanning up to 10 mm/s. The system can be used for acoustic and Eddy Current NDT instruments by simple connections for removing analog or digital signals proportional to size of defect.

Inspection of Bare Printed Circuit Board Using Planar Type ECT Probe

---Sotoshi Yamada, Masayoshi Iwahara, Instiitute of Nature and Environmental Engineering, Kazazawa University; Tetsuki Taniguchi, Faculty of Electrical and Communication Engineering, The University of Electro-Communications; Hiroyuki Wakiwaka, Faculty of Engineering, Shinshu University

---The eddy-current testing technique gives a new skill for inspection of bare printed circuit board (PCB). The combination of the high-sensitive micro ECT probe and the image processing technique enables us to detect damage(disconnection, chipping crack, imperfection of thickness and short circuit) on the trace of bare PCB. We discussed both the structure of the planar type probe and the image processing. This paper deals with the probe structure and characteristics to apply the ECT approach to high-density PCB with narrow trace width. We proposed the ECT probes of the meander coil (transmitter) and micro solenoid coil (receiver) for our purpose. The exciting coil (transmitter) is the meander coil to effectively induce eddy currents along the trace. The high frequency excitation up to 5 MHz enables us to detect the disconnection on the trace of 200 micrometer width and 35 micrometer depth. The ECT image includes many kinds of signal originated from not only disconnections and but also PCB pattern. Only the defect signal is selected by the image processing for example pattern matching method. We will fabricate a new probe made of meander coil and SV-GMR. The probe will give higher resolution to the inspection of PCB.

SESSION 4
NEW TECHNIQUES AND SYSTEMS
A. Minachi, Chairperson
BR A2

1:30 PM **Quantitative Detection of Defects Inside of Tires**
---K.-S. Kim and I.-Y. Yang, Department of Mechanical Information Engineering, Chosun University, Gwangju, South Korea; K.-S. Kang, Graduate School, Chosun University, Gwangju, South Korea

1:55 PM **Ultrasonic Signal Processing for Structural Health Monitoring**
---J. E. Michaels and T. E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

2:20 PM **Automated Measurement of Corrosion Damage Using Edge of Light Technique**
---Z. Liu, D. S. Forsyth, A. Marincak, and P. Vesely, Institute for Aerospace Research, National Research Council Canada, Montreal Road 1191, Building M-14, Ottawa, Ontario, K1A 0R6 Canada

2:45 PM **Climbing, Walking, and Swimming Robots for Nondestructive Testing in the Nuclear Power, Aerospace, Shipping, and Petrochemical Industries**
---B. Bridge, S. Chen, and T. Sattar, Research Centre for Automated and Robotic Nondestructive Testing, Faculty of Engineering, Science and Technology, London South Bank University, 103 Borough Road, London SE1 0AA, United Kingdom

3:10 PM ***Coffee Break***

3:30 PM **Structural Anomaly Mapping (SAMTM) System for Airframe Inspection: Data Acquisition/Detectability Testing**
---W. Hassan, L. Schaefer, and T. Duffy, Honeywell Engines, Systems and Services, 1944 E. Sky Harbor Circle North, Phoenix, AZ 85034; J. Edwards, D. MacEnany, C. Morel, and S. Rossenwasser, Advanced Power Technologies, Inc., 1250 N.W. 24th Street, Suite 815, Washington, DC 20037

3:55 PM **Monitoring of Loading of Long-Life Structures**
---V. Makhnenko, E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine, 11 Bozhenko Street, 03880, Kyiv, Ukraine

4:20 PM **N-SCAN®: New Vibro-Modulation System for Detection, Monitoring and Characterization**
---D. Donskoy, A. Ekimov, A. Zagrai, and S. Stoupin, Civil Engineering Department, Davidson Laboratory, Stevens Institute of Technology, Hoboken, NJ 07030

4:55 PM **Thermal Testing of Buildings Based on Quantitative Methods**
---O. V. Lebedev and V. G. Avramenko, Physics Department, Moscow State University, Moscow, Russia, Technical Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, WEMO, Moscow, Russia; O. N. Budadin and E. V. Abramova, Technical Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, WEMO, Moscow, Russia

Quantitative Detection of Defect Inside of Tires

---Koung-Suk Kim and In-Young Yang, Department of Mechanical Information Engineering, Chosun University, Gwangju, South Korea; Ki-soo Kang, Graduate School, Chosun University, Gwangju, South Korea

---In recent years, shearography has significantly improved capabilities in the areas of unbond and separation detection in tires. Although shearography has many advantages for qualitative evaluation, the technique remains the problem of quantitative analysis of inside defects, because shearography needs several effective factors including the amount of shearing, shearing direction and induced load, which exist as barrier for the quantitative analysis of inside defects. Since the factors are highly dependent on inspector's skill and also affect the in-situ workability. The factors were optimized and the size of cracks inside of pipeline and tire has been quantitatively determined.

Ultrasonic Signal Processing for Structural Health Monitoring

---Jennifer E. Michaels and Thomas E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332-0250

---Permanently mounted ultrasonic sensors are a critical component of systems under development for monitoring the health of complex and critical structures such as aircraft, bridges and buildings. Most proposed systems consist of a fixed network of ultrasonic sensors either attached to, embedded in, or adjacent to the structure, and these sensors could be piezoelectric, fiber optic, MEMS, or air-coupled, with a single sensor possibly acting as both transmitter and receiver. Regardless of the specific sensor technologies employed and the physical organization of the sensors, processing of the received ultrasonic signals plays a critical role in the viability of the overall system. Since the sensors are permanently mounted at known locations and with fixed coupling conditions, it is appropriate to consider methods that look at quantitative differences in the signals over time and to relate those differences to changes in the structure or the environment. This paper specifically considers the issues of determining if the received signal from a specific sensor has changed, quantitatively characterizing the change, and classifying the nature of the change. Results are presented from piezoelectric discs bonded to a number of different specimens subjected to both environmental changes and introduction of artificial defects.

Automated Measurement of Corrosion Damage Using Edge of Light Technique

---Zheng Liu, David S. Forsyth, Anton Marincak, and Philip Vesely, Institute for Aerospace Research, National Research Council Canada, Montreal Road 1191, Building M-14, Ottawa, Ontario, K1A 0R6 Canada

---In this study, the results of estimating "pillowing" deformations in aircraft fuselage lap joints caused by corrosion using Edge of Light™ (EOL) technique will be presented. The EOL is a computer vision based surface inspection system invented and developed at the Institute for Aerospace Research of the National Research Council Canada. Hidden corrosion in aircraft fuselage lap joints causes "pillowing" or a bulging between fasteners due to the increased volume of corrosion products over the undamaged aluminum. The EOL inspection converts changes in surface slope to changes of light intensity in the scanned image. A fully automated procedure based on EOL for quantifying the pillowing deformation, and thus the amount of material converted to corrosion products, has been developed. A fast analysis can be implemented by evaluating the one-dimensional brightness profile between the adjacent rivet centers. To fully automate the evaluation procedure, the rivet centers need to be located so that the profile can be extracted. The algorithms to locate rivets are presented. Experiments on estimating surface pillowing were carried out, and results were compared with the actual pillowing.

Climbing, Walking and Swimming Robots For Non-Destructive Testing in The Nuclear Power, Aerospace, Shipping and Petrochemical Industries

---B. Bridge, S. Chen, and T. Sattar, Research Centre for Automated and Robotic Non-destructive Testing, Faculty of Engineering, Science and Technology, London South Bank University, 103 Borough Road, London SE1 OAA, United Kingdom

---This paper describes the development of some world first designs and prototypes of climbing, walking and swimming robots for the non-destructive inspection of safety critical civil and industrial engineering structures such as aircraft, ships, dams, nuclear power plant and storage tanks located in hazardous environments and in liquids at the Centre for Automated and Robotic Non-Destructive Testing (NDT), South Bank University, UK. The common feature of the systems is that they can move over surfaces of complex contour to deploy the inspection sensors at each test point and/or are able to scan large test areas. The rationale for this approach to NDT data acquisition is presented. General design criteria including generic systems approaches and the use of modular components for rapid prototyping.

Structural Anomaly Mapping (SAMTM) System for Airframe Inspection: Data Acquisition/Detectability Testing

---Waled Hassan, Lloyd Schaefer, and Tim Duffy, Honeywell Engines, Systems, and Services, 1944 E. Sky Harbor Circle N., Phoenix, AZ 85034; Jonathan Edwards, Dave MacEnany, Caroline Morel, and Stu Rossenwasser, Advanced Power Technologies, Inc., 1250 NW 24th Street, Suite 815, Washington, DC 20037

---Airframe nondestructive inspection techniques for current and future generations of civil and military aircraft are critical for minimizing maintenance costs and complying with airworthiness regulations. The recent innovative developments of the Structural Anomaly Mapping system (SAM(TM)) by Honeywell International Inc. provide a comprehensive solution to address these challenges. This collection of fully automated scalable robotic systems allows complete inspections of airframes using non-invasive sensing techniques, whether in a fully crewed hangar maintenance bay, in the aircraft interior, or on-wing on the carrier deck. The SAM(TM) whole life airframe management system can provide a quick comparison of results across a fleet of aircraft to detect early indications of fleet-wide problems. This can reduce the manpower dedicated to these activities while improving early detection of airframe defects. In this paper an overview of the SAM(TM) system will be presented. The acoustic laser Doppler acquisition system and test setup will be discussed. The current SAM(TM) capability includes the reliable detection of 1 inch unbonds and delaminations in composite face-sheet/honeycomb core structures, less than 10% metal loss in riveted lap joints, and 1 inch or less impact damage in composite/honeycomb samples. Furthermore, the reliable detection of core repairs (potted cores) and back face unbonds is demonstrated. Several application examples will be discussed to illustrate the data acquisition and signal processing capability of the system.

Monitoring of Loading of Long-Life Structures

---Vladimir Makhnenko, E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine 11, Bozhenko Street, 03880, Kyiv, Ukraine

---Monitoring of an actual level of loading of critical long-life structures is one of the chief problems of advanced approaches to ensuring their safe operation, and is one of the key interests of the QNDE area. This problem is given currently a substantial consideration all over the world. Special systems for monitoring of loading of modern bridges, overpasses, tunnels, plates, stadium stands etc. are being developed. The purpose of such monitoring is to generate comprehensive data on an actual level of loading, especially at the "hot spots" of structures, predict the risk of initiation (propagation) of defects and estimate residual safe life of structures. Large number of the "hot spots" in actual structures, multiaxial stressed state in these zones, high requirements for reliability during a long-time service of a structure without replacement present considerable problems for generation of a comprehensive information by traditional QNDE methods. In this connection, of interest are the combined systems for monitoring of loading. Here traditional QNDE methods are employed to determine kinetics of variations in nominal strains (stresses) in main links (elements) of structures, and then special computational algorithms and computer programs are used to determine kinetics of elasto-plastic deformations at the "hot spots". The paper describes development of such systems for welded structures with welded joints considered to be the "hot spots". Computation modules have been developed, allowing modeling of kinetics of elasto-plastic deformations in zones of typical welded joints with corresponding variations in nominal stresses and temperatures. This serves as a good basis for estimation of risks of initiation and evolution of various defects associated with corrosion effects, creep, embrittlement and fatigue of a material.

N-SCAN®: New Vibro-Modulation System for Detection, Monitoring and Characterization

---Dimitri Donskoy, Alexander Ekimov, Andrei Zagrai, and Stanislav Stoupin, Stevens Institute of Technology, Civil Engineering Department, Davidson Laboratory, Hoboken, NJ 07030

---In recent years, innovative vibro-modulation technique has been introduced for detection of contact-type interfaces such as cracks, debondings, and delaminations. The technique utilizes the effect of nonlinear interaction of ultrasound and vibrations at the interface of the defect. Vibration varies the contact area of the interface modulating passing ultrasonic wave. The modulation manifests itself as additional side-band spectral components with the combination frequencies in the spectrum of the received signal. The presence of these components allows for detection and differentiation of the contact-type defects from other structural and material inhomogeneities. Vibro-modulation technique has been implemented in N-SCAN damage detection system providing a cost effective solution for the complex NDT problems. N-SCAN® proved to be very effective for damage detection and characterization in structures and structural component of simple and complex geometries made of steel, aluminum, composites, and other materials. Examples include 24 foot-long gun barrels, stainless steel pipes used in nuclear power plants, aluminum automotive parts, steel train couplers etc. This paper describes the basic principles of nonlinear vibro-modulation NDE technique, some theoretical background for nonlinear interaction and justification of signal processing algorithms. The laboratory experiment is presented for a set of specimens with the calibrated cracks and the quantitative characterization of fatigue damage is given in terms of modulation index. The paper also discusses examples of practical implementation and application of the technique.

Thermal Testing of Buildings Based on Quantitive Methods

---Oleg V. Lebedev and Vladimir G. Avramenko, Moscow State University, Physics Department, Moscow, Russia; Technical Institute of Energetic Investigations, Diagnostic and Nondestructive Testing “WEMO”, Moscow, Russia; Oleg N. Budadin and Elena V. Abramova, Technical Institute of Energetic Investigations, Diagnostic and Nondestructive Testing “WEMO”, Moscow, Russia

---The problem of redundant thermal losses through the outdoor protecting structures of buildings is actual in northern countries due to inclement climate. Reduced resistance of heat transfer (RRHT) of building’s walls is the numerical characteristic of materials forming the wall. The experimental definition of RRHT of building’s walls is based on solution of inverse problem of nonstationary heat conductivity. It has been realized the numerical calculations based on the physical-mathematical NDT model adequate to real NDT process. The problem of definition of the characteristics of materials forming the wall can be reduced to the minimizing of functional. This functional displays us the degree of deviation of experimentally obtained temperature from theoretically calculated temperature based on solution of direct problems. The direct problem is solved using Crank-Nicolson scheme second order of time and space. The final form of functional depends on two parameters: thermal conductivity coefficient (TCC) and heat transfer coefficient. The search of global minimum of functional is based on the selection of the TCC from many direct problems. The TCC minimizing the functional is used to define RRHT for chosen zone of wall. Using spatial distribution of thermal field of whole building (from IR camera) it is determined RRHT for whole building.

SESSION 5
NDE FOR COMPOSITE MATERIALS
BR A3

1:30 PM **Microstructural and Defect Characterization in Ceramic Composites Using an Ultrasonic Guided Wave Scan System**
---D. J. Roth[1], L. M. Cosgriff[2], R. E. Martin[2], M. J. Verrilli[1], and R. T. Bhatt[1], [1]NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135; [2]Cleveland State University, 21000 Brookpark Road, Cleveland, OH 44135

1:55 PM **Flaw Detection in Composites Using Vibration FRF Autocorrelation**
---B. A. Basantharao and S. J. Pardue, Department of Mechanical Engineering, Tennessee Technological University, 115 W. 10th Street, BN 224, Cookeville, TN 38505

2:20 PM **Variability of Ultrasonic Attenuation Measurements in RTM Composites: Theory and Measurements**
---S. Lonné and A. Lhémery, LIST, Commissariat à l'Energie Atomique, Saclay, France; F. Thévenot, Centre de Dévelopement Exploratoire, Dassault Aviation, France

2:45 PM **Application of Air-Coupled Ultrasound in NDE of Composite Space Structures**
---D. K. Hsu, D. J. Barnard, and J. J. Peters, Iowa State University, Center for NDE, Ames, IA 50011; D. L. Polis, Swales Aerospace Materials Engineering Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771

3:10 PM ***Coffee Break***

3:30 PM **Air-Coupled Ultrasonic Measurements in Composites**
---V. Kommareddy, J. J. Peters, V. Dayal, and D. K. Hsu, Iowa State University, Center for NDE, Ames, IA 50011

3:55 PM **Impact on the Mechanical Integrity of Carbon Fiber Reinforced Composite Plates Incorporating Embedded Piezoceramic Transducers**
---A. Gachagan, B. Hailu, A. McNab, and G. Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, G1 1XW; W. Lang, J. Hendry, and W. Banks, Centre for Advanced Structural Materials, University of Strathclyde, Glasgow, G1 1XW

4:20 PM **Quantitative Inversion Algorithm for Near-Field Microwave NDE of Disbonds in Multilayer Composites**
---M. A. Abou-Khousa and N. N. Qaddoumi, Microwave Imaging and Nondestructive Evaluation Laboratory (minel), Electrical Engineering Program, School of Engineering, American University of Sharjah, P. O. Box 26666, Sharjah, UAE

4:45 PM **Modeling of Ultrasonic Attenuation in Unidirectional Fiber Reinforced Composites Combining Multiple-Scattering and Viscoelastic Losses**
---S. Lonné, A. Lhémery, and P. Calmon, LIST, Commissariat à l'Energie Atomique, Saclay, France; S. Biwa, Department of Micro System Engineering, Nagoya University, Japan; F. Thévenot, Centre de Développement Exploratoire, Dassault Aviation, France

Microstructural and Defect Characterization in Ceramic Composites Using an Ultrasonic Guided Wave Scan System

---Don J. Roth[1], Laura M. Cosgriff[2], Richard E. Martin[2], Michael J. Verrilli[1], and Ramakrishna T. Bhatt[1], [1]NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135; [2]Cleveland State University, 21000 Brookpark Road, Cleveland, OH 44135

---In this study, the ultrasonic guided wave scan system under development at NASA Glenn Research Center was used to characterize various microstructural and flaw conditions in ceramic matrix composites. SiC/SiC and C/SiC composites, under development for advanced aerospace applications, were examined. Rather than attempting to isolate specific lamb wave modes to use for characterization (as is desired for many types of guided wave inspection problems), the guided wave scan system utilizes the total ultrasonic response (i.e., a mixed or combined mode response) in its inspection analysis. Several time- and frequency-domain parameters are calculated from the ultrasonic guided wave signal at each scan location to form images. Microstructural and defect conditions examined include delamination, cracking, density variation, and pre/post-infiltration. Results are compared with some of the more conventional NDE imaging methods. Although guided wave techniques are generally used so scanning can be eliminated, applying the techniques in the scanning mode allows a more precise characterization of defect conditions.

Flaw Detection in Composites Using Vibration FRF Autocorrelation

---Brahmaji A. Vasantharao and Sally J. Pardue, Tennessee Technological University, Department of Mechanical Engineering, 115 W. 10th Street, BN 224, Cookeville, TN 38505

---Flaw detection in composite beams is presented using an autocorrelation method on frequency response functions (FRFs) obtained from transverse vibration of a specimen. Signature plots that are representative of the damage state of the specimen were obtained experimentally by plotting autocorrelated magnitudes of the FRF data from laser vibrometer data. Flaws were detected by identifying extra peaks in the signature plot obtained from the damaged specimen when compared to that obtained from an undamaged specimen. In addition, this work also explored how capturing two close modes helped detect relatively small flaws that were not detected when the close modes were not captured. ANSYS was used to perform numerical analysis on solid models to confirm the experimental work. The frequency values and numerically generated signature plots obtained from ANSYS matched well with those from the experiment.

Variability of Ultrasonic Attenuation Measurements in RTM Composites: Theory and Measurements

---Sébastien Lonné and Alain Lhémery, LIST, Commissariat à l'Energie Atomique, Saclay, France; Françoise Thévenot, Centre de Dévelopement Exploratoire, Dassault Aviation, France

---RTM (resin transfer molding) technique of composite manufacturing is effective to build components possibly thick and of complex shape (e.g., in aeronautics). RTM parts are manufactured by arranging plies in a mould, each ply being made of a few (e.g., three) unidirectional layers in specific directions to produce specific reinforcement symmetry. Resin is then injected in the mould. This process often leads to an inner structure where plies are not perfectly parallel but rather exhibit a wavy structure. Ultrasonic testing of RTM parts is challenging since elastic wave attenuation in this material is both strongly variable and possibly high. The present paper aims at explaining this variability. For this, the various physical phenomena at different scales that can cause attenuation of ultrasonic waves in RTM are modeled: i) coupling of multiple scattering by fibers and viscoelastic losses in the surrounding resin matrix, ii) viscoelastic losses in layers of pure matrix, iii) scattering by porosity, iv) scattering by irregular geometry of interfaces between plies. These models are used together in a overall model of wave propagation allowing us to conduct a statistical study in which various structural parameters are varied. Variability of result amplitudes simulated this way successfully explains experimental measurements.

Application of Air-Coupled Ultrasound in NDE of Composite Space Structures

---David K. Hsu, Daniel J. Barnard, and John J. Peters, Iowa State University, Center for Nondestructive Evaluation, Ames, IA 50011; and Daniel L. Polis, NASA Goddard Space Flight Center, Swales Aerospace Materials Engineering Branch, Greenbelt, MD 20771

---In order to accommodate the combined weight of the Hubble Space Telescope (HST) Servicing Mission 4 payload, NASA needed to increase the carrying efficiency of the support structures in the Shuttle's payload bay (or leave hardware on the ground). To this end, NASA and its partners are designing and building a special composite pallet known as the Super Lightweight Interchangeable Carrier (SLIC). When conventional water-coupled ultrasonic scans are used for inspecting such structures, time-consuming water-proof or bake-out procedures need to be followed to avoid water ingression and potential effects on dimensional tolerance or material properties. Furthermore, a crucial design driver was minimizing cross contamination from SLIC onto Wide Field Camera 3 (a new scientific instrument for HST), which is housed on SLIC. For this reason, air-coupled ultrasound has distinct advantages as a non-contact inspection method. In this work, air-coupled ultrasonic scans are used for imaging defects in carbon fiber reinforced cyanate ester composite facesheets and honeycomb sandwich panels. Sensitivity and resolution of airscans for imaging engineered flaws were studied using 120 and 400 kHz transducers with and without focusing. In addition, conical attachments were also used to enhance the resolution. Experimental results showed that diffraction and resonance effects were more readily observed in low frequency airscans than in conventional water-coupled ultrasonic imaging. It was also demonstrated in this work that an air-coupled ultrasonic instrument can be integrated with various immersion and squirter scanning systems for inspecting composite structures in air.---The material is based upon work supported by NASA under award No. NAG-1-02098.

Air-Coupled Ultrasonic Measurements in Composites

---Vamshi Kommareddy, John Peters, Vinay Dayal, and David K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Air-coupled ultrasound is a non-contact technique and has clear advantages over water-coupled testing. Research of air-coupled ultrasonics, especially using capacitance and micromachined transducers, has been extensively reported in the literature. This paper reports our experience of applying piezoceramic air-coupled transducers for nondestructive evaluation of composites. The beam profiles of air-coupled piezoceramic transducers, with and without apodization, were mapped out. The transmission of air-coupled ultrasonic energy through composite plates of different thickness was measured experimentally; model calculation of the transmission coefficient, taking into account the frequency bandwidth of the transducer, is also underway. The occurrence of diffraction phenomenon ("Poisson bright spot") while imaging flaws in composite laminates was investigated. The resolution of scanned images obtained with air-coupled transducers was investigated for different frequency, focusing, and apodization conditions. Air-coupled transmission scan results will be presented for a variety of composite materials and structures, from thin laminates and honeycomb sandwiches to thick composite rocket
case.---This work was supported by the NSF Industry/University Cooperative Research Center for Nondestructive Evaluation at Iowa State University.

Impact on the Mechanical Integrity of Carbon Fiber Reinforced Composite Plates incorporating Embedded Piezoceramic Transducers

---A. Gachagan, B. Hailu, A. McNab, and G. Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, G1 1XW; W. Lang, J. Hendry, and W. Banks, Centre for Advanced Structural Materials, University of Strathclyde, Glasgow, G1 1XW

---This paper describes the integration of piezoelectric ceramic transducers within a carbon fiber reinforced polymer (CFRP) composite plate for the generation of a pure, zeroth order symmetric (S0) ultrasonic Lamb wave. The lateral dimensions of the transducers were in the order of 5mm - 20mm, which were considered suitable for practical embedding purposes. The composite plate configuration used throughout is a uni-directional structure, with the transducer embedded exactly within the centre. This simplified both the manufacturing process and provided a convenient solution to enable advanced modeling of the embedded transducer behavior. The critical parameters addressed were robustness of the active piezoceramic transducer during the implantation process; orientation of transducer relative to the thickness of the CFRP plate; maintaining high quality electrical connections to the piezoceramic element; efficiency of S0 Lamb wave generation; and overall impact on the structural integrity of the plate. The mechanical integrity of composite plates was measured through both conventional c-scans and four point flexural tests. Importantly, degradation of the flexural modulus is shown to be less than 10% for the embedded transducer configuration. Finally, the transducer was observed to continue operating in pulse-echo mode when a load in excess of 3500N was applied to the plate structure.

Quantitative Inversion Algorithm for Near-Field Microwave NDE of Disbonds in Multilayer Composites

---Mohamed A. Abou-Khousa and Nasser N. Qaddoumi, American University of Sharjah, School of Engineering, Microwave Imaging and Nondestructive Evaluation Laboratory (minel), Electrical Engineering Program, P. O. Box 26666, Sharjah, UAE

---Near-field microwave NDE systems utilizing open-ended rectangular waveguides constitute a competent candidate to detect and evaluate planner disbonds in multilayer composite structures. Basically, the waveguide based sensor illuminates the structure with a microwave signal and monitors the reflected waves. Minute variations in the properties of the structure cause measurable variation in the reflection coefficient at the waveguide aperture. The functional dependence of reflection coefficient on the disbond's physical properties—i.e. thickness and depth—is exploited in the detection schema. Upon measuring the reflection coefficient, the inverse problem of disbond's thickness and depth determination should be solved. This problem is ill-posed in nature and requires sophisticated algorithm to be inverted quantitatively. In this paper, we will introduce a Fuzzy-Maximum-Likelihood hybrid algorithm to be applied in conjunction with multi-frequency measurements to solve the inverse problem. While a fuzzy system is used as a filter to narrow down the range of possible solutions, the solution with maximum likelihood value will be picked form the filtered range. Furthermore, the multi-frequency measurements will provide diversity gain over the uncertainties embedded in the system. The practical potential of the proposed algorithm will be demonstrated in real life microwave NDE application. Finally, the performance of the algorithm under measurement noise will be simulated and analyzed.

Modeling of Ultrasonic Attenuation in Unidirectional Fiber Reinforced Composites Combining Multiple-Scattering and Viscoelastic Losses

---Sébastien Lonné, Alain Lhémery and Pierre Calmon, LIST, Commissariat à l'Energie Atomique, Saclay, France; Shiro Biwa, Nagoya University, Department of Micro System Engineering, Japan; Francoise Thévenot, Centre de Développement Exploratoire, Dassault Aviation, France

---Unidirectional Carbon-epoxy composite with high fiber volume fraction exhibits attenuation of ultrasonic waves. Various attempts for accurately modeling physical phenomena leading to attenuation have been undertaken. Very few consider together multiple-scattering and viscoelastic effects; if so, the two phenomena are considered to simply superimpose. Here, a model combining both effects is developed, where the two phenomena are coupled. It considers waves of various polarities defined relatively to the fiber direction. Whatever the wave polarity (shear-vertical SV, shear-horizontal SH, compression-longitudinal L), the proposed model considers a direction of propagation perpendicular to the fiber direction. The SH case only requires a scalar treatment since no mode-conversion occurs, whereas the two others require a full vector treatment accounting for mode-conversion phenomena in the fiber scattering process. The model uses classical multiple-scattering theory combined with the use of complex-valued stiffness constants implicitly accounting for wave attenuation and therefore modeling viscoelastic losses. Predictions of attenuation levels (given as amplitude factors in the form of frequency dependent filters) are compared with experimental measurements for the three polarities considered as well as with other predictions based on different modeling approaches for different volume fraction of fibers. These comparisons validate the present model and demonstrate its pertinence.

SESSION 6
STRUCTURAL HEALTH MONITORING I
J. Barnes, Chairperson
BR A4

1:30 PM **Generalized Health Management for Airframe Structure**
---A. Bartolini, R. M. Kent, and T. E. Munns, ARINC Engineering Services, LLC, MS 1-245, 2551 Riva Road, Annapolis, MD 21401

1:55 PM **A Structural Health Monitoring System Based on Continuous Acoustic Emission Sensors**
---M. J. Sundaresan and G. Grandhi, Department of Mechanical Engineering, Intelligent Structures and Mechanisms Laboratory, North Carolina A&T State University, Greensboro, NC 27411; M. J. Schulz, Department of Mechanical Engineering, Smart Structures Bio-Nanotechnology Laboratory, University of Cincinnati, Cincinnati, OH 45221-0072

2:20 PM **A Cellular System for Wireless Structural Integrity Monitoring**
---G. Benny, K. Steel, A. McNab, and G. Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, Scotland, United Kingdom

2:45 PM **Defect Monitoring of Airframe Structure Using Shear-Horizontal Guided Wave Generated with a Magnetostrictive Sensor**
---G. M. Light, S. Y. Kim, H. Kwun, and R. L. Spinks, Sensor Systems and NDE Technology Department, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238

3:10 PM ***Coffee Break***

3:30 PM **Lamb-Wave Embedded NDE with Piezoelectric Water Active Sensors for Structural Health Monitoring of Thin-Wall Structures**
---V. Giurgiutiu, Department of Mechanical Engineering, University of South Carolina, Columbia, SC 29208

3:55 PM **Structural Health Monitoring of Anisotropic Layered Composite Plates Using Guided Ultrasonic Lamb Wave Data**
---M. Prasad, S. Jagannathan, K. Balasubramaniam, and C. V. Krishnamurthy, Centre for Non-Destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Chennai, India

4:20 PM **Sparse Ultrasonic Transducer Array for Structural Health Monitoring**
---T. E. Michaels and J. E. Michaels, Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

4:55 PM **On-Line Health Monitoring for Advanced Reactor Designs**
---N. Nakagawa, F. Inanc, and R. B. Thompson, Iowa State University, Ames Laboratory and Center for NDE, Ames, IA 50011; W. R. Junker, F. H. Ruddy, J. M. Beatty, and N. G. Arlia, Science & Technology Department, Westinghouse Electric Company, Pittsburgh, PA 15235

Generalized Health Management for Airframe Structure

---Antony Bartolini, Renee M. Kent, and Thomas E. Munns, ARINC Engineering Services, LLC, MS 1-245, 2551 Riva Road, Annapolis, MD 21401

---ARINC has been conducting research with NASA Langley Research Center in the development and implementation of a general-use, information-centric health management system for complex systems. An important aspect of this work has been applications in structural health management (SHM) for aircraft, including real-time diagnosis and prognosis of structural integrity. Our work entails the development of a reasoning infrastructure that fuses information from multiple, multi-variate sources, including operation and sensor data, to identify, characterize, isolate, and predict specified faults at the system-level of a complex system or subsystem. Special consideration is given to addressing the identification of faults in a multi-fault environment. The basis of this work incorporates a novel distributed reasoning architecture, in which integrated hierarchical models perform information fusion, signal processing and feature extraction, and fault dependency analysis. The result is a generalized architecture that fuses existing and/or emerging sources while considering uncertain input data and temporal effects. We will present results from recent research on the application of this modeling approach to SHM and discuss the applicability of the approach to generalized health management. The focus of this paper is on the implementation of SHM in ARINC's Aircraft Condition Assessment and Management System (ACAMS).

A Structural Health Monitoring System Based on Continuous Acoustic Emission Sensors

---M. J. Sundaresan and G. Grandhi, Department of Mechanical Engineering, Intelligent Structures and Mechanisms Laboratory, North Carolina A&T State University, Greensboro, NC 27411; M. J. Schulz, Department of Mechanical Engineering, Smart Structures Bio-Nanotechnology Laboratory, University of Cincinnati, Cincinnati, OH 45221-0072

---A new approach for the health monitoring of structural systems and the development of the hardware and software required for this approach are described in this paper. The technique is based on detecting the acoustic emission signals from damage progression in structures using an array of sensor nodes connected in a unique manner. The system consists of a "continuous sensor" formed by connecting up to fifteen sensor nodes in series. The signal from the continuous sensor is monitored by an embeddable processor that locally processes the acoustic emission signals. This array of sensor nodes and the local processor form the unit cell of the sensory system. Large numbers of such unit cells can be linked through a digital bus that spans the structure. The unit cells of the sensory system are analogous to biological neurons in their simplicity. Hence, the structural health monitoring system that is demonstrated in the laboratory can potentially be scaled to large and complex real world structures. The configuration chosen can significantly simplify the integration of the sensory system into the structural material. The performance of the sensory system is demonstrated using various laboratory specimens.

A Cellular System for Wireless Structural Integrity Monitoring

---Graham Benny, Kenneth Steel, Alistair McNab, and Gordon Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, Scotland, UK

---Increasing demand exists for structural integrity monitoring (SIM) in a variety of industries, in particular for applications requiring large numbers of sensors applied to a structure to provide practical monitoring. Associated cabling could introduce new structural weaknesses or even failure therefore it is desirable to replace these links with wireless communications between sensors and monitoring equipment. Overall, wireless communications will provide significant increase in data integrity, reduced installation and maintenance costs and potential to avoid compromising structural integrity. Candidates for use within a wireless communications system are ultrasonic transducer technologies, which are already widely utilized in monitoring applications. These technologies have been successfully used in active systems of multiple transmitters and receivers to obtain local defect positions and dimensions and as area mapping sensors over longer ranges. Passive ultrasonic receivers may also be used to detect acoustic emission (AE) events signifying crack formation or propagation. Miniaturized wireless-coupled sensors which incorporate the sensor drive electronics, a DSP and Bluetooth communication module has been developed, initially for thickness measurement but also for time-of-flight measurement. A networked system capable of inter-sensor and base station communications in an industrial environment is in progress and preliminary results obtained will be presented.

Defect Monitoring of Airframe Structure Using Shear-Horizontal Guided Wave Generated with a Magnetostrictive Sensor

---Glenn M. Light, Sang Y. Kim, Hegeon Kwun, and Robert L. Spinks, Southwest Research Institute, Sensor Systems and NDE Technology Department, 6220 Culebra Road, San Antonio, TX 78238

---The fundamental shear-horizontal wave (SH0) offers one of the best tools for the inspection and monitoring of airfare structures for defects. The SH0 waves are non-dispersive and can travel long distances from one point. These properties provide a means to inspect areas that are usually not accessible to conventional ultrasonic inspection such as regions under insulation or covered by structure. The purpose of this presentation is to describe the magnetostrictive generation of guided SH0 waves and to describe the study conducted for monitoring notch and simulated corrosion defects in the aluminum plate. The data were acquired on different sizes of notches and corrosion defects. The waveform and amplitude of the experimental data were analyzed and compared with a two-dimensional wave propagation theory.

Lamb-Wave Embedded NDE with Piezoelectric Wafer Active Sensors for Structural Health Monitoring of Thin-Wall Structures

---Victor Giurgiutiu, University of South Carolina, Department of Mechanical Engineering, Columbia, SC 29208

---Piezoelectric wafer active sensors (PWAS) are inexpensive, non-intrusive un-obtrusive devices that can be surface-mounted on existing structures, or inserted between the layers of new composite structures. The PWAS can be used in both active and passive modes. PWAS generate and detect Lamb waves and enable the development of embedded NDE concepts. This paper will present two embedded NDE concepts based on the PWAS technology and Lamb waves approach. The first concept utilizes traveling Lamb waves, and could be described as embedded ultrasonics. It is shown that embedded PWAS are able to reproduce most of the conventional ultrasonic techniques, such as pitch-catch, pulse-echo, and phased array. Several experiments using Lamb waves traveling in thin-wall structures are presented, and detection of disbonds and cracks is illustrated. PWAS phased arrays generating a scanning Lamb-wave beams is also shown. The second concept utilizes standing Lamb waves, and is based on the local impedance approach. Embedded PWAS are shown to act as high-frequency modal sensors that detect the local vibrations modes using the electromechanical (E/M) impedance technique. The direct measurement of the high-kHz drive-point mechanical impedance spectrum is illustrated on realistic specimens with simulated cracks. These two complementary methods offer a comprehensive embedded capability for structural health monitoring of thin-wall structures.

Structural Health Monitoring of Anisotropic Layered Composite Plates Using Guided Ultrasonic Lamb Wave Data

---Mahadev Prasad, S. Jagannathan, Krishnan Balasubramaniam, and C. V. Krishnamurthy, Centre for Non-Destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Chennai, India

---Composite plates are being widely used in aircraft industries for the many advantages they provide. Inspecting these aircraft structures on a regular basis increases the inspection cost and involves a lot of time. Structural Health Monitoring (SHM) of aircrafts is of great relevance in the present age aircraft industry. In this case the inspection can be limited to cases when the predetermined SHM parameters shoots beyond a particular threshold. The present study involves using Lamb wave Tomography to image defective regions in anisotropic layered composite plates using minimum number of sensors. Commercially available PZT crystals are used as sensors. These crystals are placed at different points on the plate to obtain Lamb wave data. The energy of the Lamb wave signal is used for tomographic reconstruction using iterative tomographic reconstruction algorithms. A modified cross-hole configuration, obtained by placing the sensors on all the four sides of a plate, was found to give better information of the health of the plate when compared to the regular cross-hole configuration. It was found that by using the ratio of two sets of energy values, takes care of the anisotropy nature of composite plates.

Sparse Ultrasonic Transducer Array for Structural Health Monitoring

---Thomas E. Michaels and J. E. Michaels, Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

---Structural health monitoring of critical civil and aerospace structures is a field of growing importance. The goal is to detect cracks, delaminations, internal flaws, and microstructural changes that may be detrimental to the performance of a structure or lead to its failure. Many of these defects may be detected, located, and sized using conventional ultrasonic nondestructive evaluation methods. However, these methods are not suitable for real-time structural health monitoring. Recently, guided wave inspection methods have been proposed; however, waves induced are usually dispersive and success often depends upon exciting a single mode at a specific frequency to simplify interpretation of results. Furthermore, special transducers are required to induce specific wave modes, and mode conversion is an issue when the incident wave is reflected from external boundaries and internal defects. Thus, it is almost impossible to determine defect location and size from guided wave methods on finite sized, complicated structures. In this paper a different approach is used. A sparse array of conventional piezoelectric transducers is attached to the surface of a structure. Each transducer can be either a transmitter or a receiver. The structure is essentially flooded with acoustic energy by each transmit pulse, and recorded waveforms are analyzed to determine the state of damage progression.

On-Line Health Monitoring for Advanced Reactor Designs

---N. Nakagawa, F. Inanc, and R. B. Thompson, Iowa State University, Ames Laboratory and Center for NDE, Ames, IA 50011; W. R. Junker, F. H. Ruddy, J. M. Beatty, and N. G. Arlia, Westinghouse Electric Company, Science & Technology Department, Pittsburgh, PA 15235

---Last year, we introduced the concept of on-line sensor methodologies for monitoring structural integrity of next generation power systems, and explained the use of physics-based NDE modeling predictions for design optimization. This paper reports on the development of specific on-line monitoring sensor concepts and their intended applications, including model-based sensitivity estimations. At this stage, we mainly focus on advanced light-water reactor designs such as IRIS where we have identified steam generator (SG) integrity and the potential disturbance of the primary coolant flow as important applications of on-line monitoring for ensuring long-term continuous reactor operation. For SG applications, we will present our eddy current and EMAT sensor concepts and signal predictions based on model calculations. For deposit buildup detection in the tubing, estimates will be given for both EC probes and EMATs. We will also examine the use of EMAT for monitoring of the joints between the tube ends and the mounting plates, where circumferential cracking may occur. For monitoring primary water flow, we present a concept based on a naturally occurring tracer element (nitrogen 16) and built-in radiation detectors, with sensitivity estimations for assessing the applicability.---This work is supported by the US DOE Nuclear Energy Research Initiative (NERI) Program, Project Number 2001-076.

SESSION 7
GUIDED WAVES MODELING
M. Lowe, Chairperson
BR A1

8:30 AM **Greens Function Boundary Element Method for Waves in an Elastic Plate**
---K. Kimoto and S. Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan

8:55 AM **Lamb Quasi-Modes in Curved Plates**
---D. Gridin and R. V. Craster, Department of Mathematics, Imperial College London, South Kensington Campus, London SW7 2AZ, United Kingdom

9:20 AM **Properties of Guided Waves in Curved Plates**
---J. Fong and M. Lowe, Imperial College, Department Mechanical Engineering, London SW7 2AZ, United Kingdom

9:45 AM **Transient Ultrasonic Guided Waves in Bi-Layered Anisotropic Plates with Rectangular Cross Section**
---O. M. Mukdadi and S. K. Datta, Department of Mechanical Engineering, University of Colorado, Boulder, CO 80309-0427

10:10 AM ***Coffee Break***

10:30 AM **Properties of Guided Waves in Composite Plates, and Implications for NDE**
---M. Lowe, M. Deschamps[1], and G. Neau, Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom; Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469, 351, Cours de la Libération, 33405 Talence Cedex, France

10:55 AM **Guided Wave Focusing Feasibility in Layered Devices**
---C. M. Lee[1], J. L. Rose[1], Y. Cho[1], and I. K. Park[2], [1]411 EES Building, Engineering Science and Mechanics Department, The Pennsylvania State University, State College, PA 16802; [2]R.I. of NDE Technology, Seoul National University of Technology, 172, Gongneung-dong, Nowon-gu, Seoul, 139-743, Korea

11:20 AM **Guided Wave Inspection of Multi-Layered Structures**
---M. J. Quarry, Lawrence Livermore National Laboratory, P. O. Box 808, L-333, Livermore, CA 94566

12:10 PM ***Lunch***

Greens Function Boundary Element Method for Waves in an Elastic Plate

---Kazushi Kimoto and Sohichi Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan

---A Greens function boundary element code for waves in a plate is developed in this study. Although an ordinary boundary element method is not always competitive with other numerical methods like FEM in terms of computational time, the Greens function BEM needs no discretization on plate faces, thus can circumvents imposing artificial boundary condition or truncating boundaries. In evaluating the Greens function numerically, ray and normal mode expansions are possible options. In this paper, hybrid ray-mode representation proposed by Lu et al. is used to exploit the favorable features of each representation. However, for the use with boundary elements, the direct ray components are subtracted from the hybrid representation, and the singularity of the Greens function is treated by standard boundary element techniques. The remaining multiply reflected components are then evaluated by a combination of ray and normal mode technique depending on the temporal and spatial ranges of interest. As a numerical example, scattering by an embedded cavity is solved. The results are shown as scattered waves both at near and remote observation points. Truncation effect of ray and normal mode series is also discussed thorough the example.

Lamb Quasi-Modes in Curved Plates

---Dmitri Gridin and Richard V. Craster, Imperial College London, Department of Mathematics, South Kensington Campus, London SW7 2AZ, United Kingdom

---Wave propagation in slowly varying elastic waveguides is analysed in terms of mutually uncoupled quasi-modes. These are a generalization of the Lamb modes that exist in a uniform guide to the weakly non-uniform case. Quasi-modal propagation is dependent upon the wavelength and two geometrical length-scales, that of the longitudinal variations and the guide thickness. By changing these lengthscales one enters different asymptotic regimes. In this paper, the emphasis is on the mid-frequency regime when only a few propagating modes can exist. Our aim is to present an asymptotic theory for quasi-modal propagation in a canonical geometry, an arbitrarily curved plate of constant thickness. We derive practically useful asymptotic expressions of the quasi-modes of a curved plate; these are particularly important since an adiabatic approximation for this problem simply coincides with the Lamb modes of a flat plate of the same thickness.

Properties of Guided Waves in Curved Plates
---Jimmy Fong and Mike Lowe, Imperial College, Department Mechanical Engineering, London SW7 2AZ United Kingdom

---Circumferential guided waves have many potential applications in effectively inspecting defects in annular structures. Properties of these guided waves can be modelled using dispersion curves, which are calculated numerically. The introduction of asymptotic solutions to tackle the instability problems in the circumferential dispersion relation, which occur using the exact dispersion method, has been reported last year. This allows the circumferential dispersion curves to be characterised accurately and rapidly over a wide range of curvatures and frequencies. This paper presents an experimental study to validate the predictions, comparing the guided waves in flat and curved plates. The percentage difference in the velocity of each mode, as a function of frequency and curvature, was calculated numerically. These differences were then measured experimentally for a few selected curvatures and frequencies, using thin aluminium strips that are able to bend to different curvatures, and permanently attached transducers.

Transient Ultrasonic Guided Waves in Bi-Layered Anisotropic Plates with Rectangular Cross Section
---Osama M. Mukdadi and Subhendu K. Datta, Department of Mechanical Engineering, University of Colorado, Boulder, CO 80309-0427

---Transient ultrasonic guided waves in anisotropic bi-layered plates with finite-width are investigated in this paper. Composite bi-layered plates consisting of GaAs substrate coated with Nb sheath is considered as an example because of its application to electronics and calorimetry. The purpose is to investigate the acoustic mode coupling (“pinching”) phenomena for phonon transport. A semi-analytical finite element (SAFE) method is adopted to study the guided wave dispersion behavior in finite-width elastic plates. Nine-noded quadrilateral elements are used to model the cross section of the finite-width plate. Propagation in the axial direction is modeled by analytical wave functions. Elastodynamic Green's functions are derived using modal summation in the frequency-wavenumber and time-space domains. Results for dispersion and transient analysis of guided waves in finite-width plates are presented and compared for different aspect ratios. Group velocities are calculated and wave arrival times are computed for different plate cross sections as well as different excitation frequency. Numerical results show significant influence of the plate aspect ratio on the dispersion and transient wave response. Complex nature of quasi-mode dispersion and propagation due to pinching phenomena in anisotropic plates require such quantitative analysis to afford easy interpretation. These results would be important for nondestructive material evaluation and for characterization of phonon transport in anisotropic bi-layered plates.

Properties of Guided Waves in Composite Plates, and Implications for NDE

---Mike Lowe, Marc Deschamps[1], and Guillaume Neau, Imperial College, Department of Mechanical Engineering, London SW7 2AZ, England; Université Bordeaux 1, Laboratoire de Mécanique Physique, UMR C.N.R.S. 5469, 351, Cours de la Libération, 33405 TALENCE Cedex, France

---Guided waves are potentially very useful for the rapid NDE of plate structures. In the aerospace industry in particular, they have been proposed for the structural health monitoring of carbon fibre skin panels, in either an active or a passive configuration. In an active configuration a guided wave is deliberately generated and then later received after it has travelled through the structure; in a passive configuration an acoustic emission sensor is used to listen to sound created by the structure itself. The successful development of these ideas depends on a good knowledge of the properties of the guided waves, yet it has been found that the properties of guided waves in such materials are very much more complicated than those in a simple metal skin. The complications include steering of the directions of the phase and group velocities by the anisotropy of the plate, and attenuation because of damping of the matrix material and scattering by the fibres. The authors have studied these phenomena both analytically and experimentally, and have presented some of that work at previous QNDE meetings. This paper will present an overview of the findings and identify the key implications for practical developments of structural health monitoring techniques.

Guided Wave Focusing Feasibility in Layered Devices

---Chong Myoung Lee[1], Joseph L. Rose[1], Younho Cho[1], and Ik Keun Park[2], [1]411 EES Bldg., Engineering Science and Mechanics Department, The Pennsylvania State University, State College, PA 16802; [2]R. I. of NDE Technology, Seoul National University of Technology, 172, Gongneung-dong, Nowon-gu, Seoul, 139-743, Korea

---Presented in this paper is guided wave focusing feasibility in thickness direction to precisely tune modes for monitoring layered materials which are being widely used in various applications from structural integrities to tiny thin film devices of nano/semiconductor industry. The stress, displacement and in-plane energy distributions through the thickness of multi-layered waveguide models are numerically calculated assuming them to be elastic, homogeneous and isotropic. The understanding of the wave structures inside the multi-layered materials is essential and useful for launching and focusing a guided mode into a desired layer. The experiments were also done by the pulse echo test with angle beam transducer and comb transducer, sweeping frequency. The experimental result clearly show that the defect detection in a particular layer of multi-layered specimens can indeed be found by appropriate manipulation of the phase velocity and frequency values based on the information from wave structure profiles. Although the presented experimental work was carried out with the specimen of mm scale thickness, the promising concept and data can be readily extended to other layered devices of tiny thickness scale.

Guided Wave Inspection of Multi-Layered Structures

---Michael J. Quarry, Lawrence Livermore National Laboratory, P. O. Box 808, L-333, Livermore, CA 94566

---This study investigates the utilization of guided waves for inspecting structures that consist of multiple layers. Advances have been made in recent years using guided waves to inspect single layer structures, such as pipes, tubes, and aircraft fuselages. Multi-layered structures present many new aspects to guided wave propagation. A theoretical understanding of what modes exist, how do the modes behave, and what factors influence them needs to be acquired. Experiments must be carried out to evaluate potential for practical applications. Examples of practical applications include coated pipes, composites, and, microelectronic structures. This work is a fundamental study of ultrasonic guided waves in multi-layered plates. Experiments were conducted on multi-layered plates to demonstrate defect detection in various layers of a multi-layered structure. Analysis of the dispersion curves show that some modes are more attractive candidates than others based on their displacements and energy distribution across the structure. Experimental results show that sweeping frequency and phase velocity can be performed to find suitable modes for inspecting a given multi-layered structure. Various practical bond qualities were simulated by adjoining layers with epoxy and liquid coupling.

SESSION 8
JOINED MATERIALS, COATINGS, AND INTERFACES
R. Maev, Chairperson
BR A3

8:30 AM **Some Approaches of Ultrasonic Evaluation of Metal Sheets Adhesive Bonds**
---E. Y. Maeva, I. A. Severina, B. O'Neill, F. M. Severin, and R. G. Maev, Centre for Imaging Research and Advanced Material Characterization, Department of Physics, University of Windsor, Canada

8:55 AM **A Preliminary Study of Quantifying Biofilm Properties Using a 70-MHz Ultrasonic System**
---M. S. Good, C. F. Wend, D. S. Daly, J. S. Mclean, P. D. Panetta, S. Ahmed, and L. J. Bond, Pacific Northwest National Laboratory, P. O. Box 999, MS K5-26, Richland, WA 99352

9:20 AM **On-Line Measurement of Lubricant Film Thickness Using Ultrasonic Reflection Coefficients**
---B. W. Drinkwater, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom; R. S. Dwyer-Joyce, Department of Mechanical Engineering, University of Sheffield, Mappin Street, Sheffield, S1 3JD, United Kingdom

9:45 AM **Model for Deformation, Stress and Contact at Interfaces, and Implications for Ultrasonic Measurements**
---D. L. Hopkins and F. Reverdy, Engineering Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

10:10 AM ***Coffee Break***

10:30 AM **A Rapid Ultrasonic Method for Nondestructive Mapping of Layer Thicknesses in Steel-Backed Bronze Bearing Sleeves**
---D. Fei and D. A. Rebinsky, Caterpillar, Inc., 14009 Old Galena Road, Mossville, IL 61552

10:55 AM **Eddy Current Assessment of Duplex Metallic Coatings**
---K. J. Krzywosz, Science & Technology Development, EPRI, Charlotte, NC 28262

11:20 AM **Laser-Ultrasonics Characterization of Thermal Spray Coatings**
---C. Bescond, R. S. Lima, S. E. Kruger, and B. R. Marple, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Québec, J4B 6Y4, Canada

11:45 AM **Imaging Defects in Thin Tribological Coatings Using High Frequency Scanning Acoustic Microscopy**
---D. Fei and D. A. Rebinsky, Caterpillar, Inc., 14009 Old Galena Road, Mossville, IL 61552; P. Zinin, SOEST, HIGP, University of Hawaii, Honolulu, HI

12:10 PM ***Lunch***

Some Approaches of Ultrasonic Evaluation of Metal Sheets Adhesive Bonds

---E. Yu. Maeva, I. A. Severina, B. O'Neill, F. M. Severin, and R. Gr. Maev, Centre for Imaging Research and Advanced Material Characterization, Dept. of Physics, University of Windsor, Canada

---Proper interpretation of acoustical measurement results is still one of the main problems for ultrasonic inspection of adhesive bonding of thin metal sheets. This is due to the complicated ultrasound interaction mechanisms that take place in such systems. Mismatch of acoustical impedances leads to most of the ultrasound energy reflecting back and screening defects under the first metal-adhesive interface. Reverberation in the metal sheets masks weak information signals, while significant attenuation in the adhesive layer and its small thickness brings additional difficulties. In the present work, acoustical diagnosis of these bonds was simulated as sound penetration through a three-layer system. A new approach based on wave distortion on the disturbed interface is represented. The theoretical speculations are supported by experiments with plane and spherically focused acoustic beams in the pulse-echo mode. Acoustical images of standard types of defects in models and real industrial samples were obtained and several methods of signal processing are demonstrated. The data are proven by comparison with the results of destructive testing. The practical aspects of this method, as well as a few alternative methods (nonlinear, Lamb wave, laser ultrasound est.) are discussed and technical recommendations are provided for developing a specialized inspection system.

A Preliminary Study of Quantifying Biofilm Properties Using a 70-MHz Ultrasonic System

---Morris S. Good, Christopher F. Wend, Don S. Daly, Jeffrey S. Mclean, Paul D. Panetta, Salahuddin Ahmed, and Leonard J. Bond, Pacific Northwest National Laboratory, P. O. Box 999, MS K5-26, Richland, WA 99352

---Noninvasive measurements over a biofilm, a three-dimensional community of microorganisms immobilized at a substratum, were made using a 70-MHz ultrasonic system. Surface heterogeneity, thickness, and interior structure of a living biofilm were estimated over a 0.7-mm by 0.7-mm region. Acoustically based estimates of thickness were corroborated using confocal laser microscopy. Experimental data showed that the ultrasonic system was capable of making quantitative estimates of the spatial distribution of biofilm acoustical and physical properties. The revealed surface topology and interior structure of the substratum are expected to facilitate model development and understanding of mass transport of dissolved species into and out of a biofilm. In addition, noninvasive and nondestructive determination of the interior heterogeneity and monitoring the morphology and ongoing changes of a biofilm is of great interest to biofilm researchers. The experimental ultrasonic and optical systems and estimates of biofilm physical and acoustical properties will be discussed.---Work was supported by the U.S. Department of Energy.---Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

On-Line Measurement of Lubricant Film Thickness Using Ultrasonic Reflection Coefficients

---Bruce W. Drinkwater, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom; Rob S. Dwyer-Joyce, Department of Mechanical Engineering, University of Sheffield, Mappin St, Sheffield, S1 3JD, United Kingdom

---The reflection of ultrasound from a lubricant film in a bearing depends on the ultrasonic frequency, the acoustic properties of the liquid and solid, and the layer thickness. When the wavelength of ultrasound is much greater than the lubricant film thickness, the reflectivity can be predicted from a spring model of the film. When the wavelength and film thickness are of the same order, a multi-layered system model is required to predict the interactions. In this paper, ultrasonic reflectivity measurements have been developed as a method to determine the thickness of lubricating films in bearing systems. A wide-band ultrasonic transducer, positioned on the outside of a bearing shell is used to interrogate the lubricant film layer. The reflected signal is processed to give a reflection coefficient spectrum and the lubricant film thickness is then obtained from either the layer stiffness or the resonant frequency. The method has been validated using fluid wedges at ambient pressure between flat and curved surfaces. Experiments on the elastohydrodynamic film formed between a ball sliding on a flat and a deep-groove ball bearing were performed. Film thickness values in the range 50-500 nm were recorded which agreed well with theoretical film formation predictions.

Model for Deformation, Stress and Contact at Interfaces, and Implications for Ultrasonic Measurements

---Deborah L. Hopkins and Frederic Reverdy, Engineering Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

---Detailed models exist to describe the stresses and deformation of surface asperities on interfaces and fractures under load. However, analytical and laboratory work demonstrate that deformation of the bulk material surrounding the interface is substantial, and is the conduit for mechanical interaction between contact points. Under applied loads, deformation of the bulk material leads to substantial changes in the geometry of the void space and the distribution of stress at the interface, which in turn, affects the distribution of contact area, joint strength, wear, and the effectiveness of lubrication. Displacement-discontinuity theory describes the propagation of acoustic waves across interfaces, with transmission coefficients that depend on the stiffness of the interface. Conventional through-transmission ultrasonics has been used to validate the global relationship between joint stiffness and acoustic-wave propagation. However, short of acoustic microscopy, it is much more difficult to use ultrasonic techniques to infer the amount and distribution of contact points, and the resulting stress distribution, because the relationship between stiffness and contact area is complicated. Results from laboratory experiments and modeling are presented to describe the mechanical behavior of joints under load, along with the implication of the results for inference of interface properties from ultrasonic measurements.

A Rapid Ultrasonic Method for Nondestructive Mapping of Layer Thicknesses in Steel-Backed Bronze Bearing Sleeves

---Dong Fei and Douglas A. Rebinsky, Caterpillar Inc., 14009 Old Galena Road, Mossville, IL 61552

---A steel-backed bronze bearing is a two-layered cylindrical structure made of steel and bronze. Thickness of the bronze layer must meet a minimum requirement in order for the bearing to function properly during reliable and durable use. In this paper, a nondestructive method was developed to permit rapid measurement of the thickness of the steel and bronze layers in a bearing. The measurement involves two consecutive ultrasonic immersion time-of-flight (TOF) C-scans of the bearing. The first TOF C-scan utilizes a simultaneous velocity and thickness mapping method to measure the total wall thickness of the bearing where as the second TOF C-scan measures the thickness of the steel layer. Image analysis of the mapped thickness data yielded valuable thickness information about the steel and bronze layers including mean, standard deviation, minimum, and Cpk. Comparison to destructive optical examination of the cross-section of the bearing sleeve showed a difference of merely 2% of the thickness compared to the acoustic estimate. This ultrasonic method provided the steel and bronze thickness images in approximately 20 minutes, compared to 6 destructive thickness measurements requiring an hour.

Eddy Current Assessment of Duplex Metallic Coatings

---Kenji J. Krzywosz, Science & Technology Development, EPRI, Charlotte, NC 28262

---EPRI is involved in a multi-year program with the Department of Energy to test, evaluate, and develop a field-deployable eddy current NDE system for life assessment of blade coatings for advanced gas turbines. The coatings evaluated from these advanced GE engines include CoCrAlY (GT 29) and NiCoCrAlY (GT 33) bond coats followed by top aluminide overlay coatings. These duplex metallic coatings are commonly referred to as GT 29+ and GT 33+ coatings, respectively. In general, during cycling and continuous operation at higher operating temperature, coatings fail due to spallation of protective oxide layers, leading to consumption of protective coatings and to eventual failure of blades. To extend service life of these critical rotating components, an inspection-based condition assessment program has been initiated to help establish more optimum inspection intervals that are not dependent on time-in-service maintenance approach. This paper summarizes the latest results obtained to date using the state-of-the-art frequency-scanning eddy current tester with a built-in three-layer inversion algorithm. Significant progress has been made in assessing and discriminating the duplex metallic coatings as normal, degraded, and/or cracked. In addition, quantitative assessment was conducted by estimating various coating and substrate conductivity values.

Laser-Ultrasonics Characterization of Thermal Spray Coatings

---C. Bescond, R. S. Lima, S. E. Kruger, and B. R. Marple, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Québec, J4B 6Y4, Canada

---Non-destructive techniques to characterize the mechanical properties of thermal spray coatings are of particular importance to understand and/or model the mechanical behavior of coated materials used in various applications (e.g. wear, fatigue and high temperatures). The laser ultrasonic technique that uses lasers to generate and detect ultrasounds provides interesting potentialities to characterize such materials in a non-destructive manner. In this study, the elastic modulus values and Poisson's ratios of very uniform, dense and near-isotropic titania and WC-Co thermal spray coatings are evaluated with the laser-ultrasonic technique. The elastic properties are obtained from the velocity of Rayleigh and skimming longitudinal waves. Dispersion curves for the Rayleigh waves as well as bulk waved propagating through the thickness of the coating are also exploited. The results are compared with values obtained with the Knoop indentation technique, which has been widely used as a method for determining elastic modulus of coatings. The agreement between the two techniques is found excellent and the laser ultrasonic technique appears very promising to characterize such materials. In particular, coatings deposited on pieces of complex shapes or coatings at high temperature can be characterized while other methods cannot be applied.

Imaging Defects in Thin Tribological Coatings Using High Frequency Scanning Acoustic Microscopy

---Dong Fei and Douglas A. Rebinsky, Caterpillar Inc., 14009 Old Galena Road, Mossville, IL 61552; Pavel Zinin, SOEST, HIGP, University of Hawaii, Honolulu, HI

---Wear performance of thin tribological coatings (less than 5 microns thick) such as Cr-DLC can be adversely affected by the presence of defects; for example, voids, inclusions, cracks and delaminations. In this work, very high frequency scanning acoustic microscopy was employed to nondestructively detect and characterize subsurface defects in Cr-DLC coatings deposited on AISI 52100 steel. The coated specimens consisted of flat coupons of different coating recipes and batches and curved components including a roller and a gear tooth. Acoustic images generated at center frequencies of 200 to 1300 MHz contained numerous features that are related to surface and subsurface defects in the thin films. Subsurface defects as small as one micron were successfully detected. The depth of the subsurface defects was estimated from the images at different defocuses based on a simple geometrical acoustics model. Coating integrity was determined by estimating defect sizes and by evaluating defect density from acoustic images obtained from the samples.---This research was supported through a NIST Advanced Technology Program, cooperative agreement number 70NANBOH3048.

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SESSION 9
NDE FOR CIVIL MATERIALS AND STRUCTURES
J. Popovics, Chairperson
BR A4

8:30 AM **Low Frequency Vibration Approach to Assess the Performance of Wood Structural Systems**
---R. J. Ross, USDA Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398; X. Wang, Natural Resources Research Institute, University of Minnesota, 10 University Drive, Duluth, MN 55812-2496

8:55 AM **Detecting Rot in Power Poles with Radio Frequency Scanning**
---P. H. Steele and J. E. Cooper, Department of Forest Products, Mississippi State University, Mississippi State, MS 39762

9:20 AM **A Rayleigh-Wave Attenuation Method for Crack Depth Determination in Asphalt Pavements**
---A. Gibson and G. E. Gallo, Department of Civil and Environmental Engineering, University of Illinois, 2129D Newmark Laboratory, 205 N. Mathews Avenue, MC-250, Urbana, IL 61801

9:45 AM **Nonlinear Ultrasonic Evaluation of Concrete Microcracking**
---C. Woodward, D. V. Jauregui, and J. Stauffer, Department of Civil and Geological Engineering, New Mexico State University, Box 30001, MSC-3CE, Hernandez Hall, Room 202, Las Cruces, NM 88003; K. R. White, New Mexico State University, Las Cruces, NM 88003

10:10 AM ***Coffee Break***

10:30 AM **Shape Reconstruction of Three-Dimensional Flaw by the Measurement from the Side of Cylindrical Specimen**
---M. Yamada and M. Kitahara, Department of Civil Engineering, Graduate School of Engineering, Tohoku University, Sendai, Japan

10:55 AM **Nondestructive Evaluation of Reactive Powder Concrete**
---G. A. Washer, FHWA NDE Center, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, VA 22101; P. Fuchs, Fuchs Consulting, Inc., Turner Fairbank Highway Research Center, McLean, VA 22101; B. Graybeal, PSI, Inc., Turner Fairbank Highway Research Center, McLean, VA 22101; A. Rezaizadeh, Wiss, Janney, Elstner Associates, Inc., Turner Fairbank Highway Research Center, McLean, VA 22101

11:20 AM **Heat Transfer Fundamentals Applicable to Infrared Thermography**
---R. Chowdhury, U. Attanayaka, and H. Aktan, Civil Engineering Department, Wayne State University, 2100 Engineering Building, 5050 Anthony Wayne Drive, Detroit, MI 48202

12:10 PM ***Lunch***

Low Frequency Vibration Approach to Assess the Performance of Wood Structural Systems

---Robert J. Ross, USDA Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398; Xiping Wang, University of Minnesota, Natural Resources Research Institute, 10 University Drive, Duluth, MN 55812-2496

---The Forest Products Laboratory, USDA Forest Service, has been developing nondestructive evaluation (NDE) techniques to identify degradation of wood in structures and the performance characteristics that remain in the structure. Our previous work has focused on using dynamic testing techniques, particularly stress wave and ultrasonic transmission NDE techniques for both laboratory and field investigations. Application of our results has been limited to individual members in structures. Evaluating each member of a structural system is labor intensive and time consuming. For in situ inspection of timber structures, a more efficient strategy would be to assess whole structural systems or subsystems in terms of their overall performance and serviceability. Examining the dynamic response of a structural system might provide an alternative way to gain insight into the ongoing performance of the system. Based on this hypothesis, we began to investigate the possibility of using low frequency transverse vibration techniques to quantify the performance of simple wood structural systems. In particular, we cooperated with several organizations to investigate the use of these techniques to quantify the performance of timber bridges and floor systems. This presentation will present a review of the application of transverse vibration techniques to wood members and our results on use of these techniques for evaluating timber bridge and floor systems.

Detecting Rot in Power Poles with Radio Frequency Scanning

---Philip H. Steele and Jerome E. Cooper, Mississippi State University, Department of Forest Products, Mississippi State, MS 39762

---The potential for detecting rot in power poles with a radio frequency method was tested. Five pole sections containing both sound and rotten wood were obtained from out-of-service power poles. All pole sections had been treated with pentachlorophenol. Sections were conditioned in 12-percent EMC conditions for 12 months prior to testing. Pole sections were scanned over their length by a laboratory prototype that applied 250, 500, 2000 and 5000 KHz radio frequency signals to opposing 1-inch diameter metal electrodes in contact with the pole surface. Each capacitor pair scanned each pole along the longitudinal axis. Each radio frequency signal was applied to the transmitting electrode, propagated through the pole diameter and measured at the receiving electrode. Signal voltage attenuation and phase shift values for sound and rotten wood sections were recorded. Clear wood radio frequency signal was compared to that where rot was present. Radio frequency signals of 2000 and 5000 KHz yielded the largest absolute attenuation difference and absolute phase difference between sound wood and rotten wood. Threshold values were determined from sound and rotten wood mean data. Voltage attenuation and phase shift validation yielded respective success values of 67 and 93 percent in detecting rot in pole sections.

A Rayleigh-Wave Attenuation Method for Crack Depth Determination in Asphalt Pavements

---Alexander Gibson and Gonzalo E. Gallo, University of Illinois, Department of Civil and Environmental Engineering, 2129D Newmark Laboratory, 205 N. Mathews Avenue, MC-250, Urbana, IL 61801

---It has been established in research on concrete structures that the attenuation of surface waves is sensitive to the presence of a surface-breaking obstructing its path. This is the basis for a non-destructive crack depth measurement technique to quantitatively establish the extent of damage on a pavement subject to any kind of top-down cracking. A previously developed self-compensating technique was applied to asphalt concrete beams constructed with a variety of crack and notch configurations. Factors included in the study were different notch geometries and the effect of crack width, by comparing results from saw-cut notches to those of narrow cracks. The frequency-dependent signal transmission coefficient was measured at 30 and 50 mm spacing for both undamaged and cracked beams. A single relationship between signal attenuation and crack depth can be approached by normalizing crack depth with respect to the wavelength. The viability of Rayleigh wave attenuation measurements in asphalt pavement surfaces was proved, and further tests were carried out on full scale asphalt slabs. The method provides a basis for determination of crack depths in laboratory samples with standard dimensions used in the work, as well as a field method for diagnosis of the condition of highway pavements.

Nonlinear Ultrasonic Evaluation of Concrete Microcracking

---Clinton Woodward, David V. Jauregui, and Jason Stauffer, New Mexico State University, Department of Civil and Geological Engineering, Box 30001, MSC-3CE, Hernandez Hall, Room 202, Las Cruces, NM 88003; Kenneth R. White, Interim Dean of Engineering, New Mexico State University, Las Cruces, NM 88003

---Nonlinear ultrasonics was used to evaluate the degree of damage in concrete. In most cases, conventional linear ultrasonics can only be used to identify concrete deterioration when it reaches an advanced state. Since nonlinear ultrasonics is capable of detecting damage in its earlier stages, it was used for this project. Microcracking is a major component of most types of concrete deterioration. Here, microcracking was induced by stressing the specimen incrementally in compression. After each load increment, Rayleigh and longitudinal waves were used to evaluate the specimen. The second harmonic was found to increase with increasing levels of microcracking. Third harmonic growth was inconsistent at the power levels used in this study.

Shape Reconstruction of Three-Dimensional Flaw by the Measurement From the Side of Cylindrical Specimen

---Masaki Yamada and Michihiro Kitahara, Dept. of Civil Engineering, Graduate School of Engineering, Tohoku University, Sendai, Japan

---There are many cylindrical-shaped civil structures like bridge piers. When the structure is inspected by ultrasonics, the access point of transducers is limited to the surface of the cylinder. In this paper, the three-dimensional inverse scattering method is modified to convenient form for cylindrical structure. A cross-sectional image of the cylinder is obtained by the modified method. Moving the measurement plane along the axis of the cylinder, the cross-sectional image is obtained for each measurement plane. The three-dimensional flaw image is reconstructed piling up the obtained cross-sectional images. Cement paste cylinders with flaw models are prepared and ultrasonic measurements are carried out. The obtained wave data are fed into the modified method and the performance of the shape reconstruction is confirmed. The method is also applied to the concrete specimen and the versatility of the method is investigated.

Nondestructive Evaluation of Reactive Powder Concrete

---Glenn A. Washer, FHWA NDE Center, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, VA 22101; Paul Fuchs, Fuchs Consulting, Inc. Turner Fairbank Highway Research Center, McLean, VA 22101; Benjamin Graybeal, PSI, Inc., Turner Fairbank Highway Research Center, McLean, VA 22101; Ali Rezaizadeh, Wiss, Janney, Elstner Associates, Inc., Turner Fairbank Highway Research Center, McLean, VA 22101

---Reactive powder concrete (RPC) has been introduced as a structural material for civil engineering applications. The material consist of a finely graded combination of cement, sand, ground quartz and silica fume which combined with water form a cement paste. Small steel fibers measuring approximately 0.2 mm in diameter and 12 mm in length are distributed throughout the cement matrix and the combined material has very high strength and toughness. The material is proposed for use in the primary load bearing members in bridges, and as such nondestructive evaluation technologies are needed to evaluate material quality and monitor in-service condition. This paper reports on research to determine the effectiveness of ultrasonic testing for determining the elastic properties of RPC and for detecting cracks in the cement matrix. Comparison between static modulus of elasticity (ASTM 456) and ultrasonic modulus measurements is presented. A system for determining elastic moduli as a quality control tool will be discussed. The effect of curing conditions on ultrasonic velocities as well as methods for crack detection by longitudinal and refracted shear waves will be presented.

Heat Transfer Fundamentals Applicable to Infrared Thermography

---Rudaba Chowdhury, Upul Attanayaka, and Haluk Aktan, Wayne State University, Civil Engineering Department, 2100 Engineering Building, 5050 Anthony Wayne Drive, Detroit, MI 48202

---Infrared Thermography is expected to allow evaluation of states of material degradation through observation of surface temperature variation. Fundamentals of heat transfer phenomenon of concrete under different ambient temperature conditions by Infrared Thermography are presented. The knowledge of thermal conductivity and other thermal transport properties of construction materials involved in the process of heat transfer is essential in predicting the temperature profile and heat transfer through the material. Concrete is a non-homogeneous and anisotropic medium. The normally low thermal conductivity values for concrete have the disadvantage that transient data capture becomes difficult. Concrete is regarded as a layered medium in order to better understand its heat conduction behavior. The heat transfer through each layer is studied to understand the relative importance and contribution of each to the surface and near surface region temperature distribution. This information is essential for internal evaluation of surface and near surface variability. Finite Element Analysis is performed to determine the surface temperature variation of the near surface region of concrete by modeling the heat transfer through concrete, considering three mechanisms: a) Thermal conduction through concrete slabs of infinite length b) Solar radiation and convection from the surface

SESSION 10
THERMAL WAVE IMAGING AND THERMOSONICS
X. Han, Chairperson
BR A2

8:30 AM **Flash-Quenching for High Resolution Thermal Depth Imaging**
---H. I. Ringermacher, R. J. Filkins, and D. R. Howard, General Electric Research and Development Center, P. O. Box 8, Schenectady, NY 12301

8:55 AM **Improved Thermographic Flaw Detection from Combined Analysis of Time and Spatial Thermal Response**
---W. P. Winfree and J. N. Zalameda, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

9:20 AM **Effect of Finite Flash Duration on Thermal Diffusivity Imaging of High-Diffusivity or Thin Materials**
---J. Sun and S. Erdman, ET/212, 9700 South Cass Avenue, Argonne, IL 60439

9:45 AM **Importance of Acoustic Chaos in Sonic IR Imaging NDE**
---X. Han, Z. Zeng, W. Li, M. S. Islam, and V. Loggins, Department of Electrical & Computer Engineering, Wayne State University, Detroit, MI 48202; J. Lu, L. D. Favro, and G. M. Newaz, Institute for Manufacturing Research, Wayne State University, Detroit, MI 48202; R. L. Thomas, Physics Department, Wayne State University, Detroit, MI 48202

10:10 AM ***Coffee Break***

10:30 AM **Thermographic Materials Characterization Using Reconstructed Thermographic Data**
---S. M. Shepard, J. R. Lhota, T. Ahmed, and Y. L. Hou, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

10:55 AM **Infrared Imaging for Detection of Defects and Real-Time Monitoring of Repairs in Sculpture**
--- X. Han, Z. Zeng, W. Li, V. Loggins, and M. S. Islam, Department of Electrical & Computer Engineering, Wayne State University, Detroit, MI 48202; J. Lu and L. D. Favro, Institute for Manufacturing Research, Wayne State University, Detroit, MI 48202

11:20 AM **Vibrothermographic Inspection of Tube Braze Joints and Comparison with Dye Penetrant Inspection**
---M. W. Burke[1] and W. O. Miller[2], [1]MMED, [2]NTED, Lawrence Livermore National Laboratory, P. O. Box 808, L-333, Livermore, CA 94551

11:45 AM **Numerical Calculation of Heat Generation by Defects in Ultrasonic Infrared Imaging**
---X.-B. Mi and S.-Y. Zhang, Lab of Modern Acoustics, Institute of Acoustics, Nanjing University, 210093, China

12:10 PM ***Lunch***

Flash-Quenching for High Resolution Thermal Depth Imaging

---H. I. Ringermacher, R. J. Filkins, and D. R. Howard, General Electric Research and Development Center, P. O. Box 8, Schenectady, NY 12301

---The Flash lamp “thermal forcing function” is typically an exponentially decaying source. Ideally, one would like to achieve a short rectangular heating pulse simulating a Dirac Delta function. Then heat input is precisely limited so that image analysis can begin, without distortion from incoming heat, immediately following the flash. This allows the earliest temporal resolution of events and thus permits thickness measurements of very thin metal components or thermally thin materials. We will describe a high power handling, compact, electrical approach for lamp quenching that cuts off the lamp exponential tail precisely and present results of its effects on measurement. It can handle up to a 1.2 MW-average pulse (2400J / 2ms), thus cutting off undesirable tail after 2 ms. These units can be placed in series with every lamp thus optimizing power usage.

Improved Thermographic Flaw Detection from Combined Analysis of Time and Spatial Thermal Response

---William P. Winfree and Joseph N. Zalameda, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Mail Stop 231, Hampton, VA 23681-2199

---The detection of flaws in composites more than one half the thickness of the composite sheet is difficult with thermographic techniques. This is in part due to the spatial variability of the thermal properties of the composite. Most reduction techniques have focused on improving the detectability of the flaws by analyzing either spatial variations of the each time step in the thermal response or a point by point analysis of the temporal thermal response. This paper discusses techniques combining the information from the spatial and temporal response, based on computational models for heat flow in the composite, to improve the detectability of deep flaws. Data is presented on composites specimens with delaminations at known depths. Results of the analysis show significant improvement in the detectability of delaminations at depths greater than one half the thickness of the specimen.

Effect of Finite Flash Duration on Thermal Diffusivity Imaging of High-Diffusivity or Thin Materials

---Jiangang Sun and Scott Erdman, ET/212, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

---Thermal diffusivity imaging has been widely used as a nondestructive evaluation technique for characterizing structural components and detecting defects. The accuracy of the diffusivity calculations depends on several experimental parameters. While most of the parameters can be controlled to within acceptable range, finite flash duration is the dominant parameter affecting the accuracy for high-diffusivity or thin materials. In this study, a new formulation is developed to correct the finite flash duration of typical photographic flash lamps. Experimental results with and without the correction will be presented and discussed.---Work sponsored by the U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Industrial Technologies, under Contract W-31-109-ENG-38.

Importance of Acoustic Chaos in Sonic IR Imaging NDE

---Xiaoyan Han, Zhi Zeng, Wei Li, Md. Sawar Islam, and Vera Loggins, Wayne State University, Department of Electrical & Computer Engineering, Detroit, MI 48202; Jianping Lu, Lawrence Dale Favro, Golam Mohammed Newaz, Wayne State University, Institute for Manufacturing Research, Detroit, MI 48202; Robert Leighton Thomas, Wayne State University, Physics, Detroit, MI 48202

---In the Sonic IR imaging NDE technique, a short ultrasonic pulse (typically a fraction of a second) is applied to the target to excite the defects to heat up, while an infrared camera images the time evolution of the heating effect to identify the defective areas in the target. Although the ultrasonic sources we use in our systems provide single frequencies, the coupling between the ultrasonic transducer tip and the target can cause acoustically chaotic vibrations in the target, namely different frequency components which are multiples of rational fractions of the driving frequency are produced. The vibrational behavior is monitored by laser vibrometers. We discovered that acoustic chaos enhances the IR signal of defects. In this paper, we will present examples of the generation of chaotic vibration from the application of an ultrasonic excitation pulse when coupled non-linearly to a specimen under inspection by sonic IR imaging NDE, and the correlation of this behavior with IR signal.

Thermographic Materials Characterization Using Reconstructed Thermographic Data

---Steven M. Shepard, James R. Lhota, Tasdiq Ahmed, and Yu Lin Hou, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI, 48220 USA

---In practice, thermography is typically used to provide qualitative NDT data only, e.g. the presence of a delamination or inclusion. However, recent developments based on the Thermographic Signal Reconstruction (TSR) method have enabled significant improvements in the quantitative characterization of materials. As a result, it is possible to accurately map the thickness, thermal diffusivity or porosity of metal, composite or ceramic materials using reconstructed data. Unlike traditional thermographic measurement methods, the TSR based method does not require the use of a defect-free reference region. It is based on a low pass filtered representation of the raw data that retains the thermal conduction component of the decay signal, yet rejects both high frequency noise and time varying artifacts such as reflections from the heated flash lamp hardware. The method also facilitates the use of reconstructed time derivative images, which undergo significantly less blurring due to lateral heat diffusion. It is possible apply the technique to non-visual comparison of production samples to a previously evaluated "gold standard".

Infrared Imaging for Detection of Defects and Real-time Monitoring of Repairs in Sculpture

---Xiaoyan Han, Zhi Zeng, Wei Li, Vera Loggins, and Md. Sawar Islam, Wayne State University, Department of Electrical & Computer Engineering, Detroit, MI 48202; Jianping Lu and L. D. Favro, Wayne State University, Institute for Manufacturing Research, Detroit, MI 48202

---We will describe the application of infrared imaging to the detection of defects in stone sculptures. The technique uses an array of infrared lamps to inject heat into the surface of the sculpture, and, after an appropriate delay, makes images of subsurface defects with an infrared camera. The technique has detected defects up to approximately a centimeter deep in a limestone sculpture. We will also describe a method for real-time monitoring of the repair of the sculpture. The technique will be illustrated with its application to a Chinese Buddhist stele dating from 537AD.

Vibrothermographic Inspection of Tube Braze Joints and Comparison with Dye Penetrant Inspection

---Michael W. Burke[1] and Wayne O. Miller[2], [1]MMED, [2]NTED, Lawrence Livermore National Laboratory, P. O. Box 808, L-333, Livermore, CA 94551;

---Multiple test pieces were constructed consisting of a penetrating stainless steel tube that was subsequently brazed (AgSn) to an aluminum plate. The brazed joint area of all pieces (both front and back) were then imaged by an IR camera (200 fps) while the edge of the plate was subjected to 200 Watts of ultrasonic power at 30 KHz for 0.1 s from an Branson industrial ultrasonic welder. The fixturing for each piece was identical. An IR microscope lens (1x) was used to focus on the brazed joint area only. Results showed a spectrum of responses, from no IR emission to large amounts of heat generated at the joint. Asymmetric heating was also noted. Image sequences were then analyzed to plot the depth and general shape of the defects found. Pass/Fail criteria were established. The pieces were then subjected to a standard dye penetrant test procedure and results were photographed. The dye penetrant test results were then compared to the results from the vibrothermographic testing. Results showed a good correlation between the two types of inspection techniques for surface-breaking defects. Braze granularity, voids and porosities, flux inclusions, and deep cracks did not show in the dye penetrant data, but did show up in the vibrothermographic data. To see if the presence of dye penetrant would affect the vibrothermographic response of the pieces, they were re-tested. It was found that for surface breaking defects, the IR emissive response was modified by the presence of dye penetrant within the cracks. Finally, all tube joint samples were destructively tested by cycling to failure. The number of cycles to failure was correlated with the vibrothermographic data.

Numerical Calculation of Heat Generation by Defects in Ultrasonic Infrared Imaging

---Xiao-Bing Mi and Shu-Yi Zhang, Lab of Modern Acoustics, Institute of Acoustics, Nanjing University, 210093, China

---Ultrasonic infrared (UIR) imaging is a novel nondestructive technique for detecting cracks, disbonds and other defects, in which a pulsed ultrasonic excitation combined with an infrared (IR) camera imaging is used. Because of the high travel speed of ultrasound waves, large visual field of the IR and localized heating in defect areas, the technique has advantages of rapidity, sensitivity and nondestructivity, etc. Although some presumptions are presented for the mechanism of the heat generated by the ultrasound, however, up to now, no detailed calculation has ever been done for the heat generation by defects in UIR because of the difficulty in obtaining analytical solutions of the theory and test results of the experiment. In this paper, by using the Finite-Element-Method (FEM), based on the constitution equation of transient structural dynamics, coupled transient thermal-structural analyses of an aluminum plate are performed, which contains a 3D crack under a series of sine ultrasonic excitations with amplitude from 2 μm to 50 μm. The results show that relative rubbings of the crack surfaces take place even at an amplitude of 2 μm, however plastic deformations happen only at the amplitude ≥ 50 μm and in a very small part of the crack surfaces. The maximum temperature increases, resulting from the frictional dissipation, are 0.2 K, 3.1 K and 15.2 K within the time of 0.5 ms under the excitations with amplitudes of 2 μm, 10 μm and 50 μm, respectively.

SESSION 11
PART A: STUDENT POSTER COMPETITION
Exhibit Hall
1:00 PM

NOTE: To preserve anonymity before the judging phase, author names and affiliations are not listed here. The judging phase will take place from 1:00-3:10 p.m. and the public presentation will take place from 3:30-5:15 p.m. Winners of the competition will be announced at the Tuesday evening banquet.

Analytical Solutions to Leaky Rayleigh Waves at the Interface Between Elastic Solids and Ideal Fluids

Sizing of Transverse Surface Defects in Thick Plates Using Ultrasonic Surface Waves

Long Range Inspection of Lossy Bilayers

Far-Field Decay of Laser-Generated, Axisymmetric Lamb Waves

Flexural Longitudinal and Torsional Modes Natural Focusing Phenomena in a Pipe

Evaluation of Amorphous Diffusion Bonding by Nonlinear Ultrasonic Method

3-D Ray Tracing Analysis for Real-Time Weld Penetration Sensing with Laser Generated Ultrasound

Ultrasonic Attenuation and Backscatter in Voronoi Polycrystals

Magnetic Barkhausen Noise and Neutron Diffraction Techniques for the Study of Intergranular Residual Strains and Texture in Mild Steel

Measurement of Residual Stresses Using the Polarization of Rayleigh Surface Waves

A Monte-Carlo Model for Microstructure-Induced Ultrasonic Signal Fluctuations in Titanium Alloy Inspections

Recovery of Through-Thickness Texture Profiles in Sheet Metals by Resonance Spectroscopy

A 2-D Numerical Simulation Study of Microstructure-Induced Ultrasonic Beam Distortions

Applications of Air-Coupled Ultrasonics in Material Evaluation

A Focused, Two-Dimensional, Air-Coupled Ultrasonic Array for Non-Contact Generation

Monitoring Cement Hydration by Ultrasonic Dissipation

A Database Design for the Storage and Statistical Analysis of Impedance Data for the Characterization of Noise in Eddy-Current Scans

3:10 PM ***Coffee Break***

Analytical Solutions to Leaky Rayleigh Waves at the Interface Between Elastic Solids and Ideal Fluids

---The propagation of transient leaky Rayleigh waves in a solid-fluid half space system is studied using integral transform techniques. The obtained analytical solutions provide necessary theoretical background for optimization of air-coupled ultrasonic detection in experiments. The leaky Rayleigh wave velocity and attenuation coefficient in the frequency domain can be obtained from the established characteristic equation. The leaky Rayleigh wave responses under normal point loading, which varies in time as a step function, are first derived. Closed-form displacement and stress component expressions are then presented. The impulse responses owing to point loading can be obtained by taking differentiation of step responses; therefore, solutions to both arbitrary time-varying and space-varying (axially symmetric) transient impact loadings can be obtained by convolution in time and space domains. The solutions are compared to numerical time-domain results (Finite Integration Simulation) for verification.

Sizing of Transverse Surface Defects in Thick Plates Using Ultrasonic Surface Waves

---Sizing of transverse cracks at the surface of plate- and bar-like structures (e.g. railroad rails) is an important field of research interest. Especially suitable for this task are ultrasonic surface waves which feature a high sensitivity to surface defects and a low attenuation with propagation distance. By choosing an appropriate frequency a suitable penetration depth into the material can be achieved and dispersion can be limited. In this project, wave scattering by transverse surface defects smaller than the wavelength was investigated. Simulations using Finite Element models yielded relations between the reflection coefficient of the surface wave and the geometry of the defects. To verify these relations numerous experiments were performed with thick steel plates in which EDM notches had been machined. The experimental results show good agreement with the theoretical predictions and therefore suggest that the inverse method can be used to size defects in plates.

Long Range Inspection of Lossy Bilayers

---Research into ultrasonic guided wave non-destructive testing for the long range inspection of large metallic structures is now well advanced. The main advantage of this method is that a large area can be covered from the transducer position, so avoiding expensive scanning of the entire structure surface. However, in the presence of highly lossy coatings, such as in the case of bitumen coated pipelines, the test range can be severely reduced. As a consequence, it is of great practical importance to identify those modes and frequencies which (a) minimise the guided wave attenuation and (b) provide the best sensitivity to defects. Here, the effects of a viscoelastic coating on the characteristics of distorsional and extensional stress waves propagating in an elastic plate have been investigated theoretically. The bilayer modes can be viewed as an interaction between the free elastic plate modes and the modes of the viscoelastic layer if it were clamped on its lower surface. For low attenuation materials the interaction is strong and the bilayer mode path jumps between the two families as the frequency increases. This leads, in the phase velocity-frequency plane, to the mode repulsion phenomenon. However, as the material damping increases the interaction becomes weak and most of the energy is confined in either the metallic plate or in the attenuative layer. Mode intersection then occurs in the phase velocity-frequency plane. The guided wave attenuation of the modes whose energy travels primarily in the elastic plate exhibits periodic peaks in the frequency domain, which occur at roughly equally spaced critical frequencies. For distorsional modes minima of the guided wave attenuation occur at the Love transition frequencies.

Far-Field Decay of Laser-Generated, Axisymmetric Lamb Waves

---Ultrasonic attenuation is a combination of material losses and geometric effects. The current research quantifies these geometric effects in the far-field, where the individual modes of a Lamb wave become separated. The overall ultrasonic signal, which is a superposition of these modes, depends on plate geometry, source type and the individual mode characteristics. This research considers the amplitude decay of transient Lamb waves in an isotropic plate that are generated with an ablation source. A numerical simulation is developed using normal mode expansions, and is used to calculate amplitude decay. These numerical results are verified with an experimental program that uses laser ultrasonics to generate and detect multi-mode, Lamb waves.

Flexural Longitudinal and Torsional Modes Natural Focusing Phenomena in a Pipe

---Nonaxisymmetric guided waves in pipe can be divided into two major categories, i.e., flexural longitudinal and flexural torsional modes. The flexural longitudinal mode has been investigated in several papers. On the other hand, the flexural torsional mode computation is new and is just starting to be studied theoretically. We apply both flexural longitudinal mode and flexural torsional mode to defect detection in a pipe. The natural focusing of both flexural longitudinal and flexural torsional modes is discussed by way of the angular profiles that are generated as a wave travels in an axial direction in a pipe. Sensitivity to defects is also compared between flexural longitudinal and flexural torsional modes. Combining flexural longitudinal and flexural torsional modes, quantitative defect characterization can be greatly improved.

Evaluation of Amorphous Diffusion Bonding by Nonlinear Ultrasonic Method

---The nonlinear ultrasonic method, in particular harmonic generation, gains interest as a means to characterize bonding interface. The characteristics of bond interface in amorphous diffusion bonding, which is impossible by conventional method, is evaluated by measuring second harmonics amplitude. The amorphous bond samples are to bond steel bars with Ni-based amorphous metal as a foil of bonding material. Conventional ultrasonic method, e.g. exploited the echo height reflected from bond interface, could not identify samples manufactured at different bonding temperatures (1050°C1150°C1250°C) and at constant holding time (60s). Therefore, nonlinear ultrasonic method was utilized for the purpose of distinguishing the difference. The nonlinear ultrasonic method is to measure the higher harmonics generated by nonlinear stress-strain relationship at weak bonds. Measurements were made in contact using piezoelectric transducers in through-transmission. The fundamental and second harmonic wave frequencies are 5 and 10 MHz. In order to measure second harmonic wave amplitude, a commercial superheterodyne receiver and the pulse inversion method developed by the authors were used. The pulse inversion method is the digital-processing to extract only second (or even orders) harmonic wave by adding the opposite phase waves after corrected time-lag by cross-correlation method. The evaluation technique of amorphous bonding by the nonlinear ultrasonic method reached to not only laboratory use but also practical use. Furthermore, the experimental results were compared to destructive tests for examining the relationship between tensile strength and harmonics generation, and to micro observation for manifesting the source of second harmonics generation.

3-D Ray Tracing Analysis for Real-Time Weld Penetration Sensing with Laser Generated Ultrasound

---The ultrasound can be generated remotely with a pulsed laser and hence it serves as one of the few candidates for sensing and control of high temperature manufacturing processes such as welding. Time-of-flight (ToF) method is a relatively recent ultrasonic non-destructive testing (NDT) technique used to detect flaws in welding and monitor weld quality. ToF measurement can be correlated to weld penetration depth, and hence weld quality. Changes in material properties due to a temperature gradient will cause ultrasonic speed to vary during welding. The path of propagation of ultrasound will be curved because of the velocity changes with temperature. A ray tracing algorithm is mandatory to find out how ultrasound is propagated within the sample. In this paper, a 3-D ray tracing algorithm based on Fermat's Principle is presented. First of all, the temperature field within the weld sample is obtained by finite element analysis (FEA). Then, a set of ray equations is derived using calculus of variations. Unlike Snell's law, the derivation directly from Fermat's principle does not require the assumption of discrete plane layers and works for both 2-D and 3-D cases. Runge-Kutta method is applied to solve the initial value ray equations and shooting method is applied to solve the boundary value problem to obtain the ray path specified by the source and destination. After the curved ray path is obtained, the ToF can be found by integrating the time variable along the ray path. Assisted by geometric analysis, an analytical relationship between the ToF and penetration depth can be established by repeating the ray tracing algorithm for different penetration depths. Experimental measurements of ToF will be available to be compared to the numerical results.

Ultrasonic Attenuation and Backscatter in Voronoi Polycrystals

---Studies of elastic wave scattering in polycrystalline media are applicable to ultrasonic materials characterization and nondestructive evaluation. Ultrasonic attenuation and backscatter are used to extract microstructural parameters such as grain size and grain texture. The relations between experimental data and microstructural information require ultrasonic scattering models that often oversimplify real microstructures. Here these relations are examined in terms of numerical simulations of elastic waves through two-dimensional polycrystals. The numerical models, based on the Voronoi polycrystal, have been shown to model accurately the microstructure of polycrystalline metals and ceramics. Methods of creating Voronoi polycrystals with appropriate microstructure, including grain elongation and grain orientation, are first discussed followed by discussions of the wave propagation. The wave simulations are based on the discretization of these Voronoi cells, using finite elements, which are then integrated directly in time using ABAQUS/Explicit software. The material properties of the individual Voronoi cells are chosen according to appropriate material distributions. Here, the focus is on cubic crystals that are either statistically isotropic or transversely isotropic. Attenuation and backscatter results for both longitudinal and shear waves are presented and compared with scattering theories. These simulations provide insight into the attenuation models relevant for ultrasonic measurements involving polycrystalline materials.

Magnetic Barkhausen Noise and Neutron Diffraction Techniques for the Study of Intergranular Residual Strains and Texture in Mild Steel

---Residual stresses are very important in engineering materials since they can lead to unexpected failures. The influence of stress, and specifically residual stresses on the magnetic properties of materials is not completely understood. Magnetic Barkhausen Noise (MBN) is one of the few non-destructive techniques able to determine the existence of residual strains in ferromagnetic samples such as steels. Residual stresses can exist on different scales in engineering materials. The macroscopic residual stresses (Type 1) result from large scale, non-uniform plastic deformation. Less well known are intergranular (IS), or Type 2 residual stresses. These arise due to the non-uniform deformation on grain size scale. Neutron diffraction studies have found IS in steels to be very high in the [002] direction compared with other crystallographic directions. Interestingly, [002] is also the magnetic easy axis direction in steels. Our study is focused on finding the relationship between IS and the magnetic behavior in mild steel. The MBN and the neutron diffraction data taken after unloading of plastically deformed mild steel samples indicated a correlation between the MBN signals and IS. In cases when texture was present after deformation, the magnetic behavior was dependent on the interplay between the IS and texture.

Measurement of Residual Stresses Using The Polarization of Rayleigh Surface Waves

---This research develops a procedure to measure residual stresses using the polarization of Rayleigh surface waves. The effect of residual stresses on the wave speed and polarization of Rayleigh surface waves is analytically calculated using Stroh's formalism. The experimental procedure uses a laser Doppler vibrometer (LDV) to (nearly) simultaneously measure both the in-plane and out-of-plane displacement components of a Rayleigh wave, as a function of applied stress. Note that the proposed technique is self-calibrating. An advantage of this procedure, when compared to standard time-of-flight measurements is that the change in polarization is an order of magnitude greater than the change in wave speed.

A Monte-Carlo Model for Microstructure-Induced Ultrasonic Signal Fluctuations In Titanium Alloy Inspections

---In ultrasonic pulse/echo inspections of some jet-engine alloys, microstructural inhomogeneities act to significantly distort the amplitude and phase profiles of the incident sonic beam. As reported in earlier work, these distortions lead to ultrasonic amplitude variations. For example, the back-wall signal amplitude is often seen to fluctuate dramatically when scanning a transducer parallel to the backwall. Similar fluctuations can be seen for nominally-identical internal defects, such as arrays of flat-bottom-holes (FBH) located at a given depth. The stochastic nature of the ultrasonic response has obvious implications for both flaw characterization and probability of detection, and tools to estimate fluctuation levels are needed. In this study, as a first step, we develop a quantitative Monte-Carlo model to predict the back-wall amplitude fluctuations seen in ultrasonic pulse/echo inspections. Inputs to the model include statistical descriptions of various beam distortion effects, namely: the lateral “drift” of the center-of-energy about its expected position; the distortion of pressure amplitude about its expected pattern; and two types of wavefront distortion (“wrinkling” and “tilting”). The model inputs are deduced by analyzing through-transmission measurements in which the sonic beam emerging from an immersed metal specimen is mapped using a “point” receiver. The mapped field is compared to the model prediction for a homogeneous metal, and statistical parameters describing the differences are deduced using the technique of “maximum likelihood estimation” (MLE). Our modeling approach is demonstrated using rectangular coupons of jet-engine Titanium alloys, and predicted back-wall fluctuation levels are shown to be in good agreement with experiment. As a new way of modeling ultrasonic signal fluctuations, the approach outlined in this paper suggests many possibilities for future research.

Recovery of Through-Thickness Texture Profiles in Sheet Metals by Resonance Spectroscopy

---Sheet metals inherit crystallographic texture from the manufacturing processes that produce them, and this texture influences formability and other properties of the material. Texture can be represented by the orientation distribution function (ODF), which is completely described by an infinite sequence of texture coefficients. Many material properties, however, are influenced by only a few texture coefficients. Reconstruction of those particular texture coefficients from quick nondestructive techniques is an important concern of the manufacturing industry. Past techniques focused on determining texture on the surface of the material or an average texture through the thickness of the sheet metal. In this paper we present a method for recovering through-thickness profiles of two texture coefficients, namely W400 and W420, in orthorhombic sheets of cubic metals. Our method is based on a careful analysis of the through-thickness resonance spectra as obtained from resonance-EMAT or laser-ultrasound measurements. Shifts in resonance frequencies are related through mathematical formulae to the profiles of the two texture coefficients in question. Copper samples and resonance spectra generated by EMAT measurements are used to test the validity and usefulness of this theory. Experimental method and current results will be presented.

A 2-D Numerical Simulation Study of Microstructure-Induced Ultrasonic Beam Distortions

---In past work we have introduced an algorithm for computing ultrasonic pressure fields propagating through inhomogeneous media. The algorithm uses a volume integral formulation of the scattering problem, which is solved by an efficient FFT-based Neumann iteration. In inspections of Titanium-alloy, jet-engine materials microstructure-induced ultrasonic beam distortions and associated ultrasonic signal fluctuations are often seen. Our computational approach can be used to study these phenomena. In the present work, 2-D numerical simulations have been carried out to study the statistics governing ultrasonic beam distortions. Several microstructures are considered, each of which is modeled as a collection of uniform-sized rectangular cells with different sound speeds. The rectangular cells simulate macrograins in jet-engine alloys. Sound beams computed for propagation through the inhomogeneous microstructures are compared to those for the homogeneous case. From the differences we obtain statistical descriptions of various beam distortion effects, including the lateral “drift” of the center-of-energy about its expected position, the distortion of the pressure amplitude about its expected pattern; and two types of phase-front distortion (“wrinkling” and “tilting”). The statistical beam-distortion parameters play a key role in models for estimating the signal fluctuations seen in pulse/echo inspections; one such model is the topic of a companion article in these proceedings.

Applications of Air-Coupled Ultrasonics in Material Evaluation

---The characterization of elastic material properties by ultrasonic measurements in air has become a realistic possibility largely through recent advances in the design of air-coupled acoustic transducers. The technique presented here takes advantage of the broadband, wide angular range of focused acoustic air coupled probes to image the guided wave modes for isotropic and anisotropic plates. A stereolithographic parabolic mirror was designed to produce a line focused beam with an angular range of approximatively 16 degree. The focused acoustic beam and the large acoustic impedance mismatch between air and sample is exploited to produce the wide angular range in samples required to image most of the guided wave modes at once. The leaky waves are measured for discrete location along the sample with only one fixed incident angle in transmission setup. A 2D-FFT maps the measured data into wavenumber-frequency domain where guided wave modes are observed as peaks. Excellent correlation between theoretical and experimental results prove the validity of the method for a wide range of materials.

A Focused, Two-Dimensional, Air-Coupled Ultrasonic Array for Non-Contact Generation

---Conventional ultrasonic testing uses transducers that must be in direct contact with the component, or must use a coupling medium, such as water. Air-coupled ultrasound has the advantage of being non-contact, but suffers from losses at the air/solid boundary, due to reflections caused by high impedance differences. The objective in this research is to design a focused, 2D-array of electrostatic transducers (individual diameters of 38mm) to increase ultrasonic signal amplitude. The operating frequency is in the range from 50 kHz up to 100 kHz. Numerical simulations are used to model the sound field in air, and to design an array consisting of 20 transducers to create a line-source. The numerical simulation is used to design an array, and the numerical results are verified and validated with experimental measurements.

Monitoring Cement Hydration by Ultrasonic Dissipation

---Cement paste is an essential part of all concrete structures and is essential to the structural integrity of such structures. The physical properties of concrete, including its strength and durability, depend largely on the cement paste and its adherence to the aggregate. The process of hydration is the chemical reaction that is primarily between the cement and the water. As this reaction takes place, the strength of the cement paste increases with time. Monitoring of the hydration process provides an indirect measure of the strength development. Current monitoring techniques include thermal monitoring and nuclear magnetic resonance. Here, it is shown that ultrasonic dissipation is also related to the hydration process. Relevant experiments were conducted using several specimens of cement cubes 50.8 mm on a side. Ultrasonic dissipation was measured at regular intervals over a period of 28 days covering a frequency range of 200 - 1000 kHz. Compressive strength tests were also conducted on these specimens at 1, 3, 7, 14, and 28 days. The results show that the ultrasonic dissipation decreases as a function of curing time, asymptotic to the 28 day value. Thus, the dissipation results can be correlated directly to the strength gain of cement mortar.

A Database Design for the Storage and Statistical Analysis of Impedance Data for the Characterization of Noise in Eddy-Current Scans

---Some nondestructive inspections such as those carried out at power plants result in large amounts of data being generated and stored. Databases are often used to index and catalog the data such that it can be accessed readily after inspections have been carried out. In contrast, the use of databases is uncommon in the eddy-current research environment as the benefits rarely justify the overhead involved in constructing them. However, an investigation into the origin of noise in eddy-current impedance scans has presented a need for the creation of a database for research purposes. The said research program aims to characterize eddy-current noise sources with some thirty Inconel and Titanium flat-plate specimens. Each specimen will be scanned with one of four different eddy-current probes. The specimens will have been subjected to a variety of treatments including sanding, shot peening and annealing. A statistical analysis will be carried out on the data from each scan and compared with surface roughness measurements, optical micrographs and specimen treatment conditions. This paper reports on the design of a database to store the scan files, associated scan parameters, treatment conditions, probe information and the results of statistical analyses. The database is organized in a way that considers treatments and scans separately and as distinct operations. Base tables define probes, specimens, treatments and scans; additional tables then record scan and treatment processes – specific actions involving and linking to the base tables. The database offers a convenient and tidy data storage and handling engine. More importantly, statistical information can be tabulated as a function of virtually any experimental parameter to provide a very powerful analysis tool.

SESSION 11 – PART B: POSTERS
UT MODELING, MATERIALS CHARACTERIZATION, AND EDDY CURRENT PROBES
Exhibit Hall

3:30 PM

UT Modeling

Fast Imaging of 3-D Flaw Using Linearized Inverse Scattering Methods
---K. Nakahata and S. Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Tokyo, Japan; M. Kitahara, Department of Civil Engineering, Tohoku University, Sendai, Japan

Calculation of Guided Wave Scattering at a Defect in a Pipe
---T. Hayashi and K. Kawashima, Nagoya Institute of Technology, Nagoya, Japan; J. L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA

Three-Dimensional Boundary Element Modeling for Guided Waves Scattering from a Defect
---X. Zhao, Intelligent Automation, Inc., 7519 Standish Place, Suite 200, Rockville, MD 20855; J. L. Rose, Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

Development of an Ultrasonic Testing Simulator Using the Mass-Spring Lattice Model
---E. Baek and H. Yim, Mechanical Engineering, Hongik University, Seoul, Korea

Transferring Distance-Amplitude Correction Curves Using Ultrasonic Modeling
---H.-J. Kim[1], L. W. Schmerr, Jr.[1,2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011, [2]Department of Aerospace Engineering; A. Sedov, Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario, Canada, P7B 5E1

Modeling Ultrasonic Fields of a Transducer with Modular Multi-Gaussian Beam Model
---R. Huang and L. W. Schmerr, Jr., Iowa State University, Center for NDE, 1915 Scholl Road, and Department of Aerospace Engineering, Ames, IA 50011; A. Sedov, Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario, Canada, P7B 5E1

Generic Ultrasonic 3D Ray Tracing Incorporating Beam Energy Models
---S. Dewangan[1], B. Rangan[2], A. Krishnamurthy[2], and G. Katragadda[1], [1]Industrial Imaging and Modeling Lab, GE India Technology Center, Bangalore, India; [2]Indian Institute of Technology, Madras, India

Materials Characterization

Thermoelectric Background Signature Due to the Presence of Material Property Gradients
---H. Carreon, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán 58000-888, Mexico; B. Lakshminarayan and P. B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221-0070

Impedance Spectroscopy of Liquid-Phase Sintered Silicon Carbide
---D. S. McLachlan[1], G. Sauti[1], A. Vorster[1], and M. Hermann[2], [1]School of Physics, University of the Witwatersrand, Johannesburg, South Africa; [2], Fraunhofer Institute for Ceramic and Sintered Materials Technologies, Dresden, Germany

Evaluation of the Formation of Rare Earth Complex in Silica Gels by Photoacoustic Spectroscopy
---Y.-T. Yang and S.-Y. Zhang, State Key Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, P.R. China

Characteristic Evaluation of Impact Responses and Damages in Composite Shell with Various Curvatures
---Y. N. Kim, Department of Mechanical Design Engineering, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-gun, Chonbuk, 565-701, Korea; J. W. Park, Factory Automation Research Center for Parts of Vehicles, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; K. S. Kim and I. Y. Yang, Department of Mechanical Information Engineering, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea

Nondestructive Inspection of Metal Matrix Composites Using Guided Waves
---X. Zhao, C. Swan, R. Xu, and T. Qian, Automation, Inc., 7519 Standish Place, Suite 200, Rockville, MD 20855; T. Hay and J. L. Rose, FBS, Inc., 2134 Sandy Drive, Suite 14, State College, PA 16803; B. B. Raju, U. S. Army TACOM, 6501 E. 11 Mile Road, MS 255, Warren, MI 48397; R. Maier, Cast Metal Composites Incorporated, 16651 Sprague Road, Cleveland, OH 44136; R. Hexember, Surmet Technical Ceramics Center, 699 Hertel Avenue, Suite 290, Buffalo, NY 14207

A Study on the Splitting of the Valance Band for a CdIn2Te4 Single Crystal Using Photocurrent Measurement
---K. J. Hong, S. Y. Lee, S. H. You, J. W. Jeong, and J. J. Bang, Department of Physics, Chosun University, Kwangju 501-759, South Korea; H. Jian, Department of Election and Information, Yanbian University, Yanji City, Jilin Province,133002, China; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk, 565-701, South Korea

La Doping Effects on Double Perovskite Sr2MnMoO6
---X. Liu, Q. Huang, S. Zhang, A. Luo, and X. Shui, Lab of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China

A Study on Annealing Effects of p-CdIn2Te4 Single Crystal Obtained from Photoluminescence Measurement
---K. J. Hong, S. Y. Lee, S. H. You, J. W Jeong, and J. J. Bang, Department of Physics, Chosun University, Kwangju 501-759, South Korea; H. Jian, Department of Election and Information, Yanbian University, Yanji City, Jilin Province,133002, China; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk 565-701, South Korea

Characterization of Ferritic and Austenitic Alloys by NDT
---P. Petculescu, G. Prodan, and R. Zagan, Ovidius University, Department of Physics, Mamaia Avenue, No. 124, Cod 8700, Constanta, Romania

Eddy Current Probes

Eddy Current Testing and Sizing of Deep Cracks in a Thick Structure
---H. Huang, H. Endo, T. Uchimoto, and T. Takagi, Institute of Fluid Science, Tohoku University, Sendai, Japan; A. Mishimizu, M. Koike, and T. Matsui, Power & Industrial Systems, R&D Laboratory, Hitachi, Ltd., Hitachi, Ibaraki, Japan

High Sensitivity Eddy Current Probe for Inspection of Low Conductivity Materials
---R. Sikora, S. Gratkowski, M. Komorowski, and T. Chady, Technical University of Szczecin, Electrical Department, ul. Sikorskiego 37, 70-313, Szczecin, Poland

A Study on Image Processing for Eddy-Current Testing Based on Defect Orientation
---T. Taniguchi, Department of Electronic Engineering, The University of Electro-Communications, Tokyo, Japan; K. Nakamura, S. Yamada, and M. Iwahara, Institute of Nature and Environmental Technology, Kanazawa University

Fast Imaging of 3-D Flaw Using Linearized Inverse Scattering Methods

---Kazuyuki Nakahata and S. Hirose, Dept. of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Tokyo, Japan; Michihiro Kitahara, Dept. of Civil Engineering, Tohoku University, Sendai, Japan

---The linearized inverse scattering methods based on Born and Kirchhoff approximations have been developed for the shape reconstruction of flaws in an elastic material. A principal operation of these inverse methods is to integrate the backscattering amplitudes from flaws in the K-space, which consists of the wave numbers and observation angles that enclose the flaws. In order to perform the inverse analysis with the high speed, the algorithm of FFT is introduced to the integration of backscattering amplitudes in the K-space. In this study, the shape reconstruction of flaws in three dimensional elastic materials is demonstrated with the numerically calculated wave data. The numerical calculations are performed by means of the boundary element method, then the scattering amplitudes from flaws are obtained by the integral expression of the far field scattered wave.

Calculation of Guided Wave Scattering at a Defect in a Pipe

---Takahiro Hayashi and Koichiro Kawashima, Nagoya Institute of Technology, Nagoya, Japan; Joseph L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA

---Guided waves have been used as the most promising technique for the rapid non-destructive evaluation of large structures such as a pipe. Reflection echoes from a defect that may cause severe damage in a pipe, however, often become noise level. Guided wave focusing have been developed to enhance the reflection echoes from such a defect and to identify the location and size of the defect. Many authors in the Penn State group proved theoretically and experimentally that guided wave energy can focus at a desired position using multi-transducers located in a circumferential direction. This study shows the scattering at a defect in a pipe using a semi-analytical finite element method. Visualization results are shown in the case of axi-symmetric exciting, flexural mode focusing and torsional mode focusing. And also focusing potential with various frequency ranges and excitation modes are discussed.

Three-Dimensional Boundary Element Modeling for Guided Waves Scattering from a Defect

---X. Zhao, Intelligent Automation, Inc., 7519 Standish Place, Suite 200, Rockville, MD 20855; J. L. Rose, Department of Engineering Science and Mechanics, the Pennsylvania State University, University Park, PA 16802

---A hybrid three-dimensional Boundary Element normal mode expansion technique is developed to study the guided wave scattering from an arbitrary shape defect in a plate. A circular disk region on a plate enclosing the three-dimensional defect was meshed with constant boundary elements. Outside the meshed region, three-dimensional normal modes of both Lamb and SH waves were used to construct the incident and scattered wave field. The wave scattering amplitude in different directions from the defect will be obtained for defect characterization. Both Lamb wave and SH wave incident into the defects were studied, respectively. Mode conversion from Lamb wave to SH wave and vice versa at the defect boundary were observed. Parametric study on different size drilled through-plate holes is carried out to see the effect of defect size on wave scattering.

Development of an Ultrasonic Testing Simulator Using the Mass-Spring Lattice Model

---Eunsol Baek and Hyunjune Yim, Mechanical Engineering, Hongik University, Seoul, Korea

---Previous studies had shown that the mass-spring lattice model (MSLM), which models elastic solid media via interconnected mass points and springs, is capable of accurately simulating two-dimensional propagation, reflection, refraction, and scattering of ultrasonic waves. Those studies, however, assumed fictitious plane incident waves due to the absence of the models of ultrasonic probes. In the present work, models of ultrasonic probes were developed, and they were combined with the MSLM to develop a complete simulator of ultrasonic testing (UT). Transmitting probes were modeled via distributed forces on the boundary of the test object. By varying the temporal functions of the distributed normal forces, normal transmitting probes having various frequency characteristics may be simulated. In addition, by varying the directions of and time delays among the distributed forces, angle-beam transmitting probes may be simulated. Radiated fields from several transmitting probes are shown as examples. Receiving probes were modeled by assuming that the output voltage is proportional to the forces on the boundary exerted by the incoming waves. Several problems of typical ultrasonic testing were simulated using the developed UT simulator to demonstrate its capability to predict the waveform in ultrasonic tests.

Transferring Distance-Amplitude Correction Curves Using Ultrasonic Modeling

---Hak-Joon Kim[1], Lester W. Schmerr, Jr.[1,2], Iowa State University, [1]Center for Nondestructive Evaluation, 1915 Scholl Road, [2]Department of Aerospace Engineering; Ames, IA 50011; Alexander Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, Canada, P7B 5E1

---In the ultrasonic standards practice, it is common to manufacture reference blocks containing simple reflectors, such as a flat-bottom hole (FBH) or side-drilled hole (SDH), in order to calibrate systems sensitivity, to perform distance-amplitude correction (DAC) curves, etc. However, the construction of DAC curves is expensive and not always a simple procedure since a large number of specimens with appropriate curvatures and reference reflectors oriented at different locations and depths in the specimen are needed. Therefore, less costly and quantitative procedures are strongly needed. To address such need, in this paper, we will propose a new and efficient approach to evaluate DAC curves using an ultrasonic measurement model. Firstly, we perform the construction of DAC curves for FBHs and SDHs considering not only different flaw sizes but also interface curvatures of the specimen, as well. Based on these predicted DAC curves, new transfer curves will be proposed to relate these DAC curves. For instance, by using the proposed transfer curves, a DAC curve for a FBH can be easily estimated from a known DAC curve for a SDH which may have a different size and be in a specimen with a different interface curvature. This paper will describe in detail use of the proposed transfer curves different reference blocks.

Modeling Ultrasonic Fields of a Transducer with Modular Multi-Gaussian Beam Model

---Ruiju Huang and Lester W. Schmerr, Jr., Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road and Department of Aerospace Engineering, Ames, IA 50011; Alexander Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, Canada, P7B 5E1

---Modeling ultrasonic transducer fields is a difficult task due to the complex effects of the material properties and geometries of the testing components on the propagating waves. For example, a curved interface results in focusing/defocusing of the incident waves. A number of modeling methods, such as Gaussian-Hermite models, boundary diffraction wave models, and multi-Gaussian beam models, have already been developed and applied to simulate the wave fields generated by a transducer. Multi-Gaussian beam models, in particular, are very attractive since they are computationally efficient and can handle many common testing situations. Here, we will show that a highly modular multi-Gaussian beam model can be developed that allows one to simulate very general problems involving multiple curved interfaces. This modular model is also numerically efficient since it is in a highly explicit, analytical form. A formulation of this modular model is briefly described and some results generated numerically with this approach are also presented.

Generic Ultrasonic 3D Ray Tracing Incorporating Beam Energy Models

---S. Dewangan[1], B. Rangan[2], A. Krishnamurthy[2], and G. Katragadda[1], [1]Industrial Imaging and Modeling Lab, GE India Technology Center, Bangalore, India; [2]Indian Institute of Technology, Madras, India

---Ultrasonic data from inspections of complex structures such as aircraft engine components and weld regions of pipelines are difficult to interpret because of multiple interface reflections, mode conversions, and attenuation. Conventional ray tracing models are simplistic and do not account for beam energy distribution, mode conversions and attenuation. Finite element models are computationally intensive and not ideally suited for quick studies of energy defect interactions to aid data analysts. This paper presents an advanced 3D Ray Tracing model developed in Unigraphics incorporating beam energy distribution, attenuation, and mode conversion modeling. The model is ideal for generating quick animations to understand A-scans, B-Scans, and C-Scans from complex inspections. The model is generic and applicable to any arbitrary geometry. Results from calibration blocks demonstrate the model validity.

Thermoelectric Background Signature Due to the Presence of Material Property Gradients

---Hector Carreon, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán 58000-888, Mexico; Balachander Lakshminarayan and Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221-0070

---The detectability of small and/or weak imperfections in noncontacting thermoelectric NDE is ultimately limited by the intrinsic anisotropy and inhomogeneity of the material to be inspected. This effort was aimed at the experimental investigation of the normal and tangential magnetic fields produced by thermoelectric currents due to the presence of weak inhomogeneity in a slender bar under axial heating and cooling when the material properties exhibit a linear spatial variation in the cross section of the specimen. Experimental results from a highly inhomogeneous artificial copper/brass sintered specimen were found to be in very good quantitative agreement with the predictions of a previously developed analytical model. Similar measurements on a weakly inhomogeneous Ti-6Al-4V titanium-alloy bar were also shown to be in very good qualitative agreement with the predictions of the same analytical model although the unexpectedly high magnitude of the observed signatures could not be verified by conventional contact measurements, therefore further efforts are needed to better understand the underlying physical phenomenon and clarifying the relationship between the strength of the signature and the very complex microstructural features of this popular high-strength alloy.

Impedance Spectroscopy of Liquid-Phase Sintered Silicon Carbide

---D. S. McLachlan[1], G. Sauti[1], A. Vorster[1], and M. Hermann[2], [1]University of the Witwatersrand, School of Physics, Johannesburg, South Africa; [2]Frauenhofer Institute for Ceramic and Sintered Materials Technologies, Dresden, Germany

---Liquid-Phase Sintered Silicon Carbide (LPSSiC) materials were produced with different Y2O3:Al2O3 sintering additive ratios. Densification was achieved by hot pressing (HP) and gas pressure sintering (GPS)), which showed a significant increase with decreasing Y2O3: Al2O3 ratio. The ratio of the SiC polytypes and the amount and crystalline composition of grain boundary phases was determined using Rietveld analysis. Microstructures of the materials were related to mechanical (hardness, fracture toughness and strength, not presented) and Impedance Spectroscopy results. The Impedance Spectroscopy results were made at temperatures between 150oC and 400oC and analyzed using Effective Media and/or percolation theory. In order to correctly fit the results it was necessary to use or model the frequency dependence of the conductivity or dielectric constant of both the SiC grains and the complicated grain boundary material, produced from the sintering aids at each temperature. The impedance arcs for the SiC grains in the different samples varied widely, more due to the "semi-conductor" doping of the grains (from Al in the Al2O3), than the SiC polytypes in the grains.

Evaluation of the Formation of Rare Earth Complex in Silica Gels by Photoacoustic Spectroscopy

---Yue-Tao Yang and Shu-Yi Zhang, State Key Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, P.R. China

---Rare earth complexes have received great interest because of their important roles in studies of luminescent materials, NMR shift reagents and biological systems. However, rare earth complex solids are usually soft, easily melted, and with few desired mechanical properties. Thus these complexes have been impeded from direct applications as luminescent phosphors or other optical devices. One approach to solve the above problem is to dope some complexes into solid matrices by sol-gel method, which has been established as an excellent method for the preparation of inorganic-organic composite materials under mild conditions. In this work, a neodymium complex with salicylic acid is incorporated into silica gels by sol-gel method. The formation of neodymium complex with salicylic acid in silica gels is evaluated by detecting its photoacoustic (PA) spectra in situ. The nephelauxetic parameters of neodymium ion in silica gels are calculated based on the PA assignments, and the intensities of f-f transitions are interpreted by calculating their PA branching vectors. The PA study indicates that salicylic acid does not coordinate with neodymium ion upon gelation at 40°C because of the acid environment of the gel, but the complex is believed to form in the silica gel after further heat treatment at 100°C. This result is also confirmed by the infrared and visual absorption spectra.

Characteristic Evaluation of Impact Responses and Damages in Composite Shell with Various Curvatures

---Y. N. Kim, Department of Mechanical Design Eng., Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; K. H. Im, Dept. of Automotive Engineering, Woosuk University, Wanju-gun, Chonbuk, 565-701, Korea; J. W. Park, Factory Automation Research Center for Parts of Vehicles, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; K. S. Kim and I. Y. Yang, Department of Mechanical Information Eng., Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea

---Composites are considered for many structural (aerospace vehicles, automobiles, trains and ships) applications structural weight. However, impacted composite structures have 50-75% less strength than undamaged structures. The present work experimentally characterizes and explores the response of composite structures with a wide range of structural configurations to both impact and quasi-static loadings. In this study, CF/Epoxy(Carbon Fiber/Epoxy Resin) composite laminates with various curvatures was used. The objective of this study is to find a method for changing the radius of the curvature and to determine how the impact velocity affects the contact force-deflection, damage area and absorbed energy under low-velocity impact loadings. By experimenting with composite structures, we found that there were substantial differences between the responses of a flat-plate and shell to transverse loading. And contact force, damage area, and absorbed energy of the composite shells were a function of curvature radius and impact energy.

Nondestructive Inspection of Metal Matrix Composites Using Guided Waves

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---New materials known as Metal Matrix Composites (MMC) are light in weight, and resistance to high temperature and wear. Track shoes made of MMC will yield long service life and significant weight reduction. For the above advantages to materialize, the Silicon Carbide (SiC) in the MMC must be free of defects such as crack, porosity and disbond. Nondestructive inspection techniques are needed for both in-process and in service defect detection. Ultrasonic guided waves (Lamb wave, Rayleigh wave, etc.) combined with advanced signal classification algorithms (Physics based feature extraction and Support Vector Machines) demonstrated great potential for various defect inspection, classification and sizing. MMC specimens with surface notch, sub-surface crack, 10% volume ratio porosity, and 20% porosity were manufactured and tested, which showed up to 93 % correctness of classification of the four types of defects. Crack, delamination, and protuberances of MMC on an actual track shoe were also successfully detected.---This research was supported by Army TACOM under contract DAAE07-03-C-L054.

A Study on the Splitting of the Valance Band for a CdIn2Te4 Single Crystal Using Photocurrent Measurement

---K. J. Hong, S. Y. Lee, S. H. You, J. W. Jeong, and J. J. Bang, Department of Physics, Chosun University, Kwangju 501-759, South Korea; H. Jian, Department of Election and Information, Yanbian University, Yanji City, Jilin Province,133002, China; K.H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk, 565-701, South Korea

---The p-CdIn2Te4 single crystal has been grown by using Bridgman method without a seed crystal in a three-stage vertical electric furnace. From the photocurrent measurement, it was found that the three peaks of A, B, and C corresponded to the intrinsic transition due to the band-to-band transition from the valence band state £F7(A), £F6(B), and £F7(C) to the conduction band state £F6, respectively. Also, the valence band splitting of the CdIn2Te4 crystal has been first confirmed through the photocurrent spectroscopy. The crystal field splitting and the spin orbit splitting were obtained to be 0.2360 and 0.1119 eV, respectively. Also, the temperature dependence of the band gap energy of the CdIn2Te4 crystal has been driven as the following equation of: Eg(T) ƒ- Eg(0) ƒ{ (9.43 „e 10-3)T2/(2676 ƒy T). In this equation, the Eg(0) was estimated to be 1.4750, 1.7110, and 1.8229 eV at the valence band state A, B, and C, respectively. The band gap energy of the p-CdIn2Te4 at room temperature was determined to be 1.2023 eV.

La Doping Effects on Double Perovskite Sr2MnMoO6

---X. Liu, Q. Huang, S. Zhang, A. Luo, and X. Shui, Lab of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China

---Recently, transition metal oxides with ordered double-perovskite structure, Sr2MMoO6 (M = Fe, Co, Mn and Cr), attract considerable interest from the viewpoint of fundamental physics and technological application to magnetoresistance devices. Among them, Sr2FeMoO6 is known to be a ferromagnetic metal with a high critical temperature Tc ~ 420 K. In this system, Fe3+ ions (3d5) behave as local spins, while the conduction band is occupied by the 4d electrons of Mo5+ (4d1) ions. On the other hand, Sr2MnMoO6 is a paramagnetic insulator due to the absence of the 4d electrons in the Mo6+ (4d0) ions. Thus, electron doping in Mo4d band is expected to induce an insulator to metal phase change. In this study, we perform mirage method to investigate the electron doping effect on the thermal diffusivity of Sr2MnMoO6 by substitution of La3+ ions for Sr2+ ions. We find that the thermal diffusivity gradually increases with increase of the La doping concentration x: 0.33 cm2/s for x = 0.0 and 0.49 cm2/s for x = 0.4. Such an enhancement of the thermal diffusivity is ascribed to occupation of the doped electrons mainly in the Mo4d band, implying the enhanced conductivity. We further compare the charge doping effect on Sr2MnMoO6 with that on Sr2FeMoO6, and discuss the micro-mechanism of the charge doping effect.

A Study on Annealing Effects of p-CdIn2Te4 Single Crystal Obtained from Photoluminescence Measurement

---K. J. Hong, S. Y. Lee, S. H. You, J. W. Jeong, and J. J. Bang, Department of Physics, Chosun University, Kwangju 501-759, South Korea; H. Jian, Department of Election and Information, Yanbian University, Yanji City, Jilin Province,133002, China; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk 565-701, South Korea

---The p-CdIn2Te4 single crystal was grown in the three-stage vertical electric furnace by using Bridgman method. The quality of the grown crystal has been investigated by the x-ray diffraction and the photoluminescence measurements. From the photoluminescence spectra of the as-grown CdIn2Te4 crystal and the various heat-treated crystals, the (Do, X) emission was found to be the dominant intensity in the photoluminescence spectrum of the CdIn2Te4:Cd, while the (Ao, X) emission completely disappeared in the CdIn2Te4:Cd. However, the (Ao, X) emission in the photoluminescence spectrum of the CdIn2Te4:Te was the dominant intensity like an as-grown CdIn2Te4 crystal. These results indicated that the (Do, X) is associated with VTe acted as donor and that the (Ao, X) emission is related to VCd acted as acceptor, respectively. The p-CdIn2Te4 crystal was found to be obviously converted into the n-type after annealing in the Cd atmosphere. The origin of (Do, Ao) emission and its TO phonon replicas is related to the interaction between donors such as VTe or Cdint, and acceptors such as VCd or Teint. Also, the In in the CdIn2Te4 was confirmed not to form the native defects because it existed in the stable form of bonds.

Characterization of Ferritic and Austenitic Alloys by NDT

---P. Petculescu, G. Prodan, and Z. Remus, Ovidius University, Department of Physics, Mamaia Avenue, No. 124, Cod 8700, Constanta, Romania

---In this paper we characterize 3 samples used in petrochemical industry by NDT method with ultrasonics. The 3 samples are 10TiNiCr180, 16Mo3, P5 in Romanian standard or W1.4541, IEMo3, P5 in European norms, for which the chemical composition is known by spectral analysis. The experimental set-up is supplied by PAC (IPR-100, AID 100 and SMC4). The method used here is a pulse-echo technique by direct contact. We use transducers of 4 MHz and 10 mm diameter. We determine acoustic parameters like the propagation velocity and the attenuation at the working frequency in 10 points (every point is the mediated value of 8 measurements). The sampling ratio is 32MHz and we reconstruct the signal using a sinus attenuated function in order to obtain a sampling rate of 320 MHz. This soft method improves the signal shape. We use 2 echoes and the common exponential relation Ae^(áx) gives the peak attenuation. The experimental results obtained by Pac are compared with the one determined by USK7D.

Eddy Current Testing and Sizing of Deep Cracks in a Thick Structure

---Haoyu Huang, Hisashi Endo, Tetsuya Uchimoto, and Toshiyuki Takagi, Institute of Fluid Science, Tohoku University, Sendai, Japan; Akira Mishimizu, Masahiro Koike, and Tetsuya Matsui, Power & Industrial Systems, R&D Laboratory, Hitachi, Ltd., Hitachi, Ibaraki, Japan

---Eddy current testing (ECT) is a well-known nondestructive testing method because of its high detecting speed and high sensitivity. Due to the skin effects, ECT is mostly used for the detection of surface cracks, and the sizing of deep cracks remains difficult. For thick structures, not only detecting but also the sizing of a crack is considered important. In this paper, the design of a novel ECT probe is presented and applied to the testing of a 20mm thickness plate made of SS304. Three kinds of cracks with depths of 5,10,15mm are tested, and the difference of ECT signals for cracks can be found. Using a fast simulator of ECT based on an edge based finite element method, the authors have already shown that successful results have been obtained in crack sizing in steam generator tubes even by applying a steepest descent method. For a thick plate case, the problems of the local minimum become severer. Moreover, the difference of the ECT signals is very small. Using former the optimization method, reconstructions succeed for 5mm and 10mm cracks but failed in the 15mm cracks cases. Thus, optimization methods using gradient of the estimation function are not proper for deep cracks. By applying a new random searching method, the sizing results of deep cracks show better results than the former method.

High Sensitivity Eddy Current Probe for Inspection of Low Conductivity Materials

---Ryszard Sikora, Stanislaw Gratkowski, Mieczyslaw Komorowski, and Tomasz Chady, Technical University of Szczecin, Electrical Department, ul. Sikorskiego 37, 70-313 Szczecin, Poland

---Electromagnetic inspection methods have gained growing attention in case of living organisms' examination. From the safety point of view there are strict limitations on a testing frequency and an applied magnetic field strength. These restrictions as well as a low electrical conductivity of the tissue cause that it is necessary to develop a high sensitivity transducers. In this paper authors propose an eddy current probe, which is suitable for inspection of low conductivity structures. The probe consists of an excitation coil and two differentially connected search coils. The detection circuit was designed in this way that a resonance for an operating frequency was obtained. It creates possibility to achieve a high sensitivity of the measuring system. The transducer was used to examine heterogeneities of low conductivity specimens. The test specimens consist of various plexiglas elements placed into a tank filled with drinking water or water solution of NaCl. Results of measurements confirm usability of the sensor and the whole measuring system. The sensor offers high sensitivity, but a further work should be carried out in order to improve a spatial resolution.

A Study on Image Processing for Eddy-Current Testing Based on Defect Orientation

---Tetsuki Taniguchi, Department of Electronic Engineering, The University of Electro-Communications, Tokyo, Japan; Kazunori Nakamura, Sotoshi Yamada, and Masayoshi Iwahara, Institute of Nature and Environmental Technology, Kanazawa University

---Eddy-current testing (ECT) method using meander and mesh type coil is a useful tool for the examination of delicate metallic objects, but it requires the scanning of samples in both vertical and horizontal directions, and which results in the necessity to analyze two images for one sample. This paper presents a synthesis method of those two images into one image without loss of the information on defect signals. Consequently, we need analyze only one figure to achieve the actual recognition and feature extraction of defects. The proposed method utilizes a classification technique of defect orientations by using nonseparable two-dimensional (2D) filters. The two images derived by vertical/horizontal scanning were added after eliminating the component in horizontal/vertical directions respectively. By so doing, we can get a picture with correct amplitude information of defects, which is impossible by simple summation of pictures. Adopting this strategy together with nonlinear filtering technique for denoising, we can achieve more precise processing compared with the conventional approach based on the product of 1-D frequency responses. Through an application example to an aluminum plate with plural defects, the effectiveness of the proposed approach is demonstrated.

SESSION 12
LASER ULTRASONICS
H. Ringermacher and M. Dubois, Co-Chairpersons
BR A1

8:30 AM **Keynote: Concepts and Applications for Laser Ultrasonic Testing in European Aircraft Industry**
---S. Seebacher and W. Bisle, Airbus Deutschland GmbH, Testing Technology Germany-ESWNG, Huenefeldstr 1-5, 28199 Bremen, Germany

9:10 AM **Review of LaserUT™ Production Implementation**
---T. E. Drake, Jr., Lockheed Martin, Tactical Aircraft Systems, P. O. Box 748, Ft. Worth, TX 76101-0748

9:30 AM **Optical Amplification of the Laser-Ultrasonic Signal**
---A. Blouin and J.-P. Monchalin, Industrial Materials Institute, National Research Council Canada, 75, de Mortagne Boulevard, Boucherville, Quebec, Canada, J4B 6Y4

9:50 AM **Scanning Laser Line Source Technique Using Monopolar Rayleigh Waves**
---Y. Sohn and S. Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, 327 Catalysis Building, Evanston, IL 60208

10:10 AM ***Coffee Break***

10:30 AM **Acoustic Waves Generated by a Laser Line Pulse in a Transverse Isotropic Cylinder: Application to the Measurement of Stiffness Coefficients of Isotropic Rods**
---Y. Pan, C. Rossignol, and B. Audoin, Laboratoire de Mécanique Physique, UNM CNRS 5469, Université Bordeaux I, Talence, France

10:50 AM **In-Line Monitoring the Austenitic Grain Size of Seamless Mechanical Steel Tubing Using Laser-Ultrasonics**
---G. Lamouche, S. E. Kruger, M. Lord, D. Lévesque, J.-B. Guénette, S. Bolognini, C. Bescond, T. Veres, A. Moreau, D. Bouchard, C. Néron, C. Padioleau, J.-P. Monchalin, and J. Bussière, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Quebec, J4B 6Y4, Canada; E. F. Damm and R. V. Kolarik II, The Timken Company, 1835 Dueber Avenue S.W., Canton, OH 44706; G. V. Jeskey, Jeskey Consulting, retired from the Timken Company

11:10 AM **Graded Coating Inspection Using Laser Generated Surface Acoustic Waves**
---O. O. Balogun and T. Murray, Aerospace and Mechanical Engineering, Boston University, Boston, MA 02215

11:30 AM **Laser-Ultrasonic Characterization of Fiber Reinforced Composites: Effect of the Generation Laser Transverse Modes**
---B. Campagne, D. Lévesque, C. Néron, A. Blouin, and J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Quebec, J4B 6Y4, Canada

11:50 AM **Large Array Laser Ultrasonic Detector Based on Multiplexed Two Wave Mixing Using an Infrared Long Pulse Laser Source**
---Y. Zhou and S. Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Room 331, Catalysis Building, Evanston, IL 60208

12:10 PM ***Lunch***

Keynote: Concepts and Applications for Laser Ultrasonic Testing in European Aircraft Industry

---Soenke Seebacher and Wolfgang Bisle, Airbus Deutschland GmbH, Testing Technology Germany-ESWNG, Huenefeldstr 1-5, 28199 Bremen Germany

---New materials and manufacturing processes in aircraft industry demand efficient quality assurance procedures. Due to the growing number of composite parts with complex geometry highly automated, contact-less inspection methods are needed to reduce the human factor and to increase the throughput and sensitivity. For this reason the major European aircraft companies started a common project INCA consisting of competent European and American partners to investigate laser ultrasonic as a possible solution and to merge some of their research activities in this area. An overview of the current activities, deficits and advantages concerning this testing method will be given with respect to flexibility, speed, sensitivity as well as costs. The generation laser, the interferometer and the detection laser are the most important technical components, the capability, specification, set-up and purchasing of which with all its detours and progresses helped the consortium to answer questions like: What is the inspection concept behind laser ultrasonic testing? Which might be the typical applications in aircraft industry? This contribution will address these important topics that determine the layout of our future laser ultrasonic testing equipment.

Review of LaserUT™ Production Implementation

---Thomas E. Drake, Jr., Lockheed Martin, Tactical Aircraft Systems, P. O. Box 748, Fort Worth, TX 76101-0748

---The Lockheed Martin LaserUT system was certified for production inspection of F-22 composite materials in June of 2000. Since that time, the inspection of all complex composite materials manufactured at the Fort Worth facility has been performed by this unique system. This review will: 1) present an introduction to the LaserUT system, 2) discuss inspection results from a variety of materials used on advanced fighter programs, and 3) summarize some near-term enhancements planned for the next-generation systems. This system was designed specifically to improve inspection throughput relative to water-based pulse-echo systems. The past three years of full-time factory use has verified that LaserUT can provide five to ten times productivity improvements compared to conventional approaches. This lowers the total capital investment in automated inspection systems and reduces operational labor costs for high-volume composite manufacturing facilities.

Optical Amplification of the Laser-Ultrasonic Signal

---Alain Blouin and Jean-Pierre Monchalin, Industrial Materials Institute, National Research Council Canada 75, de Mortagne blvd., Boucherville, Quebec, Canada, J4B 6Y4

---The signal at the output of a phase demodulator for the optical detection of ultrasound varies as the light power received by the demodulator, while the shot noise varies as the square root of this light power. Therefore, optical amplification of the detection laser light seems an elegant method to improve sensitivity. However, the amplified spontaneous emission (ASE) associated to the optical amplification process is a source of both phase and intensity noises. Two configurations are possible, one with the amplifier located ahead of the inspected surface (pre-amplification) and one after (post-amplification). We will discuss the advantages and drawbacks of these two schemes when a photorefractive two-wave mixing demodulator and a confocal Fabry-Perot demodulator are used. The main result is that pre-amplification improves the signal-to-noise ratio significantly, the useful signal and the ASE being both affected by a large attenuation factor, whereas post-amplification gives usually a lesser improvement with a much more complex setup to attenuate ASE. We will also show that the best signal-to-noise ratio is obtained when the power received by the detector equals the power of the master-oscillator laser.

Scanning Laser Line Source Technique Using Monopolar Rayleigh Waves

---Younghoon Sohn and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, 327 Catalysis Building, Evanston, IL 60208

---In recent work at Northwestern University, the scanning laser source (SLS) technique has been proposed as an effective way to image surface-breaking cracks. The SLS technique monitors the changes in laser generated ultrasound (a wavepacket centered around the Rayleigh wave is usually monitored) as a laser source is scanned over a surface containing defects. It has been shown that the SLS technique provides enhanced signal to noise performance compared to conventional pitch-catch or pulse echo methods. SLS is therefore an appropriate tool for the detection of small surface-breaking cracks that are sub-wavelength in depth. In previous work, either a point source or a short line source was used for generation of ultrasound. The resulting Rayleigh wave was typically bi-polar in nature. As the SLS is scanned past a surface-breaking crack, it has been shown that the amplitude and frequency of the bi-polar Rayleigh wave signal vary, showing a characteristic signature indicative of the flaw. In this paper, we demonstrate a Scanning Laser Line Source (SLLS) technique using a true thermoelastic line source which leads to generation of monopolar Rayleigh waves in the absence of flaws. As the SLLS is scanned over a surface-breaking flaw, the monopolar signal is shown to become bi-polar, dramatically indicating the presence of the flaw. The SLLS technique is demonstrated both experimentally and through hybrid mass-spring-lattice simulations. Experiments for the SLLS technique performed using a line focused Nd:YAG laser and an interferometric detector will be discussed. Both numerically- and experimentally-generated Rayleigh waves show characteristic monopolar shape in the absence of flaws and become bi-polar as the SLLS approaches the flaw. Numerical simulations performed to gauge the effect of crack depth on the SLLS signatures demonstrate that the technique can also be used to size cracks.

Acoustic Waves Generated by a Laser Line Pulse in a Transverse Isotropic Cylinder. Application to the Measurement of Stiffness Coefficients of Isotropic Rods

---Y. Pan, C. Rossignol, and B. Audoin, Laboratoire de Mécanique Physique, UNM CNRS 5469, Université Bordeaux 1, Talence, France

---Nondestructive evaluation of the stiffness coefficients of cylindrical rods is desired for several industrial applications. For instances, it would enable one to estimate damage in a structure under use or it would provide unknown stiffness coefficients of transverse isotropic fibers used in composite material industry. In this paper it is shown that such measurements can be achieved with the laser ultrasonic technique. Firstly, the acoustic field generated in a homogeneous and transversely isotropic cylinder by a laser line pulse is obtained theoretically. A two-dimensional Fourier transform is used to calculate the acoustic displacement at the cylinder surface. Experimental and theoretical normal displacements are obtained and compared for aluminum cylinders which diameters equal 4 mm and 10 mm. Very good agreements are observed in the time, shape and relative amplitude i) of the Rayleigh waves with different roundtrips, and ii) of the various longitudinal and shear bulk waves propagating through the cylinder or reflected at the free circular surface. Secondly, measurement of the stiffness coefficients of isotropic rods is performed after identifying their corresponding time arrival. Accuracy of the identification with regards of i/ the ratio of the source width to the rod diameter and ii/ the signal to noise ratio is discussed. Results on aluminum cylinders are presented.

In-Line Monitoring the Austenitic Grain Size of Seamless Mechanical Steel Tubing Using Laser-Ultrasonics

---Guy Lamouche, Silvio E. Kruger, Martin Lord, Daniel Lévesque, Jean-Benoit Guénette, Stéphane Bolognini, Christophe Bescond, Teodor Veres, André Moreau, Dominique Bouchard, Christian Néron, Christian Padioleau, Jean-Pierre Monchalin, and Jean Bussière, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Quebec, J4B 6Y4, Canada; E. F. Damm and Robert V. Kolarik II, The Timken Company, 1835 Dueber Avenue SW, Canton, Ohio, 44706; Gerald V. Jeskey, Jeskey Consulting, retired from the Timken Company

---At QNDE last year, the Timken Company and the Industrial Materials Institute (IMI) reported the successful installation and operation of an innovative laser ultrasonic system to monitor the wall thickness and eccentricity of seamless mechanical steel tubing on the production line. The robust system has been used continuously for more than a year now, monitoring over 450 000 tubes and steadily providing key information to the manufacturing organization. In another effort being done under with a funding grant from the U.S. Department of Energy, IMI and Timken are building on this success by adding a valuable functionality to the system to measure austenitic grain size at high temperature on the production line. The prior austenite grain size of carbon and alloy steel is of high importance due to its strong impact on the mechanical properties of the final product. The relationship between austenitic grain size and ultrasound measurements was established in the laboratory with a laser-ultrasonic system coupled to a Gleeble™ thermo-mechanical simulator. Specific issues addressed included: diffraction, surface roughness, eccentricity, high-temperature ultrasound absorption and effective averaging. All of this information was gathered and included in a software that allows online and real-time grain size measurements using the same hardware described last year. The current paper reviews the development of the grain size measurement capability and shows latest results.

Graded Coating Inspection Using Laser Generated Surface Acoustic Waves

---Oluwaseyi O. Balogun and Todd Murray, Aerospace and Mechanical Engineering, Boston University, Boston. MA 02215

---Functionally graded materials (FGMs) have spatial variations in composition and structure resulting in corresponding changes in material properties. FGMs can be tailored to specific applications in which the functional requirements of a component are position dependent. Laser ultrasonics is a promising technique for the evaluation of the thermoelastic property distributions in FGMs, for online process control during FGM growth, and for in-service assessment of FGM degradation after thermal cycling or exposure to harsh environments. In this work, a model for the laser generation of ultrasound in graded materials is used to explore the dependence of the generated acoustic waves on the composition profile and to evaluate the feasibility of using laser generated surface acoustic waves (SAWs) to determine the depth dependent properties of graded coating materials. The materials studied exhibit elastic property gradations from the coating surface to the interface with the substrate. The graded coatings are modeled as multilayered systems and the number of layers required to achieve a desired level of convergence of the model over a given frequency range is determined. For an assumed compositional profile, the elastic properties of the respective layers are calculated using a modified rule of mixtures formulation. Numerical results showing the sensitivity of SAW dispersion behavior to various composition profiles are presented. In addition, an inversion algorithm is developed to extract position dependent elastic properties from measured SAW dispersion behavior and preliminary results are obtained using simulated experimental data.

Laser-Ultrasonic Characterization of Fiber Reinforced Composites: Effect of the Generation Laser Transverse Modes

---Benjamin Campagne, Daniel Lévesque, Christian Néron, Alain Blouin, and Jean-Pierre Monchalin, Industrial Materials Institute, National Research Council Canada, 75 de Mortagne blvd., Boucherville, Quebec, Canada

---Laser-ultrasonics has been used with success for the microstructure evaluation of metallic materials. Reliable results are obtained when accurate measurement of ultrasonic attenuation or velocity are performed. Extension of these techniques to fiber reinforced polymer composites could provide information on consolidation, fiber contents and porosity in these materials. Ultrasonic generation in composite materials is usually performed by using a pulsed TEA CO_2 laser. In this case, the transverse mode pattern of the laser could change from shot-to-shot, thus affecting the accuracy of the attenuation measurement. Two solutions are possible to circumvent this problem. The first approach consists in numerically correcting for the diffraction effect produced by the change of mode distribution by using a Monte Carlo integration after simultaneous acquisition of the ultrasonic signal and the laser mode pattern. The second approach consists in modifying the resonator of the laser cavity to get a single transverse mode that is highly reproducible, thus requiring a much simpler diffraction correction. Both approaches have been tested on a bare carbon epoxy plate with laser generation in the thermoelastic regime. The results obtained from using either of the two approaches show significant improvement when diffraction corrected and are compared to those using conventional ultrasonics.

Large Array Laser Ultrasonic Detector Based on Multiplexed Two Wave Mixing Using an Infrared Long Pulse Laser Source

---Yi Zhou and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Room 331 Catalysis Building, Evanston, IL 60208

---At Northwestern University, Multiplexed Two-Wave Mixing Interferometers (MTWM) have been developed for laser ultrasonics applications. Such systems enable simultaneous detection of ultrasonic motion at a number of points. The detection-array of laser beams is created by passing a single laser beam through an optical phase grating. The multiple diffracted orders are either imaged by a lens system directly onto the test object or are piped through an optical fiber system to the test object. In both cases, the array size and shape can be readily reconfigured as needed. The scattered beams from the object are collected using a lens system and piped to a photorefractive crystal where these are combined with a single reference beam to form a multiplexed two-wave mixing configuration. Each of the output beams from the photorefractive crystal is focused onto an image plane containing a photodetector array. The MTWM system can be used in several modes for laser ultrasonic NDE of flaws and materials characterization. These include: (i) linear phased-arrays for laser ultrasonic imaging of scatterers, (ii) linear arrays for direct determination of guided wave dispersion; and (iii) circular array for SAW imaging of anisotropic materials. Previously, we have demonstrated a 9-element MTWM system using a continuous wave argon-ion laser and a BSO photorefractive crystal. In this paper, we present an infrared version of the MTWM system with a long pulse laser system as the laser source. The long pulse laser system is a high power pulsed Nd:YAG laser system which and is an ideal source for configuring large array detectors while still retaining sufficient detection sensitivity. We demonstrate a 16-element MTWM system using the long pulse laser source. Applications of this 16-element MTWM system for laser ultrasonic imaging using surface acoustic waves and bulk waves are also presented.

SESSION 13
MATERIALS CHARACTERIZATION
ELASTIC, PLASTIC, AND VISCOELASTIC PROPERTIES
L. Jacobs, Chairperson
BR A4

8:30 AM **Estimation of Single-Crystal Elastic Constants from Ultrasonic Measurements on Polycrystalline Specimens**
---P. Haldipur, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Correlation Between Ultrasonic Velocity and Poisson's Ratio: An Attempt Towards Rationalization of Elastic Constants for Isotropic Solid Materials**
---B. Raj, A. Kumar, and T. Jayakumar, Met. and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, 603102, India; K. K. Ray, Indian Inst. of Tech., Kharagpur, 721302, India

9:10 AM **Quantitative Air-Coupled Ultrasonic Materials Characterization with Highly Focused Acoustic Beams**
---S. D. Holland, S. V. Teles, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:30 AM **Effects of Layer Properties on the Ultrasonic Resonance of Composite Spheres**
---S. Ahmed and P. D. Panetta, Pacific Northwest National Laboratory, Richland, WA 99352

9:50 AM **Ultrasonic Sensitivity Studies for Titanium Billet Inspections**
---C.-P. Chiou, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:10 AM ***Coffee Break***

10:30 AM **Elasticity Imaging of Ferroelectric Domain Structure in PZT by Ultrasonic Atomic Force Microscopy**
---T. Tsuji and H. Ogiso, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan; K. Fukuda and K. Yamanaka, Department of Materials Processing, Tohoku University, Sendai, Miyagi, Japan

10:50 AM **Determination of the Degree of Plastic Deformation Utilizing Ultrasonic Velocity Measurements**
---P. D. Panetta[1], B. Francini[1], S. Ahmed[1], M. Morra[1], G. A. Alers[2], and K. Johnson[1], [1]Pacific Northwest National Laboratory, Richland, WA 99352; [2]EMAT Consulting, San Luis Obispo, CA 93401

11:10 AM **Materials Degradation and Altering Response to Ultrasonic Scattering by the Light Statistical Approach in Austenitic Thermal Loaded Materials**
---J. A. Pitkänen, P. Kauppinen, and H. Jeskanen, VTT Industrial Systems, PL 1704, Kemistintie 3, FIN-02044 VTT, Espoo, Finland

11:30 AM **Rapid Low Frequency Measurement of the Acoustic Properties of Solid Viscoelastic Materials**
---F. Simonetti and P. Cawley, Department of Mechanical Engineering, Imperial College, London, SW7 2AZ, United Kingdom

11:50 AM **Epoxy Thermosets: The Detection of Adverse Stoichiometry Using Ultrasonic Dielectric and NMR Techniques**
---R. E. Challis and M. E. Unwin, School of Electrical Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

12:10 PM ***Lunch***

Estimation of Single-Crystal Elastic Constants From Ultrasonic Measurements on Polycrystalline Specimens

---P. Haldipur, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---In past work we reported on measurements of ultrasonic velocity, attenuation and backscattering in nickel-alloy materials used in the fabrication of rotating jet-engine components. Attenuation and backscattering were shown to be correlated to the average grain diameter, which varied with position in the billet specimens studied. The ultrasonic measurements and associated metallographic studies found the local microstructures to be approximately equiaxed and free of texture in these cubic-phase metals. In this paper we explore a method for deducing the single-crystal elastic constants of a metal using the combined ultrasonic and metallographic data for a polycrystalline specimen. We specifically consider the case seen in the jet-engine alloys: polycrystalline cubic microstructures having equiaxed, randomly-oriented grains. We demonstrate how the three independent elastic constants $\{C_{11}, C_{12}, C_{44}\}$ can be deduced from the density, the mean grain diameter, the ultrasonic attenuation at one or more frequencies, and the longitudinal and shear wave speeds. The method makes use of the attenuation theory of Stanke and Kino, and three formulations for the average sonic velocity through a polycrystalline material (the so-called Voigt, Reuss and Hill averages). Elastic constant inputs to the models are adjusted to optimize the agreement with experiment. The method is demonstrated using specimens of IN718, Waspaloy, and pure Nickel, and the sensitivity of the deduced elastic constants to uncertainties in the input data are studied.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

Correlation Between Ultrasonic Velocity and Poisson's Ratio: An Attempt Towards Rationalization of Elastic Constants for Isotropic Solid Materials

---Baldev Raj, Anish Kumar, and Tammana Jayakumar, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam 603102, India; Kalyan K. Ray, Indian Institute of Technology, Kharagpur 721302, India

--- A polycrystalline isotropic material can be characterized by two independent elastic constants. Hence, identification of any new relationship between the two independent elastic constants for isotropic solid materials would reduce the number of required independent elastic constants to one. In this direction, an attempt has been made to study the variation in Poisson's ratio with other elastic constants using the experimental data generated by the authors and also that collected from the literature for various isotropic solid materials, such as pure elements, ceramics, polymers and intermetallics. The analysis reveals that Poisson's ratio decreases with increase in other elastic constants. A linear correlation has been obtained between Poisson's ratio and ultrasonic shear wave velocity with almost constant slope for any given alloy system with different microstructures associated with various heat treatments, alloying elements, grain size, temperature effect etc. This observation brings out the possibility for rationalization of elastic constants based on a unified approach to link Poisson's ratio with shear wave velocity at least for a given group of alloy systems with different microstructural conditions. It has also been shown from the basic relationships among the elastic constants that the shear wave velocity is affected more than ultrasonic longitudinal wave velocity for any change in the material condition. Further, the error in the measurement of shear wave velocity would also be less (due to larger time of flight for the same thickness). Hence, shear wave velocity is found to be a more reliable parameter for material/microstructural characterization, as compared to longitudinal wave velocity.

Quantitative Air-Coupled Ultrasonic Materials Characterization with Highly Focussed Acoustic Beams

---Stephen D. Holland, Sorin V. Teles, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Plate-wave dispersion spectra have been inferred directly in a single air-coupled coordinate scan using mirror-focussed acoustic beams on both transmitting and receiving transducers. The spectra of the leaky Lamb modes are extracted through a two-dimensional FFT of the measured broadband focused air-coupled signal, as we have demonstrated previously in water. To enhance the typically weak air-coupled signal, we have employed a novel signal coding scheme using a random-phase constant-amplitude analog burst 200 microsec in length. Subsequent correlation yields the system impulse response, from which we obtain the processed results as a wavenumber-versus-frequency plot. Comparison of the inferred dispersion curves with calculated spectra using nominal stiffness values, shows mode resolution and agreement with predictions as good and the water-coupled results reported earlier.---This material is based on work supported by NASA under award NAG-1-029098.

Effects of Layer Properties on the Ultrasonic Resonance of Composite Spheres

---S. Ahmed and P. D. Panetta, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

---If all the resonance frequencies of an elastic object are known, in principle, one can deduce a number of its physical properties like elastic constants, density, dimensions, shape, etc. The efficient calculation of the resonance frequencies is required for the effective application of resonant ultrasound spectroscopy (RUS) to determine the relevant properties of an elastic object. However, general analytic expressions are not available for the normal node free vibrations of a body with arbitrary shape and elastic properties. It was noticed by Holland and Demerest that a simple variational principle can be applied to compute the normal mode frequencies of an elastic body with free boundaries. Based on this variational method, Visscher et. Al. developed the XYZ algorithm which can be applied to compute the resonance frequencies of a body with arbitrary shape and elastic properties. Since layered systems are finding increasing applications in engineering, computational studies are being carried out here to investigate the suitability of RUS as an NDE technique to determine imperfections in a layered system. Specifically, the normal mode frequencies of a four-layered sphere are computed here by the XYZ algorithm. It will be shown that the deviations from specified layer properties cause noticeable effects on the resonant frequencies.

Ultrasonic Sensitivity Studies for Titanium Billet Inspections

---C. P. Chiou, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011; Jeff Umbach, Pratt & Whitney, Jupiter, FL 33478

---In the past few years, significant efforts have been made under a research program known as the Engine Titanium Consortium to develop improved NDE techniques for inspecting engine titanium alloys. Recently, an important task was launched to investigate the sensitivity to various parameters of cylindrical billet inspections conducted using the “conventional” and “multi-zone” techniques. The conventional method uses a single transducer to cover the entire depth of interest, while the multi-zone technique employs an array of transducers each focused within a separate depth zone. The objective of the study was to determine the variation range of the inspection parameters in question, and the relative influence (sensitivity) to these parameters of the inspection’s accuracy and reproducibility. The parameters in question include the transducer focal lengths, the water path between the transducer and billet, and the transducer tilt angles with respective to the billet entry surface. In order to quantify the effects of these parameters, ultrasonic models were extensively employed to compute signal strengths of flat-bottomed hole standards and synthetic inclusions as well as backscattered grain noise levels. In this presentation we will summarize the results of our study, including comparisons between experiment and model simulations in terms of rate of signal variations with respect to parameter changes. We will also compare the performance of the conventional and the multi-zone techniques using signal-to-noise ratios as a measure of goodness. - This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #029 and performed at Iowa State University's Center for NDE and Pratt & Whitney as part of the Engine Titanium Consortium program through the Airworthiness Assurance Center of Excellence.

Elasticity Imaging of Ferroelectric Domain Structure in PZT by Ultrasonic Atomic Force Microscopy

---Toshihiro Tsuji and Hisato Ogiso, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan; Kenji Fukuda and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---In order to understand the influence of nano-scale domains on ferroelectric films for a non-volatile memory and MEMS products, it is necessary to characterize the domains with nm spatial resolution. Though the atomic force microscopy (AFM) is a possible tool for it, the elasticity imaging is difficult since the cantilevers are too soft to deform stiff samples. To solve this problem, we have developed ultrasonic atomic force microscopy (UAFM) which can deform samples such as ceramics and alloys, by means of the inertia of the cantilever at the resonance vibration. In this study, we applied UAFM to the elasticity characterization of the domain structure. In PZT ceramics annealed above Curie point, domain structure was observed in an AFM with the AC bias applied between a conductive tip and a sample. The elasticity distribution due to micro scale grains rather than domains was observed by the UAFM image at the 1st deflection mode. On the other hand, the domain wall area was clearly observed by the image at the 2nd deflection mode and the elasticity on it was lower than that on the domain area. These findings provide the information on the domain wall property that is useful for the diagnosis of piezoelectric devices, and indicate that the domain structure can be continuous beyond the grain boundary.

Determination of the Degree of Plastic Deformation Utilizing Ultrasonic Velocity Measurements

---P. D. Panetta[1], B. Francini[1], S. Ahmed[1], M. Morra[1], G. A. Alers[2], and K. Johnson[1], [1]Pacific Northwest National Laboratory, Richland, WA 99352; [2]EMAT Consulting, San Luis Obispo, CA 93401

---Maintaining the integrity of the nation's aging infrastructure is of primary importance. Specifically there is a desire to characterize plastically deformed regions in structures to monitor their integrity. Of particular importance is the accurate prediction of the lifetime of damaged natural gas pipelines due to outside force. In order to accurately predict the remaining life it is essential to accurately determine the degree stress and strain in the damaged region for input into fracture mechanics models. Currently, determination of the degree of stress and strain in damaged regions utilizing ultrasonic velocity measurements is complicated by the inherent texture variations in the alloys and the difficulty in separating these effects from the stress and strain contributions. We will report ultrasonic velocity measurements on plastically deformed steel specimens to elucidate the state of damage. Specifically, we have found the shear wave birefringence is directly related to the degree of plastic strain and combinations of SH wave velocities are independent of texture contributions. Ultrasonic results will be compared with finite element modeling calculation of the stress and strain distributions.

Materials Degradation and Altering Response to Ultrasonic Scattering by the Light Statistical Approach in Austenitic Thermal Loaded Materials

---Jorma A. Pitkänen, Pentti Kauppinen, and Harri Jeskanen, VTT Industrial Systems, PL 1704, Kemistintie 3, FIN-02044 VTT, Espoo, Finland

---Materials degradation is complicated process including multiple phenomena. Degradation is critical on the near surface areas. These areas contain many types of defects and material phase changes which are also caused from the degradation of the material. The information received from those material properties are measured with special ultrasonic probe optimised for surface measurement. With help of combining large area information from the measured data and calculating areas of interest in the sound path information information can be gained to improve potential estimation of degradation levels. The technique is based on combination of three factors: using back scattered ultrasonic signals and induced leaky Rayleigh wave information (1), and simple statistical data analysis (2) in combination with optimised ultrasonic transducer for (3). The back scattered ultrasonic signals is a measure of geometrical reflectors such as mircopores, precipitations, segregations,and cracks as well as backscattering from phase boundary changes during fatigue damaging and increase of degradation inside the material. The leaky Raylegh wave component is sensitive to surface properties as known from normal Rayleigh wave probes. Cracks cause strong effect on leaky Rayleigh wave. Deep crack cancels the leaky Rayleigh wave signal totally. Those effects are introduced into the material during thermal load and are measured and analyzed in this study.

Rapid Low Frequency Measurement of the Acoustic Properties of Solid Viscoelastic Materials

---F. Simonetti and P. Cawley, Imperial College, Department Mechanical Engineering, London SW7 2AZ, England

---The measurement of the acoustic shear properties of solid viscoelastic coatings plays a major part in the prediction of the test range of an ultrasonic guided wave propagating in a metallic structure coated with a highly attenuative material such as bitumen. Since the properties of viscoelastic materials are extremely sensitive to temperature variations and oxidation phenomena which strongly depend on the surrounding environment, there is need for a technique which allows rapid in-situ measurements to be performed. The main difficulty comes from the limited dimensions of samples (typically the size of a coin) due to the breakage of the coating as it is detached from the metallic substrate. In this paper a novel technique is presented. A small sample (6mm diameter disk with the same thickness as the coating) is clamped between two steel rods. The fundamental torsional guided mode, T(0,1), is sent from the free end of one rod and detected at the free ends of each rod. The shear velocity and shear damping of the sample are derived from the measured reflection and transmission coefficients of T(0,1) through the sample. Neither glue nor couplant is used at the interfaces between the sample and the two rods. Results for several types of bitumen coatings are presented and an experimental validation of the technique is provided.

Epoxy Thermosets: The Detection of Adverse Stoichiometry Using Ultrasonic Dielectric and NMR Techniques

---Richard E. Challis and Marion E. Unwin, University of Nottingham, School of Electrical Engineering, University Park, Nottingham, NG7 2RD United Kingdom

---Epoxy thermosets are formed from the polymerization of resin and hardener components and the final engineering properties of the cured material are affected by the relative proportions of these two constituents, expressed as a stoichiometric ratio (SR). For the quality assurance of both the forming process and the final product, non-invasive techniques are necessary to give an indication that the SR is within an acceptable range. In this paper we investigate the use of dielectric (DE) and ultrasonic (UT) spectroscopies as a means to track cure and estimate SR. The time course of the cure reaction up to gel is also observed by low resolution 20MHz NMR. DE results are expressed as the growth of the á-relaxation time constant during the cure cycle which gives an early indication of SR in reactions where the resin component is in excess. Compression and shear wave UT data also provide an early indication of excess resin. At the end of the cure cycle, post vitrification, it is more difficult to assess SR, particularly in situations where the hardener component is in excess. We show that a combination of UT measurements of phase velocity and mechanical loss tangent can provide clear indications of low SR, acceptable SR, and high SR for hardener to resin ratios in the range 0.25 to 2.0.

SESSION 14
ACOUSTIC EMISSION
M. I. López Pumarega, Chairperson
BR A3

8:30 AM **Could Acoustic Emission Testing Show a Pipe Failure in Advance?**
---S. D. Soares and J. C. Guimarães Teixeira, Brazilian Oil Company, PETROBRAS, R&D Center, Ilha do Fundão, Quadra 7, Cidade Universitária, Rio de Janeiro, Brazil 21949-900

8:50 AM **Acoustic Emission During Tensile Deformation of Thermally Treated and Sodium Exposed Zirconium Alloys**
---B. Raj, C. K. Mukhopadhyay, P. K. Chaurasia, S. Murugan, T. Jayakumar, and P. V. Kumar, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, 603102, India

9:10 AM **Barkhausen Effect and Acoustic Emission in a Metal Glass, Preliminary Results**
---M. I. López Pumarega and M. Armeite, Ensayos No Destructivos y Estructurales, Comisión Nacional de Energia Atómica, San Martin, Buenos Aires, Argentina; R. Piotrkowski, Escuela de Ciencia y Tecnologia, Universidad Nacional de General San Martin, San Martin, Buenos Aires, Argentina; E. March and J. E. Ruzzante, Universidad Tecnológica Nacional, Regional Buenos Aires, Buenos Aires, Argentina; R. López Sánchez, Departamento de Ciencias de la Tierra y Fisica de la Materia Condensada, Universidad de Cantabria, Spain

9:30 AM **A New Residual Life Evaluation Method on Impacted Fiber Reinforced Polymer Composites by Means of Acoustic Emission Under Stress**
---C. Caneva, F. Domenichini, and M. Valente, Department of Chemical and Materials Engineering, Via Eudossiana 18, 00184, Rome, Italy

9:50 AM **Development of Leak Detection Technique for Heat Exchanger Using Acoustic Emission Technique**
---J.-H. Lee and M.-R. Lee, School of Mechanical Engineering, Pusan National University, Pusan, 609-735, Korea

10:10 AM ***Coffee Break***

Could Acoustic Emission Testing Show a Pipe Failure in Advance

---Sergio Damasceno Soares and José Cláudio Guimarães Teixeira, Brazilian Oil Company, PETROBRAS, R&D Center, Ilha do Fundão, Quadra 7, Cidade Universitária, Rio de Janeiro, RJ, Brazil 21949-900

---During the last 20 years PETROBRAS has been attempting to use Acoustic Emission (AE) as an inspection tool. In this period the AE concept has changed from a revolutionary method to a way of finding areas to make a complete inspection. PETROBRAS has a lot of pressure vessels inspected by AE and with other NDTs techniques to establish their relationship. PETROBRAS R&D Center has conducted destructive hydrostatic tests in pipelines samples with artificial defects made by milling. Those tests were monitored by acoustic emission and manual ultrasonic until the complete failure of pipe sample. This article shows the results obtained and a brief proposal of analysis criteria for this environment of test.

Acoustic Emission During Tensile Deformation of Thermally Treated and Sodium Exposed Zirconium Alloys

---Baldev Raj, Chandan K. Mukhopadhyay, Pramod K. Chaurasia, Sankaravadivelu Murugan, Tammana Jayakumar, and Puranam V. Kumar, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, India 603102

---The compatibility of Zircaloy-2 and Zr-2.5%Nb alloys with sodium at a temperature of 613K for a maximum duration of 4500 hours has been established by comparing the changes in tensile properties due to exposure to sodium at that temperature and equivalent thermal treatment separately. The changes in tensile properties were found to be very marginal and almost similar due to both the treatments. Acoustic emission (AE) signals recorded during tensile testing of untreated, sodium exposed and thermally treated specimens were found to be useful to get better insight into the effect of thermal treatment and sodium exposure on the deformation behavior. AE generated during tensile deformation has been characterized with respect to the occurrence of slip, twinning and, decohesion and fracture of hydrides. Higher AE was generated during yielding, in all the specimens. Reduced AE observed at higher strains in the untreated specimens is attributed to the reduced contribution from slip and twinning. Reduced AE in the yield region in all the treated specimens as compared to the untreated specimens is attributed to precipitation of hydride platelets that reduce the mean free path for dislocation movement. Higher AE generated during post-yield deformation in the sodium exposed and thermally treated specimens as compared to untreated specimens is attributed to decohesion and fracture of hydride platelets. The increased amount of hydrides in the specimens with increased duration of sodium exposure led to higher amount of AE in the post yield region. This is attributed to the increased extent of decohesion and fracture of hydrides. All the inferences drawn from the AE results have been supported by optical metallography and scanning electron fractography.

Barkausen Effect and Acoustic Emission in a Metal Glass, Preliminary Results

---M. I. López Pumarega and M. Armeite, Ensayos No Destructivos y Estructurales, Comisión Nacional de Energía Atómica, San Martin, Buenos Aires, Argentina; R. Piotrkowski, Escuela de Ciencia y Tecnología, Universidad Nacional de General San Martín, San Martín, Buenos Aires, Argentina; E. March and J. E. Ruzzante, Universidad Tecnológica Nacional, Regional Buenos Aires, Buenos Aires, Argentina; R. López Sánchez, Departamento de Ciencias de la Tierra y Física de la Materia Condensada, Universidad de Cantabria, Cantabira, Spain

---The variation of a magnetic field on a ferromagnetic material produces the movement of the walls of the magnetic domains. This movement is carried out by a sequence of discrete jumps, with similar characteristics to the complex dynamic systems called SOC ("Self Organized Criticality"), as earthquakes, seismic movements, sand avalanches, Acoustic Emission, etc. The movement of the atoms, which have a magnetic moment, produces an electric voltage that can be detected by a coil next to the sample; this effect is called Barkhausen Noise (BN). That collective movement of atoms also produces a local change of the stress field, originating an elastic wave, detected on the sample surface as Acoustic Emission (AE). This last phenomena is known as Magneto Acoustic Emission (MAE). It is well known that MAE depends on the microstructure of the metal. The dependence of MAE with internal residual stresses is also known. The present work was carried out as part of a Research Project of the Faculty of Science, Universidad de Cantabria (Spain), and the Elastic Waves Group of the Comisión Nacional de Energía Atómica (Argentina). A set of preliminary results are shown here. AE and BN signals obtained by magnetization in two perpendicular directions on a foil of a metal glass are analyzed. The material is physically characterized and the obtained signals are analyzed with different techniques: Statistics, FFT, wavelets, etc.

A New Residual Life Evaluation Method on Impacted Fiber Reinforced Polymers Composites by Means of Acoustic Emission Under Stress

---Claudio Caneva, Flavio Domenichini, Marco Valente, Dept. of Chemical and Materials Engineering, Via Eudossiana 18, 00184 Rome, Italy

---Principle of the method is that irreversible structural modifications, produced by an impact event on composite material, can appear when it is submitted to tensile stresses under given procedures. Such modifications can be detected, located, and characterized by means of Acoustic Emission. In the experimental procedure, the previously impacted specimen was loaded and then unloaded for several time with progressively growing stresses, until the final failure occurs; the steps are interspaced by "relaxation" cycles, in order to minimize the residual stresses and to allow the material to return in elastic field. When the critical strength threshold level due to impact damage was overcome, vibrational wave emissions began, which could be detected by the Acoustic Emission technology (AE). This method is therefore used here in order to evaluate the damage amplitude, after impact events, inside the composite. The system had been validated on different composite configurations. The results confirm AE efficiency and sensitivity: by AE parameters analysis it is possible to distinguish damage type, evaluate how much it is critical and individualize its localization, on laminated composites. At last, such a methodology allows evaluating the material response in working conditions.

Development of Leak Detection Technique for Heat Exchanger Using Acoustic Emission Technique

---Joon-Hyun Lee and Min-Rae Lee, School of Mechanical Engineering, Pusan National University, Pusan, 609-735, Korea

---In this study, a nondestructive evaluation technique for detecting the leak in heat exchanger has been developed. The leak defects having a hole-shape are analyzed using acoustic emission technique(AE) on both sides of pin of heat exchanger. A specially designed PC-based leak detection system using the A/D board is developed. Since the AE waveforms are very difficult to distinguish the leak signals. Therefore it is necessary to consider the signal analyses of the transient waveform. Some signal processing techniques have been introduced to classify the signals associated with the leak-defects in the pin of heat exchanger from the measured leak signal. Wavelet Transform(WT) is a powerful tool for processing transient signals with temporally varying spectra that helps to resolve high and low frequency transient components effectively. In this study, the analyses of the AE signals are presented by employing the WT analyses.

SESSION 15
THERMAL TECHNIQUES
N. Nakagawa, Chairperson
BR A3

10:30 AM **A 2-D Inverse Heat Conduction Formulation for Determination of Heat Source Characteristics from Thermal Images**
---N. V. Nair and K. Balasubramaniam, Center for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai, Tamil Nadu, India; S. K. Das, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai, Tamil Nadu, India

10:50 AM **Multiparameter Thermal Imaging**
---V. F. Bakirov and R. A. Kline, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182; W. P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA

11:10 AM **Discrete Variable Thermal Tomography**
---V. F. Bakirov and R. A. Kline, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182; W. P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA

11:30 AM **Direct Way of Correct Heat Flow Determination in Thermal Nondestructive Testing**
---O. V. Lebedev and V. G. Avramenko, Physics Department, Moscow State University, Moscow, Russia, Technological Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, WEMO, Moscow, Russia; O. N. Budadin and E. V. Abramova, Technological Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, WEMO, Moscow, Russia

11:50 AM ***Lunch***

A 2-D Inverse Heat Conduction Formulation for Determination of Heat Source Characteristics from Thermal Images

---Naveen V. Nair and Krishnan Balasubramaniam, Center for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai, Tamil Nadu, India; Sarit K. Das, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai, Tamil Nadu, India

---Inverse Heat Conduction Problems (IHCP) is a very common temperature measurement technique in situations requiring non-invasiveness in heat transfer measurement. Common examples include measurement of temperatures in ducts, measurement of heat transfer coefficient of flows inside pipes, and thermal non-destructive evaluation techniques such as thermography, lock-in thermography, thermosonics etc. In this context, the inverse problem is defined as the determination of the time-temperature distribution at a particular boundary (called the output t-T profile), known the time-temperature profile at another boundary (called the input t-T profile). Inverse heat conduction problems are, in general, ill-posed because they violate the uniqueness condition and also are unstable (discontinuous) in presence of noise. The solution of such a problem can then be posed as one of selection of a unique solution from among a set of feasible solutions. This problem of selection is usually referred to as regularization. Here a regularization technique called the “Maximum Entropy Method” is used. In this work, a new, intuitive method of parametrizing the input t-T profile for two dimensional problems is introduced which greatly reduces computational effort and also leads to more stable solutions. The entropy function based on the parameterized input is then developed. The function is then maximized to obtain the final unique solution. Preliminary simulation results using the regularization technique are shown and compared with non-regularized solutions.

Multiparameter Thermal Imaging

---Vadim F. Bakirov and Ronald A. Kline, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182; William P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA

---Thermal imaging is a rapidly emerging area as it offers the capability for full field quantitative nondestructive evaluation. In particular, thermal techniques can be used to accurately measure material parameters (thermal conductivity, heat capacity) on a local basis. Here we describe a tomographic reconstruction technique that can be used to image both thermal conductivity and heat capacity from heat conduction data. This requires the ability to accurately measure surface temperature evolution at any point on the surface of a body due to a localized thermal excitation such as a laser source. Two independent parameters (maximum temperature and time for the maximum in the first derivative of temperature with respect to time) are required for the reconstruction. Using a coupled parameter version of the Algebraic Reconstruction Technique (ART) one can reconstruct the two thermal parameters tomographically. Results from simulated data are presented to illustrate the utility of the approach.

Discrete Variable Thermal Tomography

---Vadim F. Bakirov and Ronald A. Kline, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182; William P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA

---Tomographic reconstruction is being utilized with increased frequency in many imaging applications. Typically, one wishes to reconstruct a material parameter distribution (density, stiffness, etc.) where that parameter can take on a large range of possible values. These reconstructions are important in looking at local material inhomogeneity problems. However, there are other situations where one wishes to reconstruct a feature that can only take on a limited set of values. Imaging cracks in an otherwise homogeneous solid is one such problem. In this work we describe a tomographic imaging technique from heat propagation data which can be used for crack reconstruction. Here, the reconstruction domain is divided into pixels where each individual pixel is either solid or void. When a crack is present, several adjacent pixels are imaged as voids to reconstruct its shape. Introducing the appropriate boundary conditions around the perimeter of each pixel (whether solid or void) is critical in the reconstruction process. The technique developed here is based on the Algebraic Reconstruction Technique (ART) and sensitivity matrix approach described previously. Results are presented for sample geometries to show how this approach can be utilized.

Direct Way of Correct Heat Flow Determination in Thermal Nondestructive Testing

---Oleg V. Lebedev and Vladimir G. Avramenko, Moscow State University, Physics Department, Moscow, Russia; Technological Institute of Energetic Investigations, Diagnostic and Nondestructive Testing “WEMO”, Moscow, Russia; Oleg N. Budadin and Elena V. Abramova, Technological Institute of Energetic Investigations, Diagnostic and Nondestructive Testing “WEMO”, Moscow, Russia

---One of the most important characteristics of heat transfer processes is the heat flow. It consists of two base components - radiant heat and convection heat. Correct value of heat flow is achievable only using simultaneously three heat flow transducers. After solution of heat conductivity equation and Fourier analysis it is found that perturbation of temperature on the surface of controlled material is proportional to the linear size of transducer due to positioning of transducer on the surface of material. If the typical linear size of transducer is 1cm so local perturbation of temperature is 0,1C. Using perturbation theory it is found optimal mutual configuration of three heat flow transducers. Two heat flow transducers must be situated on the distance between their centers of the two typical sizes of transducer. The third transducer must be settled on considerable distance from two transducers. The procedure is added by measuring of efficient coefficient of heat transfer of transducers. For this purpose it is mounted temperature transducer measuring temperature difference between controllable material and air. Solving nonstationary heat conductivity equation and Fourier analysis it is found that efficient coefficient of heat transfer of transducers must be averaged during time interval approximately 100 seconds.

SESSION 16
UT MODELING, SCATTERING, AND PROPAGATION
S. K. Datta, Chairperson
BR A2

8:30 AM **Application of BEM for the Visualization of Scattered Wave Fields from Flaws**
---M. Kitahara, Department of Civil Engineering, Tohoku University, Sendai, Miyagi, Japan; K. Nakahata, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, O-okayama, Tokyo, Japan; T. Ichino, Hisai Area Office, Mie Prefectural Gov., Hisai, Mie, Japan

8:50 AM **Modeling of the Ultrasonic Scattering by Internal Cracks in an Anisotropic Component**
---A. E. Bostrom, Chalmers University of Technology, Department of Applied Mechanics, SE-412 96 Goteborg, Sweden

9:10 AM **A Semi-Analytic-FEM Hybrid Model for Simulating UT Configurations Involving Complicated Interactions of Waves with Defects**
---N. Gengembre, A. Lhémery, and R. Omote, LIST, Commissariat à l'Energie Atomique, Saclay, France; T. Fouquet and A. Schumm, R&D Sinetics, Electricité De France, Clamart, France

9:30 AM **Inverse Scattering for Reconstruction of Cavity Shapes in Anisotropic Solid**
---S. Hirose and Y. Hara, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Tokyo, Japan

9:50 AM **Prediction of Angle Beam Ultrasonic Testing Signals from a Surface Breaking Crack in a Plate Using Multi-Gaussian Beams**
---S.-J. Song, J.-S. Park, and Y. H. Kim, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; J.-H. Lee, Korea Institute for Nuclear Safety, Daejon, Korea

10:10 AM ***Coffee Break***

10:30 AM **Models and Methodology for the Characterization of Surface-Breaking Cracks Using an Ultrasonic Near-Field Scattering Measurement**
---J. C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031; J. Knopp and J. L. Blackshire, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH; S. Sathish, University of Dayton Research Institute, Dayton, OH 45433

10:50 AM **Measurement Models for Predicting the Ultrasonic Response from Side-Drilled Holes**
---A. L. Lopez[1,2], H.-J. Kim[1], and L. W. Schmerr, Jr.[1,2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Department of Aerospace Engineering; A. Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, Canada, P7B 5E1

11:10 AM **A Localized Multi-Gaussian Ultrasonic Beam Model**
---L. W. Schmerr, Jr.[1,2], H.-J. Kim[1], and A. Sedov[3], Iowa State University, [1]Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Department of Aerospace Engienering; [3]Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, P7B 5E1, Canada

11:30 AM **A Simple Method to Computer Ultrasonic Wave Propagation in Layered Anisotropic Media**
---L. Wang and S. I. Rokhlin, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

11:50 AM **Application of Ultrasonic Modelling to the Positioning of Defects in a Cladded Component**
---G. Haiat and P. Calmon, DRT/SISC, Commissariat à l'Energie Atomique, CE-Saclay, Gif sur Yvette, 91191, France; F. Lasserre, Intercontrôle, Rungis, 94583, France

12:10 PM ***Lunch***

Application of BEM for the Visualization of Scattered Wave Fields From Flaws

---Michihiro Kitahara, Dept. of Civil Engineering, Tohoku University, Sendai, Miyagi, Japan; Kazuyuki Nakahata, Dept. of Mechanical and Environmental Informatics, Tokyo Institute of Technology, O-okayama, Tokyo, Japan; Taisuke Ichino, Hisai Area Office, Mie Prefectural Gov., Hisai, Mie, Japan

---The elastodynamic boundary element method is applied to the visualization of the scattered wave fields around flaws. In the formulation of BEM, the multigaussian beam model is introduced in order to simulate the wave fields radiated from the transducer. First, the unknown quantities on the flaw boundaries are determined by the boundary element method. Then near fields are calculated from the integral representation of the scattered wave fields. The calculated near fields are visualized in the vicinity of flaws. The results of the near field visualization are utilized to interpret the far field backscattered waveforms. The backscattered waveforms are obtained from the far field expression of the scattered waves. It is shown from the numerical examples that the near field visualization is useful to interpret the far field backscattered waveforms and therefore it contributes to characterize the geometrical feature of flaws.

Modeling of the Ultrasonic Scattering by Internal Cracks in an Anisotropic Component

---Anders E. Bostrom, Chalmers University of Technology, Department of Applied Mechanics, SE-412 96 Goteborg, Sweden

---Thick-walled anisotropic components appear in some applications, e.g. in the nuclear power industry. Ultrasound is often used to detect defects in such components, but the results are often hard to interpret. Modeling work can be of great value in this context, particularly for the possibility to perform parametric studies. In this paper hypersingular integral equation methods are used to compute the scattering by internal cracks in a component of arbitrary anisotropy. A realistic model of an ultrasonic contact probe is used for the transmitting probe, and a reciprocity argument is used for the receiving probe. By comparing the scattering by strip-like, rectangular, and circular cracks (the circular crack is restricted to lie in the isotropy plane of a transversely isotropic solid) the influence of the shape of the crack is investigated. Numerical results are given for the different shapes at a few frequencies and some conclusions regarding the shape influence are drawn.

A Semi-Analytic-FEM Hybrid Model for Simulating UT Configurations Involving Complicated Interactions of Waves with Defects

---Nicolas Gengembre, Alain Lhémery, and Ryuji Omote, LIST, Commissariat à l'Energie Atomique, Saclay, France; Thierry Fouquet and Andreas Schumm, R&D Sinetics, Electricité De France, Clamart, France

---Semi-analytic models for UT simulation provide quantitative predictions in a wide range of situations. They allow fast computations, a crucial requirement in the industrial context. Approximations made in deriving them may fail at predicting responses from defects of complex geometry where scattering involves complicated processes. In such cases, numerical schemes such as FEM, which do not rely on physical assumptions and approximations, are required. However, numerical schemes are computing intensive (computation time, memory) considering typical wavepaths of hundreds of wavelengths in NDT configurations. To combine the advantages of both methods while minimizing their inconveniences, a hybrid model has been developed. Most of the propagation is computed using a semi-analytic model (CEA code Champ-Sons), while wave - defect interaction is computed numerically by a FEM scheme (EDF code Athéna) in a small region surrounding the defect. An integral formulation extending Auld's reciprocity principle to the transient case has been derived to allow both codes to exchange the computed results required to predict the echo-response from the defect. In this paper, the theoretical derivation of the coupling formula is first derived. Then, its numerical implementation is discussed. Lastly, examples are given to illustrate the interest of hybrid computations in UT simulations.

Inverse Scattering for Reconstruction of Cavity Shapes in Anisotropic Solid

---Sohichi Hirose and Yoichi Hara, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Tokyo, Japan

---Linearized Born and Kirchhoff inverse scattering has been used to reconstruct the shapes of defects in an isotropic elastic solid, e.g., see Kitahara et al. (2002). For an anisotropic solid, however, the inverse scattering analysis has not yet been developed well, although it is well known that anisotropic properties of elastic media affect much on wave scattering and shape reconstruction of defects. In this paper, a linearized inverse scattering analysis for an anisotropic solid is developed on the basis of the Born approximation and the Kirchhoff approximation. In numerical examples, scattering behaviors of two dimensional elastic waves in far field are analyzed by means of the boundary element method and then fed into the inverse method to reconstruct the cavity shapes in a anisotropic solid.

Prediction of Angle Beam Ultrasonic Testing Signals from a Surface Breaking Crack in a Plate Using Multi-Gaussian Beams

---Sung-Jin Song, Joon-Soo Park, and Young H. Kim, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; Jin-Ho Lee, Korea Institute for Nuclear Safety, Daejon, Korea

---Since surface breaking cracks are one of the most dangerous defects that can occur in steel structures, detection and sizing of them has been one of the essential tasks in angle beam ultrasonic testing. For the optimization of interrogation conditions and the proper interpretation of test result, it is useful to have a model that can predict the ultrasonic testing signals theoretically under the given conditions. This paper will describe a modeling approach to predict the angle beam pulse-echo signals to be captured from surface breaking cracks in a plate in a computationally efficient manner. For this purpose, the multi-Gaussian beams are adopted to describe the radiating beam patterns in the interrogating specimen, and the scattered beam fields are calculated based on the Kirchhoff approximation. In addition, the characteristics of the ultrasonic testing system (including a pulser/receiver, cable, transducer, wedge and couplant) are considered in terms of the system efficiency factor. By combining these three ingredients, the surface breaking crack signals are predicted at different interrogating positions. The accuracy of the proposed model will be verified by the initial experiments.

Models and Methodology for the Characterization of Surface-Breaking Cracks Using an Ultrasonic Near-Field Scattering Measurement

---John C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031; Jeremy Knopp and James L. Blackshire, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH; Shamachary Sathish, University of Dayton Research Institute, Dayton, OH

---Far-field measurements of the reflection and transmission coefficients for incident Rayleigh waves by a surface-breaking crack have been used to characterize crack depth. However, this approach is limited to small cracks relative to the wavelength and is sensitive to variation in crack angle and crack face contact condition. Recently, the intensification of the ultrasonic field for an incident Rayleigh wave on a surface-breaking crack was observed experimentally through a near-field surface displacement measurement using a laser interferometer. To gain a better physical understanding of these measurement results, 2D models of the near-field scattering of surface waves from surface-breaking cracks were developed using both the boundary element method (BEM) and the finite element method (FEM). Regions of intensification and decay were found to be highly localized around the crack site, and offer an advanced NDE technique for detecting and characterizing surface-breaking cracks. Excellent agreement was found between the experimental and simulated data. Studies were performed to evaluate the sensitivity of the near-field response to variation in crack depth, crack angle, and pulse shape. Lastly, potential near-field measures were evaluated and found to demonstrate expanded range and improved accuracy with respect to far-field measures.

Measurement Models for Predicting the Ultrasonic Response from Side-drilled Holes

---Ana L. Lopez[1,2], Hak-Joon Kim[1], and Lester W. Schmerr, Jr.[1,2], [1]Iowa State University, Center for NDE, Ames, IA 50011; [2]Department of Aerospace Engineering; Alexander Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, Canada, P7B 5E1

---A side-drilled hole (SDH) is a commonly used reference reflector in ultrasonic nondestructive evaluation. Here, we will develop measurement models and scattering models that allow us to simulate the SDH ultrasonic response. The scattering models considered will include an explicit model based on the Kirchhoff approximation, as well as an "exact" separation of variables solution. Two measurement models are also derived. One of these, which allows for the variation of the incident fields over the cross-section of the SDH, is appropriate for large holes. A simpler model, which neglects those variations, is also described. Examples are given of the received waveforms and peak-to-peak voltage responses for a number of different size SDHs and the differences due to the various scattering models plus measurement models are discussed.

A Localized Multi-Gaussian Ultrasonic Beam Model

---Lester W. Schmerr Jr.[1,2] , Hak-Joon Kim[1], and Alexander Sedov[3], [1]Center for NDE, Iowa State University, Ames, IA, 50011, USA; [2]Dept. of Aerospace Eng., Iowa State University, Ames, IA, 50011, USA; [3]Dept. of Mechanical Eng., Lakehead University, Thunder Bay, Ontario, Canada, P7B 5E1

---A Gaussian beam is an important building block for modeling the wave field of an ultrasonic NDE transducer because one can define the propagation of a Gaussian beam and its transmission/reflection at boundaries completely in terms of analytical expressions. In addition, those analytical expressions remain well-behaved even in the presence of caustics and focal points in the ultrasonic wave field. To date, these advantages of a Gaussian beam have been exploited in modeling planar and focused circular piston transducers by using the superposition of a small number (10-15) of Gaussians over the face of the transducer whose widths are comparable to that of the transducer itself. This model we will call the multi-Gaussian (MG) beam model. Here, we will show that by using the summation of small, localized Gaussians instead one can also accurately model the wave fields of ultrasonic transducers, leading to a new, versatile second generation multi-Gaussian (MG^2) beam model. The advantage of the MG^2 model over the original MG model is that the MG^2 model can model non-piston as well as piston-like transducer behavior, can treat non-circular as well as circular transducers, and can potentially handle more complex problems, such as the radiation through interfaces with rapidly changing curvature and through inhomogeneous media, where the MG approach fails. We will describe the formulation and use of the MG^2 model for a variety of 2-D and 3-D problems for isotropic, homogeneous media and discuss how the number and width of the localized Gaussians influence the accuracy of predictions of the transducer wave field.---This work was supported by the NSF Industry/University Cooperative Research program.

A Simple Method to Computer Ultrasonic Wave Propagation in Layered Anisotropic Media

---Lugen Wang and Stanislav I. Rokhlin, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---Based on a simple second-order thin layer asymptotic expansion for the transfer matrix, an asymptotic solution for the stiffness matrix for a general anisotropic piezoelectric thin layer is obtained. The total transfer/stiffness matrix for thick layers or multilayers is calculated recursively with arbitrary precision by subdividing these layers into thin sublayers and combining recursively the thin layer transfer/stiffness matrices. It is shown that these methods converge to the exact solution and a hybrid transfer-stiffness matrix combination provides smallest computational error. The new method is computationally stable, efficient and easy to implement. To solve by this method the wave propagation in a semi-space, it is replaced by a perfectly matched attenuating layer. The advantage of the method is that one does not need to compute the exact wave propagation solution for each anisotropic layer of the system and only the elastic constants of the layers are required. Examples are given for wave propagation in multidirectional composites and layered piezoelectric media.

Application of Ultrasonic Modelling to the Positioning of Defects in a Cladded Component

---Guillaume Haiat and Pierre Calmon, DRT/SISC, Commissariat à l'Energie Atomique, CE-Saclay, Gif sur Yvette, 91191, France; Frédéric Lasserre, Intercontrôle, Rungis, 94583 France

---Accurate positioning and sizing of defects are a strong requirement for ultrasonic non destructive testing (NDT). In complex configurations, this positioning can be greatly improved by taking into account modelling results. In the case of the inspection of the pressure vessel of French nuclear reactors, the complexity arises from the austenitic cladding of the component: The inspected surface may present irregularities which may disturb the ultrasonic beam and consequently make difficult the positioning of a defect. In addition the anisotropy of the austenitic cladding has strong effects. In this communication we present a work made in the aim of improving the accuracy of the positioning by using the modelling tools of CIVA, the NDT software developed in CEA. A method has been developed which involves modelling of the propagation in the component. The real surface of the vessel is deduced from ultrasonic (L0) measurements and then inputted in the calculations. We describe the method and show some examples of application.

SESSION 17
FERROMAGNETIC MATERIALS AND MEASUREMENTS
A. Pignotti, Chairperson
BR A4

1:30 PM **Incorporation of Hysteresis Effect into Finite Element Modeling**
---J. Lee, S.-J. Lee, Y. Melikhov, D. C. Jiles, M. Garton, R. Lopez, and L. Brasche, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

1:50 PM **Creep Void Detection for Low Alloy Steel Using AC Magnetic Method**
---M. Shiwa, W. Cheng, R. Kume, and H. Yoneyama, Tsurumi R&D Center, Japan Power Engineering and Inspection Corporation, 14-1 Benten-cho, Tsurumi-ku, Yokohama, Kanagawa, 230-0044, Japan

2:10 PM **A New Approach to Modeling the Magnetomechnical Effect**
---L. Li and D. C. Jiles[1], Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [1]Ames Laboratory, U. S. Department of Energy, Ames, IA 50011

2:30 PM **Evaluation of Stress Loaded Steel Samples Using Selected Electromagnetic Methods**
---T. Chady, Technical University of Szczecin, Electrical Department, ul. Sikorskiego 37, 70-313 Szczecin, Poland

2:50 PM **Damage Detection by the Mode-Selectable Magnetostrictive Transducer for Cylindrical Ferromagnetic Waveguides**
---Y. Kim, S. W. Han, and Y. Y. Kim, School of Mechanical & Aerospace Engineering and National Creative Research Initiatives Center for Multiscale Design, Seoul National University, Seoul, Korea

3:10 PM ***Coffee Break***

Incorporation of Hysteresis Effect into Finite Element Modeling

---Junyoul Lee, Seong-Jae Lee, Yevgen Melikhov, David C. Jiles, Michael Garton, Rick Lopez, and Lisa Brasche, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

---Hysteresis occurs in ferromagnetic materials, arising usually as a result of cooperative behavior of a large number of identical interactive elements. Often hysteresis effects have been ignored in magnetic modeling due to the multi-valued property causing difficulty in its incorporation into numerical calculations such as those based on finite elements. Therefore a linear approximation of magnetic permeability or a nonlinear B-H curve formed by connecting the tips of the hysteresis loops has previously been used widely in magnetic modeling for these types of calculations. In recent years the widespread and increasing capability of computers has made the modeling of hysteresis available to a much wider range of researchers. We employed the Jiles-Atherton (J-A) hysteresis model for development of a finite element method (FEM) algorithm incorporating hysteresis effects. J-A model is suited for numerical analysis such as finite element modeling because of the small number of degrees of freedom and its simple form of equation. A FEM algorithm for hysteretic materials has been developed for estimation of the volume and the distribution of retained magnetic particles around a defect site. The volume of retained magnetic particles was found to depend not only on the existing current source strength but also on the remaining magnetization of a hysteretic material. Detailed algorithms and simulation results will be presented.

Creep Void Detection for Low Alloy Steel Using AC Magnetic Method

---Mitsuharu Shiwa, Weiying Cheng, Ryouich Kume, and Hiroshi Yoneyama, Tsurumi R&D Center, Japan Power Engineering and Inspection Corporation, 14-1 Benten-cho, Tsurumi-ku, Yokohama, Kanagawa, 230-0044 Japan

---Nondestructive detection of creep void was developed for low alloy steel by using AC magnetic method. Two types of 2.25Cr-1Mo steel specimens, base metal (BM) and simulated heat affected zone (HAZ) under aging and creep damage, were prepared for the tests. The aging temperature was 873K. The applied stresses of creep damage were 39 MPa and 54 MPa at temperature of 873K. A differential type probe was used to detect AC magnetic signals. The exciting and detecting coils were coaxially arranged with a ferrite core. Signals were recorded using a 2-channel waveform recorder. The hysteresis loss (HL) was analyzed. It was observed that the HL of BM and HAZ changed in opposite direction, that is, HL of BM increased and HL of HAZ decreased with aging time. On the other hand, the HLs of both BM and HAZ decreased with creep time. The HL of creep samples was affected by both aging and stress-induced damage. In order to evaluate creep damage, stress-induced damage (SID) parameter was proposed to remove aging factor of materials from HL. All creep damage samples of SID value under 0.8 were observed creep void by scanning electron microscope (SEM).

A New Approach to Modeling the Magnetomechanical Effect

---Lu Li and David C. Jiles*, Iowa State University, Ames, IA 50011; *Ames Laboratory, U.S. Department of Energy, Ames, IA 50011

---The magnetomechanical effect is the change of magnetization of a magnetic material resulting from the application of stress. One of the major challenges today is to provide reliable models for non-linear and hysteretic effects in materials. Development of an accurate model description of the magnetomechanical effect becomes increasingly important in the development of stress sensors using magnetostrictive materials and applications of magnetic measurements to evaluation of stress in materials. The previous theory on magnetomechanical effect has recently been refined by including a new linear term in the model equation. The new model equation for interpreting the magnetomechanical effect has been developed based on analogy with the Rayleigh law. In some circumstances, the refined model shows that the modified theory provides a better description of the magnetization changes under stress. But in others, it does not. Selection of model parameters for materials with positive or negative magnetostriction can be difficult for a long time. Investigations based on experiments have been done in order to determine the relationship between model parameters and material properties. These have been used to evaluate the generality of the new model theory.

Evaluation of Stress Loaded Steel Samples Using Selected Electromagnetic Methods

---Tomasz Chady, Technical University of Szczecin, Electrical Department, ul. Sikorskiego 37, 70-313 Szczecin, Poland

---The evaluation of fatigue damage and thus the remaining lifetime of structural is a task of enormous practical relevance. Defects, stress and fatigue damages are causing changes of materials' magnetic and electric properties. Therefore, the electromagnetic NDE techniques are the most promising methods for the above purpose. In this paper the magnetic leakage flux and eddy current method were utilized. Seven samples made of ferromagnetic material with different level of applied stress was prepared. First, the leakage magnetic fields were measured by scanning the surface of the specimens with Giant Magnetoresistive (GMR) gradiometer. The extremely small size of the sensing elements and resistor separation guarantee very good spatial resolution. The same samples were evaluated using an eddy current sensor. Next, two-dimensional results of measurements were processed by digital filters. A comparison between the results obtained from both methods were carried out. Finally, selected parameters of the measured signal were calculated and utilized to evaluate level of the applied stress. A strong coincidence between amount of the applied stress and the maximum amplitude of the derivative was confirmed.

Damage Detection by the Mode-Selectable Magnetostrictive Transducer for Cylindrical Ferromagnetic Waveguides

---Youngkyu Kim, Soon Woo Han, and Yoon Young Kim, School of Mechanical & Aerospace Engineering and National Creative Research Initiatives Center for Multiscale Design, Seoul National University, Seoul, Korea

---In recent years, ultrasonic inspection techniques adopting magnetostrictive effects have received much attention because they are non-destructive and require no direct physical contact with target systems. By selecting the desired wave mode and thus rejecting the unwanted modes amongst propagating waves in cylindrical ferromagnetic waveguides, we can effectively detect various types of flaws. However, a bending wave mode selecting technique, in particular, has not been fully developed yet. The purpose of this work is to present a technique to select either bending or longitudinal waves alone from compound waves propagating in ferromagnetic cylindrical waveguide. To achieve this goal, a new bias magnet configuration suitable for bending mode selection is suggested. Several experimental results are conducted to verify the effectiveness of the proposed method.

SESSION 18
RELIABILITY AND POD
J. Harris, Chairperson
BR A4

3:30 PM **Ultrasonic Study of Crack Under a Dynamic Thermal Load**
---J. A. Pitkänen, VTT Industrial Systems, Espoo, Finland; M. Kemppainen, Trueflaw Ltd., Espoo, Finland; I. Virkkunen, Helsinki University of Technology (HUT), Department of Mechanical Engineering, Laboratory of Engineering Materials, Espoo, Finland

3:50 PM **The Effect of Flaw Surface Roughness and Beam Tilt Angle on Ultrasonic Pulse Echo Detectability**
---R. B. Tait, J. Meyer, and T. Ralegoma, University of Cape Town, Department of Mechanical Engineering, Private Bag Rondebosch, Cape Town, South Africa; G. Wilson, Inspection and Test, Koeberg Nuclear Power Station, ESKOM, Private Bag X10, Kernkrag, 7440, Cape Town, South Africa

4:10 PM **A 2D Static Ultrasonic Array of Passive Probes for Improved Probability of Detection**
---P. C. Snowdon and S. Johnstone, University of Durham, School of Engineering, South Road, Durham, DH1 3LE United Kingdom; S. Dewey, Swinden Technology Centre, Corus, Rotherham, South Yorkshire, United Kingdom

4:30 PM **A Software System for Inspection Qualification**
---D. McNab, P. Leggat, R. Robinson, and A. McNab, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, G11XW, United Kingdom; M. W. Toft, Berkley Technology Centre, BNFL Magnox Generation, Berkley, Gloucestershire, GL 13 9PB, United Kingdom; J. McDonald, University of Strathclyde, Centre for Electrical Power Engineering, Glasgow, G1 1XW, United Kingdom

4:50 PM **Aircraft Wiring Integrity Verification Using Pseudo-Random Binary Sequence**
---E. van Doom, Intelligent Automation, Inc., Rockville, MD 20855

5:10 PM **Determination of Default POD for Hard-Alpha Inclusions in Titanium Rotating Components for Aircraft Engines**
---R. B. Thompson, W. Q. Meeker, C.-P. Chiou, and L. Brasche, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Ultrasonic Study of Crack Under A Dynamic Thermal Load

---Jorma A. Pitkänen, VTT Industrial Systems, Espoo, Finland; Mika Kemppainen, Trueflaw Ltd., Espoo, Finland; Iikka Virkkunen, Helsinki University of Technology (HUT), Department Mech.Eng, Laboratory of Engineering Materials, Espoo, Finland

---In pipings the defects play a key role for determining the life of component. Also the risk for pipe failure combined to the defects has to be taken into account. In this study thermal dynamic load has been applied to austenitic material (AISI 304) in order to introduce dynamic behavior into the crack. The studied crack (~20 mm x 7 mm) has been produced by thermal loaded cycles in beforehand. Different ultrasonic techniques were used to reveal information from interaction of ultrasonic waves from dynamic behavior of a crack face in the sonified volume. The ultrasonic probes in the study are typical probes for defect detection and sizing on site inspections. This information helps us to understand some effects in nuclear pipings such as detection of cracks with special techniques and difficulties in sizing of the cracks in real situations. In this case the material is loaded to exceed the yield strength. The used thermal cycles caused high variations in the temperature scale from 20C (68 F) to 600C (1112 F) in the crack volume especially on the crack surface area. These factors cause large stress variations in the vicinity of the crack. Effects which have been detected during analysis from the measurements explain well difficulties in ultrasonic inspections of those materials on site. Experimental work explains reasons why some defects are missed in the real pipings. Used ultrasonic techniques are described in details and conclusion for applicability of those techniques has been drawn.

The Effect of Flaw Surface Roughness and Beam Tilt Angle on Ultrasonic Pulse Echo Detectability

---Robert B. Tait, Janine Meyer, and Thabo Ralegoma, Department of Mechanical Engineering, University of Cape Town, Private Bag Rondebosch, Cape Town, South Africa; Graham Wilson, Inspection and Test, Koeberg Nuclear Power Station, ESKOM, Private Bag X10, Kernkrag, 7440, Cape Town, South Africa

---Non destructive testing (NDT), using ultrasonic pulse echo techniques, is often employed to detect and also determine the size of, any crack like defects in high value engineering plant, such as pressure vessels and piping. This is especially so if they are susceptible to crack growth through fatigue or stress corrosion cracking (SCC) during service. In such situations, fracture mechanics based “fitness for purpose” assessments are essential, and a vital aspect of this is the capability to detect flaws reliably and consistently, and also to size them accurately. Recent investigations have shown that detectability of crack like defects appear to be dependent on the roughness of the cracks, as well as on the angle of deviation of the ultrasonic beam from the normal. This paper utilizes a custom built oil bath and ultrasonic system to investigate crack like flaw detectability as a function of surface roughness and beam tilt angle in particular, but also considering flaw size, distance, and probe frequency. The roughness tests include actual (slow and rapidly grown) fatigue cracks and SCC cracks, as well as machined surfaces, together with the effect of orientation of the flaw growth to the beam, and the tests indicate that surface roughness does indeed affect detection capability, which has implications for the NDE inspection and quality assurance community.

A 2D Static Ultrasonic Array of Passive Probes for Improved Probability of Detection

---Paul C. Snowdon and Sherri Johnstone, University of Durham, School of Engineering, South Road, Durham DH1 3LE, United Kingdom; Stephen Dewey, Swinden Technology Centre, Corus, Rotherham, South Yorkshire, United Kingdom

---This paper will show that increasing the probability of detection (POD), without also increasing the amount of false positives, is feasible through the use of data fusion. Experiments have been carried out using an ultrasonic 2D array of eight 5MHz straight beam immersion probes. The probes were arranged to give maximum material coverage of a 70mm x 70mm section of steel bar. A mid-section 3mm side drilled hole was used to simulate a defect. A single probe excitation and multi probe detection arrangement was used to collect information from areas of the sound field, which would be lost using a standard pulse echo technique. A Sonomatic USPC 3100 flaw detector, was used in conjunction with a Hewlett Packard “Infinium” oscilloscope. Ultrasonic theory suggests that the reflected beam intensity would have insufficient signal to noise ratio to be of practicable use with this probe array geometry. However, work presented in this paper shows firstly that the pre-processed signal to noise ratio is in excess of 34dB for distances of 22.5mm from the probe center and secondly the probability of detection can be improved by fusing the signal information from all the detecting probes.

A Software System for Inspection Qualification

---Douglas McNab, Patricia Leggat, Robbie Robinson, and Alistair McNab, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, G11XW, United Kingdom; Michael W. Toft, Berkley Technology Centre, BNFL Magnox Generation, Berkley, Gloucestershire, GL13 9PB, United Kingdom; James McDonald, Centre for Electrical Power Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom

---In safety critical and non-routine situations, the inspection capability can be demonstrated by an independent process of Inspection Qualification (IQ); also, termed Inspection Validation. Under the ENIQ methodology for IQ, a Technical Justification forms a key element in assuring the performance of the inspection. This document contains evidence from physical reasoning, theoretical modeling and practical trials on identified worst-case defects linked to experience of inspection of other similar components to support the validity of an inspection. However, the qualification process is costly and time consuming and as such, an approach that could aid in its production would be beneficial. This paper describes the development of an intelligent approach to inspection qualification utilizing interactive software tools combined with an NDT Workbench, empowering the NDT engineer to design and evaluate the capability of an ultrasonic inspection within a single environment. Six software components exist at present. These include: a ray-tracing tool, a coverage analyzer, a worst-case defect search engine, theoretical flaw response models, a flaw modeling expert system and a case-based reasoning system. This paper discusses the motivation for the system, the design and implementation of the tools and the benefits it will provide.

Aircraft Wiring Integrity Verification using Pseudo-Random Binary Sequence

---Eric van Doorn, Intelligent Automation, Inc, Rockville, MD 20855

---High rates of wiring problems, combined with aging aircraft fleets, are creating a critical need for a reliable, easy means to test aircraft wiring. Many failure modes are intermittent, such as arcing, and tests performed on a maintenance schedule have low probability of detecting such problems. We inject a low voltage Pseudo-Random Binary Sequence (PRBS) into the cable. The correlation of the PRBS with the signal received from the wire yields the impulse response of the circuit, which completely characterizes the transfer function of the cable. If the cable changes due to chafing, high resistance points, or other defects or precursors of defects, its transfer function will change, which can be detected and diagnosed. This method is independent of signals on the wires, so it can be used for on-line all-the-time testing. It can be executed with very low-cost equipment, without disconnecting the wire (bundle) under test, and is sensitive enough to detect insipient failures. We report on results of FAA funded Phase I work, which include successful detection of wire insulation/shielding chafing and carbonization, wire fouling, and partial shorts. We will also report on ongoing Phase II work, which will start in March 2003.

Determination of Default POD for Hard-Alpha Inclusions in Titanium Rotating Components for Aircraft Engines

---R. B. Thompson, W. Q. Meeker, C.-P. Chiou, and L. Brasche, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The probability of detection (POD) is a measure of the effectiveness of an inspection. In the context of the probabilistic design and life management of aircraft engines, POD plays two distinct roles. POD estimates, combined with an analysis of defects that have been found during production, provide a basis for estimating the initial distribution of defects that were produced by the manufacturing process. The result is an exceedance curve, the probability that a defect exists of a specified size or greater. POD can then be further used to estimate how this exceedance curve is modified by inspections made either during the manufacturing process or in service, a step in determining the probability of part failure after a specified period of service. This paper describes recent advances in updating the Default POD estimates that are used in determining the initial exceedance curves. The approach, based on the Re technique used in the generation of the original default POD curves is first described. Included is an examination of the basic assumptions of that technique and the degree to which they are supported by experimental data. POD estimates are then presented based on incorporating new data sets into the analysis. The nature of the data sets, the selection of the metric for defect “size” that is used in the POD analysis, the determination of this size parameter from metallographic data or ultrasonic data, the statistical assumptions made in the analysis, and the POD estimates will be discussed.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University’s Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

SESSION 19
NEW TECHNIQUES AND SYSTEMS
G. Alers, Chairperson
BR A3

1:30 PM **Precise Nondestructive Evaluation of Bearing Balls by Floating Resonance Method**
---K. Yamanaka, H. Cho, S. Ishikawa, and T. Yakahasi, Tohoku University, Department of Materials Processing, Sendai Miyagi, Japan; K. Tanimoto and H. Takii, Koyo Seiko Co. Ltd., Kashiwara, Osaka, Japan

1:50 PM **Lock-In Thermographic Inspection Under Non-Quasi-Steady-State Conditions**
---J. C. Chen, Rowan University, Department of Mechanical Engineering, Glassboro, NJ 08028; P. J. Kulick and S. Mandayam, Rowan University, Department of Electrical and Computer Engineering, Glassboro, NJ 08028

2:10 PM **Development of Magnetic Particle Method for Forensic Recovery of Serial Numbers**
---D. Utrata and M. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

2:30 PM **Hall-Effect Measurements Under AC Excitation for the Reconstruction of Obliterated Serial Numbers in Magnetic Steels**
---M. J. Johnson, C. C. H. Lo, and L. Naidu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

2:50 PM **A Blind Test of Uniquely Identifying a Metallic Item with an Ultrasonic Intrinsic Tag (UIT) Prototype Instrument**
---M. S. Good, B. E. Simpkins, L. J. Kirihara, J. R. Skorpik, J. A. Willett, P. G. Heasler, K. J. Lessor, and H. A. Undem, Pacific Northwest National Laboratory, Nondestructive Measurement and Characterization Sciences Group, Richland, WA 99352

3:10 PM ***Coffee Break***

3:30 PM **Characterization of Effluents Given off by Wiring Insulation**
---W. T. Yost, K. E. Cramer, and D. F. Perey, Langley Research Center, National Aeronautics and Space Administration, 3 E. Taylor Street, Hampton, VA 23681-2219

3:50 PM **Effluent Based Characterization of Aerospace Wiring**
---K. E. Cramer, W. T. Yost, and D. F. Perey, Langley Research Center, National Aeronautics and Space Administration, 4 Langley Blvd., MS 231, Hampton, VA 23681

4:10 PM **Expert System Development for Use in Theoretical Ultrasonic NDT Simulations**
---R. J. Robinson, A. McNab, D. M. McNab, and P. Leggat, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, G1 1XW, United Kingdom; M. W. Toft, Berkley Technology Centre, BNFL Magnox Generation, Berkley, Gloucestershire, GL 13 9PB, United Kingdom

Precise Nondestructive Evaluation of Bearing Balls by Floating Resonance Method

---Kazushi Yamanaka, Hideo Cho, Satoru Ishikawa, and Tsuyoshi Yakahashi, Department of Materials Processing, Tohoku University, Sendai, Miyagi, Japan; Kiyoshi Tanimoto and Hirokazu Takii, Koyo Seiko Co. Ltd. Kashiwara, Osaka, Japan

---Resonant ultrasound spectroscopy (RUS) of bulk and surface acoustic waves (SAWs) is widely used for testing the surface and inside of objects. However, the resonance properties (resonance frequency and mode amplitude ratio) are disturbed by the contact with supports and transducers. To eliminate this disturbance, we proposed the floating resonance (FR) method in which the resonance property is evaluated using laser ultrasonics after floating the objects, thus avoiding contact to supports and transducers. In the FR method, resonance measurement in completely noncontact condition is realized for the first time. In a preliminary application to bearing balls, we floated an 8-mm-diameter steel bearing ball using an air flow controlled with a mass-flow controller and improved the reproducibility of resonance frequency to better than 0.005%. A localized surface defect was detected by comparing the bulk wave resonance frequencies before and after introducing the defect, which is difficult under the conventional RUS configuration. In an application to surface defects on 8 and 6-mm-diameter silicon nitride bearing balls of moderate tolerance, artificial slits as shallow as 10 micrometer was successfully detected in attenuation measurement of 10 to 40 MHz SAWs after multiple round trips of around 20 turns.

Lock-in Thermographic Inspection Under Non-Quasi-Steady-State Conditions

---John C. Chen, Department of Mechanical Engineering, Rowan University, Glassboro, NJ 08028; Philip J. Kulick and Shreekanth Mandayam, Department of Electrical and Computer Engineering, Rowan University, Glassboro, NJ 08028

---Lock-in thermography is an attractive method for the nondestructive inspection of a variety of engineering materials and defect types. The chief advantages to this technique is its relative ease of application, hardware simplicity, and low computational requirements. One of its drawbacks, however, is that the sample being examined, which is heated by some means in a sinusoidal manner, should be at quasi-steady-state prior to the initiation of inspection. For samples of significant thermal mass (large size, mass, or specific heat), this may be a long duration. In this study, we undertake lock-in thermographic NDE of steel samples of various thicknesses and with various artificial defects included. Furthermore, we compare the results with that obtained when quasi-steady-state was not achieved (i.e., during the heat-up phase prior to quasi-steady-state) to determine the usefulness of the technique under these conditions.

Development of Magnetic Particle Method for Forensic Recovery of Serial Numbers

---Dave Utrata and Marcus Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Magnetic particle testing is one method used by crime labs for the recovery of obliterated serial numbers. The use of this method is well intentioned for such work, but little technique development and implementation guidance has been generated for forensic investigators. This effort is intended to define conditions that increase the likelihood that this technique will be successfully applied in forensic work. To that end, a number of basic questions need to be addressed. Practitioners of this method for nondestructive inspection are well aware that successful inspection will be the result of the proper selection of a number of variables. The use of a magnetic field of appropriate magnitude and orientation, the correct nature of the magnetizing current (AC/DC/rectified) and a suitable choice of magnetic particle suspension are all important considerations for subtle, quantitative work. Investigators in crime labs currently use the magnetic particle method in a manner that provides only sporadic success at best.---This work is sponsored by the Midwest Forensics Resource Center.

Hall-Effect Measurements Under AC Excitation for the Reconstruction of Obliterated Serial Numbers in Magnetic Steels

---M. J. Johnson, C. C. H. Lo, and L. Naidu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Existing techniques employed to recover obliterated serial numbers fall mainly into one of two categories, those requiring extensive sample preparation including the use of acid etchants, and those utilizing magnetic particles to image irregularities in surface magnetic properties. The former is time consuming and utilizes potentially harmful chemicals while the latter messy and potentially low in sensitivity. A new approach is being investigated whereby the stray magnetic field is measured using a Hall-effect sensor. The sample is magnetized using an electromagnetic c-core yoke. For increased sensitivity, an AC approach is being utilized that benefits from the use of a lock-in amplifier. Studies have been conducted comparing the sensitivity of the new approach to existing magnetic particle methods. In these studies, excitation frequencies in the range of a few Hertz to several-hundred Hertz have been used in order to determine an optimum value.---This work is sponsored by the Midwest Forensics Resource Center.

A Blind Test of Uniquely Identifying a Metallic Item with an Ultrasonic Intrinsic Tag (UIT) Prototype Instrument

---Morris S. Good, Bret E. Simpkins, Leslie J. Kirihara, James R. Skorpik, Jesse A. Willett, Patrick G. Heasler, Kimberly J. Lessor, and Halvor A. Undem, Nondestructive Measurement and Characterization Sciences Group, Pacific Northwest National Laboratory, Richland, WA 99352

---Interest has increased in intrinsic identification of metallic items due to the motivation of reducing the number of weapons of mass destruction. Desired features of a technology to perform such a task include the condition of maintaining the pristine state of the item, high accuracy without false calls, easy use, an assurance that restricted data is not revealed, and high resistance to counterfeiting. Development of the Ultrasonic Intrinsic Tag (UIT) for metallic items began in 1991. The selected tag signature was a 5-mm by 5-mm C-scan of ultrasonic backscatter at 20 MHz and 1-mm depth below the part surface. A tag site was defined on the part surface and forthcoming signatures were compared to a reference signature initially acquired from the tag site. A blind study was performed in 2002 whereby reference tag signatures were acquired from five metallic items. Then, one of five units was randomly selected for presentation to the UIT operator for identification. In this comparison, all other identifying features were covered prior to presenting the unit to the UIT operator. The UIT was then used to compare a newly acquired tag signature to each reference signature. All resulting decisions were correct. The physical basis of the measurement, the current prototype instrument, data acquisition and analysis algorithms, instrument performance, and the blind test will be discussed.---Work was supported by the U.S. Department of Energy.---Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

Characterization of Effluents Given Off by Wiring Insulation

---William T. Yost, K. Elliott Cramer, and Daniel F. Perey, National Aeronautics and Space Administration, Langley Research Center, 3 E. Taylor Street, Hampton, VA 23681-2219

---When an insulated wire is heated, the insulation emits a variety of effluents. This paper discusses the basis of emissions of effluents from wiring insulation. Several species are emitted at relatively low temperatures, while others are emitted when the wire reaches higher temperatures. We isolate the emissions by relative molecular weight of the effluents and measure the effluent concentration both as a function of time (temperature held constant) and by wire temperature. We find that the Law of Mass Action describes and predicts the time-dependence of the emission of a specific effluent caused by the heating. The binding energy is determined by performing an Arrhenius Plot on the temperature data. These dependencies are discussed and working equations are derived. Data collected from 20 gauge wire (MIL-W-22759/11-20) is used to illustrate and confirm the validity of the theory.

Effluent Based Characterization of Aerospace Wiring

---K. Elliot Cramer, William T. Yost, and Daniel F. Perey, Langley Research Center, National Aeronautics and Space Administration, 4 Langley Blvd., MS 231, Hampton, VA 23681

---This paper discusses a wire insulation characterization method under development, which identifies the relative molecular weight and binding energy of effluents given off during wire heating and is aimed at nondestructively assessing wire insulation degradation. An overview of how this technique can be used to monitor wire insulation emissions is presented. A series of measurements made on wire specimens (MIL-W-22759/11-20) with poly-tetraflouroethylene (PTFE or Teflon®) insulation is presented. Changes of up to 55% in the emission concentration of two particular effluents were observed by repeated heating the wire specimens. Temperature measurements of the conductor and insulation were correlated to effluent emission concentrations. A basis for the changes in effluent concentration is also presented and leads to a determination of binding energies and associated time constants.

Expert System Development for Use in Theoretical Ultrasonic NDT Simulations

---Robert J. Robinson, Alistair McNab, Douglas M. McNab, and Patricia Leggat, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; Michael W. Toft, Berkley Technology Centre, BNFL Magnox Generation, Berkley, Gloucestershire, GL 13 9PB, United Kingdom

---An Expert System is currently under development, which will assist an NDT engineer to obtain valid solutions of the ultrasonic response from a flaw, utilizing one of four theoretical modeling programs. These programs are based on the Geometrical Theory of Diffraction (GTD) and the Elastodynamic Kirchoff Theory (Coffey and Chapman). When the modeling programs are run on a PC warning flags are highlighted when the model is used in a manner, which may result in invalid results. A level of expertise in the theoretical background of the models is required to interpret these flags. It is possible to develop a series of coded rules which represent the processes a suitably qualified engineer would adopt to address highlighted warning flags. These coded rules can then be embedded within an expert system. This paper describes the architecture of the expert system and how various rules are activated to address warning flags. The expert system involves the embedding of an inference engine, Rete++, within the application. This is a code-generating C++ class library that encapsulates the Eclipse inference engine. Information regarding tests run and their associated results are passed into working memory. The coded rules act on this information to update a test, address warning flags and produce valid ultrasonic simulated inspections.

SESSION 20

UT TRANSDUCERS, MATERIALS, AND OPTICAL PROBES

A. Lhémery, Chairperson

BR A1

1:30 PM **Transducer Modules for Dry-Coupled Ultrasonic Inspection of Aircraft Structures**
---I. N. Komsky, Northwestern University, Center for QEFP, Evanston, IL 60208

1:50 PM **Center Zone Ultrasonic Inspection of 14 Inch Diameter Ti Billets**
---A. D. Degtyar and A. I. Lavrentyev, United Technologies Prat & Whitney, East Hartford, CT 06108; J. A. Umbach, United Technologies Pratt & Whitney, West Palm Beach, FL 32344

2:10 PM **Opposite Phased Transducer, Novel Type of Transducer**
---J. A. Pitkänen and P. K. Kauppinen, VTT Industrial, Espoo, Finland; V. Kniazev, Wave Process Simulation System Laboratory, Moscow, Russia

2:30 PM **Tomographic Imaging of an Ultrasonic Field in a Plane Using a Linear Array**
---K. R. Waters, Washington University, Department of Physics, Laboratory for Ultrasonics, St. Louis, MO 63130; P. H. Johnston, NASA Langley Research Center, Hampton, VA 23681

2:50 PM **Free Response of Piezoelectric Crystals in Series and in Parallel**
---P. H. Johnston, NASA Langley Research Center, 3 E. Taylor Street, MA 231, Hampton, VA 23681

3:10 PM ***Coffee Break***

3:30 PM **Calculation of SAW Dispersion Due to Ion Implantation of Quartz**
---X. R. Zhang, B. Lin, X. N. Yin, and D. Zhang, Nanjing University, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China

3:50 PM **Investigation of the SAW Property Change for Surface Processed LiNb03 Crystal**
---B. Lin, X. R. Zhang, X. M. Lu, and D. Zhang, Nanjing University, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China

4:10 PM **Physical Principles of Magnetic Fluid Guides Used for Nondestructive Testing**
---A. R. Baev, P. P. Prokhorenko, and A. L. Mayorov, Institute of Applied Physics, National Academy of Sciences of Belarus, 16, Academicheskaya st., Minksk, 220072, Belarus

4:30 PM **Development of a Novel Vibration Sensor Using Optical Fiber and Its Application to Composite Materials**
---I. Ohsawa[1], K. Kageyama[1], H. Murayama[1], M. Kanai[1], Y. Machijima[2], F. Matsumura[2], and K. Nagata[2], [1]The University of Tokyo, 7-3-1, Hongo, Bunkyo-key, Tokyo 113-8656, Japan, [2]LAZOC Inc., 1-5-1 Marunouchi, Chiyoda-ku, Tokyo 110-0005, Japan

Transducer Modules for Dry-Coupled Ultrasonic Inspection of Aircraft Structures

---Igor N. Komsky, Center for QEFP, Northwestern University, Evanston, IL 60208

---Several types of transducer modules have been developed at Northwestern University to overcome the problems that are associated with the application of liquid or gel couplants. The modules deploy polymer films to transmit the ultrasound through a dry interface. These films are very flexible, so even with a low pressure they can be adapted to the irregular inspection surfaces. The dry-coupled transducer modules may be used for transmission and reception of both longitudinal and transverse ultrasonic waves in the MHz frequency range. To couple ultrasonic waves from the piezoelectric element into the inspected structure the polymer films are utilized at either one or several interfaces inside the module. One design of the dry-coupled modules contains a “stepping” mechanism that moves the ultrasonic transducer up and down in a “shuttle-like” motion while the module is scanned over the inspection area. Optional application of the independent motor for the transducer motion provides for possible adjustments of the sensor’s “ground” time during inspection “steps”. Another (rolling) module design includes the rotor with a flexible polymer tire that rotates around the stator which contains straight-beam or angle-beam transducers. To accommodate both types of the ultrasonic transducers in the same module elongated stators and rotors were developed and manufactured. The elongated module is also more efficient since it has larger contact area with the inspection surface. The prototype dry-coupled modules have been integrated with the portable ultrasonic inspection units and tested on a number of aircraft structures.---This material is based upon work supported by the Federal Aviation Administration under Contract # DTFA03-98-D-00008, Delivery Order # DTFA03-01-F-IA049 and performed at Northwestern University as part of the Center for Aviation Systems Reliability program through the Airworthiness Center of Excellence.

Center Zone Ultrasonic Inspection of 14 Inch Diameter Ti Billets

---Andrei D. Degtyar and Anton I. Lavrentyev, United Technologies Pratt & Whitney, East Hartford, CT 06108, USA; Jeffrey A. Umbach, United Technologies Pratt & Whitney, West Palm Beach, FL 32344, USA

---Jet engine rotating parts are commonly made of pieces cut from cylindrical billets of titanium or nickel alloys. For sensitivity beyond the current #3 FBH requirement, 14” diameter Ti billets pose an inspection challenge because of the long metal travel path and high material noise. The paper describes the design and performance evaluation of the transducers intended for the inspection of the region near the centerline of 14” diameter titanium billets. Two bi-cylindrical transducers were designed using various modeling tools including ultrasonic beam models. The models were used to predict and optimize transducer performance. The two bi-cylindrical transducers were built based on the developed designs and they were characterized using the Engine Titanium Consortium developed V (z) method to determine their actual focal characteristics versus the nominal design parameters. The transducer performances were evaluated experimentally using a chord block with flat bottom holes at the beginning, middle and end of the billet central zone. Sensitivity of the bi-cylindrical transducer inspection was compared to that of a conventional single-zone inspection.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order IA029 and performed at Pratt & Whitney as part of the Engine Titanium Consortium program.

Opposite Phased Transducer, Novel Type of Transducer

---Jorma A. Pitkänen and Pentti K. Kauppinen, VTT Industrial, Espoo, Finland; Vadim Kniazev, Wave Process Simulation System Laboratory, Moscow, Russia

---Defect sizing is an important task for giving input to fracture mechanics evaluation. The exact evaluation of sound field is key factor to analyse defects in materials. Sizing accuracy is affected by the size of the sound field. There are available several methods for sizing: SAFT, Acoustic Holography, Tip diffraction, TOFT, Amplitude dependence. In SAFT and acoustic holography applications the sound field is calculated according to back propagation of sound waves from an object (defect, flaw). The echoes are calculated according their origin. In tip diffraction defect external sides are determined according the direct echoes from crack tips. Amplitude dependence is affected by the sound field size and by the defect size. This method is sometimes unreliable for sizing. A novel type of transducer, opposite phased transducer is based on sound field determination in designing the phase of the probe. The sound field is calculated according to ultrasonic modelling software based on finite difference method and the designed sound field according to calculations is very narrow for a long distance in a sound path. The experimental evidence shows wanted effects produced by the probe. This Phenomen can be used for instance in defect sizing by using an opposite phased transducer.

Tomographic Imaging of an Ultrasonic Field in a Plane Using A Linear Array

---Kendall R. Waters, Washington University, Department of Physics, Laboratory for Ultrasonics, St. Louis, MO 63130; Patrick H. Johnston, NASA Langley Research Center, Hampton, VA 23681

---Quantitative ultrasonic characterization of inhomogeneous and anisotropic materials is often complicated by signal fluctuations resulting from phase aberration of the insonifying ultrasonic field. We discuss a method based on tomographic reconstruction techniques for the visualization of an ultrasonic field propagated through a material, which enables consideration of the aberrations. Tomographic reconstruction of the field is made possible by the phase-sensitive nature of the tall, narrow piezoelectric elements of a one-dimensional receiving array. We perform simulations of propagated ultrasonic fields using the plane wave decomposition technique, and then apply the tomographic reconstruction algorithm in order to evaluate the feasibility of the proposed imaging method. We then perform experimental measurements of the field propagated through textile-based composites using the NASA Langley Ultrasonic Phased Array Testbed System with a one-dimensional receiving array (2.25 MHz, 64 elements, each 1 cm x 250 μm). Images (1 cm x 1 cm) of the in-phase and quadrature parts of the complex pressure field are reconstructed, and subsequently combined to consider the magnitude and phase. The imaging of an ultrasonic field in a plane by tomographic reconstruction using a one-dimensional array is an enabling technique, which offers the potential for improved ultrasonic characterization of complex materials.

Free Response of Piezoelectric Crystals in Series and in Parallel

---Patrick H. Johnston, NASA Langley Research Center, 3 E. Taylor Street, MS 231, Hampton, VA 23681

---Stacks of longitudinally polarized piezoelectric crystals with alternating polarity have long been used to achieve high acoustic outputs, such as in lithotripter transducers. These devices benefit from the constructive interference of the waves from each of the individual crystals in the stack. Crystals exhibiting a shear piezoelectric response can also be stacked in this manner, although the alignment of the shear axes is a strong factor in their behavior. For crystals whose piezoelectric response includes both longitudinal and shear, it can be considered that the two modes represent separate crystals which are electrically in parallel (common electrodes) but mechanically uncoupled (orthogonal modes). In this work, the free response is considered of piezoelectric crystals of various polarities, which are stacked (mechanically and electrically in series) or are parallel (electrically parallel and mechanically uncoupled). Measurements of impedence magnitude are compared with results from PSPICE simulations using a Mason model. These PSPICE models may serve as the basis for designing physical transducers from crystal stacks.

Calculation of SAW Dispersion Due to Ion Implantation of Quartz

---X. R. Zhang, B. Lin, X. N. Yin, and D. Zhang, Nanjing University, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China

---As early as the end of 1970s, Hartemann investigated the effect of ion implantation on surface-acoustic-wave (SAW) propagating along the ion-implanted surface of quartz. We also got the same experimental results for ion-implanted Y-X quartz, but observed a different result for ion implanted ST quartz at that time. Now, we calculate the SAW dispersion for quartz with a surface implanted by ions based on the perturbation theory suggested by Alude. We consider a Gaussion function as a perturbation function for implantation layer caused by ion implantation. The calculation results shows that: the property of SAW dispersion for ion-implanted quartz is related with the kind of the ions, the implanted does and stop range of the ions. The velocity decrease for H+ or He+ ions -implanted, and the dispersion ratio for the sample implanted by higher does of ion is higher than for that by lower does ion. The larger the stoping range the smaller change of the SAW velocity is, when the ion does is the same. We also calculate dispersion of SAW based on the theory of SAW propagating in the anisotropic thin film deduced by Farnell and Adler for comparison. The detail results, discussions, and comparison between the experimental and the calculation results are presented in this article.

Investigation of the SAW Property Change for Surface Processed LiNb03 Crystal

---B. Lin, X. R. Zhang, X. M. Lu, and D. Zhang, Nanjing University, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China

---We had measured the velocity change and observed dispersion phenomena of surface Acoustic wave (SAW) propagating along the surfaces of LiNbO3 diffused by Ti ions or diffused by Ti ions and treated by proton-exchange. Recently, we calculate the influence of the surface processing on the SAW velocity change based on the perturbation theory for LiNbO3 crystal with surface diffused by Ti and Ti-diffused and proton-exchange. We consider the ions distribution along the diffusion depth can be described by an error function and an exponential function for perturbation layer caused by ion diffusions with stabilized and unstabilized sources respectively, and by a step function for the perturbation layer caused by proton-exchange. The calculation results show that: the SAW velocity change depends on the ratio between the number of the Ti ions with Nb ions within the perturbation layer, and the depth of the perturbation layer. The SAW change for the Ti-diffused and proton-exchanged LiNbO3 depends on the depths of Ti-diffused layer and the PE layer. The velocity of SAW propagating along the PE layer decrease with the depth PE layer increasing. The detail results, discussions, and comparison between the experimental and the calculation results are presented in this article.

Physical Principles of Magnetic Fluid Guides Used for Nondestructive Testing

---A. R. Baev, P. P. Prokhorenko, and A. L. Mayorov, Institute of Applied Physics, National Academy of Sciences of Belarus, 16, Academicheskaya Street, Minsk 220072, Belarus

---This paper presents the results of analysis and investigations of the peculiarities of ultrasound excitation and propagation in solids, when magnetic fluid (MF) is used as a fluid guide, controlled by magnetic field. MF are proposed to be used in ultrasonic testing: ensuring an acoustic contact between the object to be tested and ultrasonic probe; ultrasound excitation in solid by laser pulse radiation; changing of diagram directivity of ultrasonic probes or another ultrasonic systems under action of magnetic field. Some data on waves amplitude and directivity of ultrasonic probes with magnetic fluid prism for excitation head and surface waves in solids against fluid content have been obtained. The results of the experimental research of ultrasound focusing by MF lenses are in agreement with the theoretical analysis.

Development of a Novel Vibration Sensor Using Optical Fiber and its Application to Composite Materials

---Isamu Ohsawa[1], Kazuro Kageyama[1], Hideaki Murayama[1], Makoto Kanai[1], Yuichi Machijima[2], Fumio Matsumura[2], and Keiichi Nagata[2, 1]The University of Tokyo, 7-3-1, Hongo, Bunkyo-key, Tokyo 113-8656, Japan, [2]LAZOC Inc. 1-5-1 Marunouchi, Chiyoda-ku, Tokyo 110-0005, Japan

---A novel fiber-optic vibration sensor was developed by using a conventional optical fiber. A loop type optical fiber sensor showed excellent sensitivity to elastic wave activity. The principle of the sensor is based on Doppler-effect in curved optical fiber, and frequency of light wave transmitted through a curved fiber is shifted by vibration at the curved region. The basic characteristics of the loop sensor were examined by propagating an elastic wave in a steel plate and detecting it with the sensor. The performance of the sensor is also examined experimentally by applying quasi AE signal, and detected propagation of elastic wave in composite materials and its adhesive joint specimen. The experimental results show that the sensitivity is almost equivalent to PZT AE sensor. Failure of the composite specimen can be also detected successfully. Several configurations of the sensor have been designed and very high sensitivity (maximum strain resolution is 10^{-11} m/m) has been achieved in the extremely wide frequency band from 0.1 to 3MHz by applying Laser Doppler velocimetry. Practically numberless sensing points can be arranged on a single optical fiber, and regional monitoring which covers large area of the structures can be achieved.

SESSION 21

UT, EC, AND MFL MODEL BENCHMARK PROBLEMS

D. O. Thompson, Chairperson

BR A2

1:30 PM **Developments of the World Federation's Second Eddy Current Benchmark Problem**
---Y. Tian, Z. Zeng, Y. Li, L. Udpa, and S. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

1:50 PM **Computational Results of the Eddy Current Benchmark Problem 3 (2-D FEM Analysis)**
---M. Swierczynski, S. Gratkowski, K. Stawicki, R. Sikora, and T. Chady, Technical University of Szczecin, Electrical Department, ul. Sikorskiego 37, 70-313 Szczecin, Poland

2:10 PM **Finite Element Modeling of the World Federation's Second MFL Benchmark Problem**
---Z. Zeng, Y. Tian, S. Udpa, and L. Udpa, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824

2:30 PM **The World Federation's Electromagnetic Benchmark Problems: A Progress Report on Results Obtained to Date**
---S. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824-1226

2:50 PM **Ultrasonic NDE Modeling-Analytical and Numerical Foundations**
---L. W. Schmerr, Jr.[1,2], S.-J. Song[3], and A. Sedov[4], [1]Iowa State University, Center for NDE, Ames, IA 50011; [2]Iowa State University, Department of Aerospace Engineering, Ames, IA 50011; [3]Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; [4]Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, P7B 5E1 Canada

3:10 PM ***Coffee Break***

3:30 PM **Ultrasonic Benchmarking: Past Progress and Future Goals**
---R. B. Thompson, Iowa State University, Center for NDE, Ames, IA 50011

3:50 PM ***Open Discussion***

Developments of the World Federation's Second Eddy Current Benchmark Problem

---Yong Tian, Zhiwei Zeng, Yue Li, Lalita Udpa, and Satish Udpa, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---As part of an international effort to validate different numerical models, this work presents numerical results obtained by simulating the second eddy current benchmark problem proposed by the World Federation of Nondestructive Evaluation Centers (WFNDEC). The problem involves prediction of responses generated by eddy current coil sensors scanning an inconel tube containing a defect. A variety of defect geometries are considered and the effect of the presence of a ferromagnetic support plate was also investigated. The simulation involved the use of A-V formulation based finite element method.

Computational Results of the Eddy Current Benchmark Problem 3 (2-D FEM Analysis)

---Marcin Swierczynski, Stanislaw Gratkowski, Krzysztof Stawicki, Ryszard Sikora, Tomasz Chady, Technical University of Szczecin, Electrical Department, ul. Sikorskiego 37, 70-313 Szczecin, Poland

---This paper shows results obtained as a solution of "Eddy Current Benchmark Problem 3". The objective of the benchmark is optimization of eddy current probe designed for Inconel tube inspection. It was necessary to determine the optimal operating frequency and dimensions of the coil. In order to solve the problem a two-dimensional model was proposed and analyzed using finite element method (FEMLABR package). Application of the simplified two-dimensional model is acceptable if size of the coil is relatively small in comparison with the tube diameter. It was assumed, that the optimal design of the coil should provide a maximum current density in the area of hypothetical flaw in relation to a total current in the tube. During optimization process two constraints were assumed: a constant coil cross-section (number of turns) and a minimal value of lift-off. Intermediate results of the analysis, final solution and conclusions will be given in the full version of the paper.

Finite Element Modeling of the World Federation's Second MFL Benchmark Problem

---Zhiwei Zeng, Yong Tian, Satish Udpa, and Lalita Udpa, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824

---This paper presents results obtained by simulating the second magnetic flux leakage benchmark problem proposed by the World Federation of NDE Centers. The geometry consists of several notches machined on the internal and external surface of a rotating steel pipe that is placed between the poles of a magnet. The model calculates the radial component of the leaked field in the vicinity of notches. The nonlinear material properties of the ferromagnetic pipe are taken into account in simulating the problem. The velocity effects caused by the rotation of the pipe are, however, ignored for reasons of simplicity.

The World Federation's Electromagnetic Benchmark Problems, A Progress Report on Results Obtained to Date

---Satish S. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824-1226

---This paper summarizes the progress made to date in simulating the electromagnetic benchmark problems proposed by the World Federation of Nondestructive Evaluation Centers. Two sets of problems in each of the areas of eddy current and magnetic flux leakage NDE methods have been proposed to date by the Federation. The benchmark problems are inspired by issues faced in industry. This paper compares the simulation results obtained by research groups around the world. The results are also compared with experimental results in cases where they are available. Ideas for future benchmark problems will also be discussed.

Ultrasonic NDE Modeling–Analytical and Numerical Foundations

Lester W. Schmerr Jr.[1,2], Sung-Jin Song[3], and Alexander Sedov[4, 1]Center for NDE, Iowa State University, Ames, IA, 50011; [2]Dept. of Aerospace Eng., Iowa State University, Ames, IA, 50011; [3] School of Mech. Eng., Sungkyunkwan University, Suwon, Korea; [4]Dept. of Mech. Eng., Lakehead University, Thunder Bay, Ontario,Canada, P7B 5E1

---Ultrasonic models can serve as engineering tools for designing and optimizing ultrasonic NDE inspections and for estimating their performance. These models include models of the sound generation and propagation process (transducer beam models), models of the flaw scattering process, and overall system models that combine beam and flaw modeling in a self-consistent fashion to predict a measured voltage response. Here, we will review techniques that have been used to date for such models and compare analytical and semi-analytical approaches and numerical methods. In transducer beam modeling, for example, we will discuss the use of paraxial ray theory models, point source and plane wave superposition models, and finite and boundary element approaches. For flaw scattering, we will consider models based on the Born and Kirchhoff approximation as well as boundary element and finite element methods. We will also discuss the use of these models in overall ultrasonic system models that are based on general reciprocity principles.---This work was supported by the NSF Industry/University Cooperative Research program.

Ultrasonic Benchmarking: Past Progress and Future Goals

---R. B. Thompson, Iowa State University, Center for NDE, Ames, IA 50011

---As NDE simulation tools begin to find more widespread use in critical engineering applications, it is becoming increasingly important to quantify their accuracy. The long-range goal is to develop a suite of tools that can be used throughout the world to simulate the results of NDE measurements. However, in many simulations, various approximations are made to speed the computations or increase flexibility and user friendliness. It is therefore necessary to define the range of conditions over which particular models can be used with confidence. This paper summarizes an ultrasonic model benchmarking activity that is being conducted by the World Federation of NDE Centers. The first two phases of this activity involved the comparison of the predictions of a series of models for a set of benchmark problems involving well-defined experimental geometries and input signals. Those results will be reviewed. In many cases, the models were found to be in good agreement. However, regions were identified that require further attention. Lessons learned will be summarized and actions that have been taken will be discussed. The final step in qualifying a simulation tool for industrial use is a validation against experimental data. Plans for a set of validation experiments, to be conducted during the next year, will be summarized. Suggestions by the audience will be encouraged.

SPECIAL EVENING SESSION
BR A1

8:00 PM Future Directions in Sensors

---There is a growing interest in applications of embedded and integrated sensors to ensure the reliability of structural components. The Wednesday night discussion session will be designed to elucidate future directions and key issues. A panel will first present the views of different organizations on needs and opportunities, and this will be followed by a general audience discussion. The panel will include Vitali Rao, National Science Foundation; John Barnes, Air Force Research Laboratories; Bita Ghaffari, Ford Motor Company, and representatives of other organizations as dictated by their schedules. Each of these organizations is very interested in the sensors area, but each has a different mission and set of objectives. The session will be targeted at identifying the commonalities and differences in those needs and opportunities.

SESSION 22
GUIDED WAVES, MODELS, AND MEASUREMENTS
S. Ahmed, Chairperson
BR A1

8:30 AM **FE Modeling of Lamb Waves Propagation and Diffraction in Viscoelastic Composite Material Plate**
---B. Hosten and M. Castaings, Université Bordeaux 1, Laboratoire de Mécanique Physique, UMR C.N.R.S. 5469 351, Cours de la Libération 33405 – TALENCE Cedex, France

8:55 AM **On the Scattering and Mode Conversion of the A_0 Lamb Wave Mode at Circular Defects in Plates**
---P. Fromme, P. D. Wilcox[1], M. Lowe, and P. Cawley, Imperial College, Department of Mechanical Engineering, London SW7 2AZ, England; [1]Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1 TR, England

9:20 AM **Modeling the Excitation of Lamb and SH Waves by Shear Surface Tractions**
---P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom

9:45 AM **A Two Dimensional Model for Crack Sizing in Pipes**
---W. Luo and J. L. Rose, The Pennsylvania State University, Department of Engineering Science & Mechanics, University Park, PA 16802; H. Kwun, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78228

10:10 AM ***Coffee Break***

10:30 AM **Numerical Analysis of the Rayleigh Wave Dispersion Due to Surface Roughness**
---W. Hassan, Honeywell Engines, Systems, and Services, 1944 E. Sky Harbor Circle N., Phoenix, AZ 85034; M. Blodgett, Air Force Research Laboratory (AFRL/MLLP), 2230 10th Street, Suite 1, Dayton, OH 45433; S. Bondok, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Rhodes Hall, ML 0070, Cincinnati, OH 45221

10:55 AM **V(X) Ultrasonic Material Characterization Systems Employing Pairs of Line-Line and Line-Point Focused Transducers**
---S. A. Titov, R. G. Maev, University of Windsor, Centre for Imaging Research and Advanced Material Characterization, Department of Physics, Canada; A. N. Bogatchenkov, Institute for Biochemical Physics of Russian Academy of Science, 4 Kosigin St., Moscow, 117977, Russian Federation

11:20 AM **High-Sensitivity Air-Coupled Ultrasonic Imaging with the First-Order Symmetric Lamb Mode at Zero Group Velocity**
--- S. D. Holland and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:45 AM **Development of a Guided Lamb Waves Array for the Monitoring of Structural Integrity**
---P. Fromme, P. D. Wilcox[1], M. Lowe, and P. Cawley, Imperial College, Department of Mechanical Engineering, London SW7 2AZ, England; [1]Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1TR, England

12:10 PM ***Lunch***

FE Modeling of Lamb Waves Propagation and Diffraction in Viscoelastic Composite Material Plate

---Bernard Hosten and Michel Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469 351, Cours de la Libération 33405 - TALENCE Cedex, France

---Composite materials made of long fibers and polymeric matrix are anisotropic and viscoelastic. Phase velocity and attenuation of bulk modes are dependent on the direction. For industrial plate-like structures made of plies in various directions, the “in plane” anisotropy is usually small. However, the “out of plane” anisotropy is high since the matrix essentially controls the mechanical behavior in the normal direction. Then for modelling Lamb waves propagation, composed of bulk waves going up and down in the plate, it is mandatory to take into account the anisotropic viscoelasticity. The velocity of a bulk mode propagating in any direction is governed by the real part of the material stiffness and the attenuation by the imaginary part. It was proved experimentally that in a large frequency domain, these moduli can be measured and considered as constant with frequency, since the bulk mode attenuation is proportional to the frequency. A Finite Element code is used in a stationary mode to compute for each frequency the stress and displacement field in a plate made of anisotropic viscoelastic material. An appropriated spatial load at one of the plate boundary is applied to generate a Lamb wave in the plate. The number of computations is limited by the frequency content of the excitation (less than 50). Then the temporal response at any node of the plate can be reconstructed with inverse FFT. The velocity, attenuation and nature of the propagating modes can also be identified in the classical frequency/wave number representation. This paper will show the tremendous effect of the attenuation on the propagation of Lamb waves in a typical carbon epoxy material that is used in aerospace industry, even with frequencies (100-200 KHz) much lower than frequencies usually used in NDT. Preliminary results will present the interaction of the Lamb wave with an ellipse-shaped delamination and the limitations introduced by the attenuation to localize this defect.

On the Scattering and Mode Conversion of the A_0 Lamb Wave Mode at Circular Defects in Plates

---P. Fromme, P. Wilcox[1], M. Lowe, and P. Cawley, Imperial College, Department of Mechanical Engineering, London SW7 2AZ, England; [1]University of Bristol, Department of Mechanical Engineering, Queen’s Building, University Walk, Bristol BS8 1TR, England

---The integrity of structures can be monitored using permanently attached guided wave arrays. Fast inspection from a single sensor location is achieved by employing guided Lamb waves, propagating along the structure and monitoring the condition of large parts of the structure without the need for moving parts. The first antisymmetric Lamb wave mode A_0 is excited and measured using piezoelectric transducer elements. The sensitivity of the measurement method to typical structural defects is investigated. Many structures, e.g., offshore oil platforms, contain large plate-like components, which can suffer from severe corrosion during their service life. The corrosion damage often shows as large area thickness reduction and is modeled as a circular part-through hole. The scattering and mode conversion of the first antisymmetric Lamb wave mode A_0 at the defect is studied. The scattering properties are calculated numerically employing a three-dimensional finite element model and verified in laboratory experiments. Good agreement is found and the sensitivity of the guided wave measurement to this kind of defect can be predicted.

Modeling the Excitation of Lamb and SH Waves by Shear Surface Tractions

---Paul D. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom

---The guided wave field from weakly coupled guided wave transducers such as EMATs can be calculated using Huygens' principle if the field from a suitable point source can be modeled. Previously, accurate models for the excitation of Lamb waves from normal (out-of-plane) point and line forces have been used as the basis of Huygens' models for a variety of transduction methods such as the liquid wedge technique and inter-digital transducers. However, in order to apply Huygens' principle to model the guided wave field from a transducer that applies shear surface tractions, it is first necessary to obtain a model of the field from an in-plane point force. Unlike the guided wave field from an out-of-plane point force, which is axi-symmetric and contains only Lamb waves, the field from an in-plane point force is non-axi-symmetric and comprises both Lamb and SH waves. A method is presented that enables the non-axi-symmetric field from an in-plane point force to be predicted starting from the easily computable excitability of straight-crested Lamb and SH waves due to line sources in a plane strain model. The method is validated against finite element modeling and the predictions of the acoustic field from a number of EMAT geometries are presented and compared with experimental data.

A Two Dimensional Model for Crack Sizing in Pipes

---Wei Luo and Joseph L. Rose, Department of Engineering Science & Mechanics, The Pennsylvania State University, University Park, PA 16802; Hegeon Kwun, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78228

---Stress corrosion cracking (SCC) is a defect that can occur in the axial direction of a pipeline and result in catastrophic pipeline failures. Current technologies for pipeline inspection cannot size and characterize the SCC. Circumferential guided wave inspection is suggested. A simplified two dimensional model for crack sizing in pipes is presented. Boundary element modeling analysis and the normal mode expansion technique was used to study defect sizing and discrimination in a pipe-like structure. The theoretical results agree with the experiments in utilizing a magnetostrictive (MsS) technique for generating circumferential shear horizontal guided wave in pipe. There is a monotonic increase in amplitude with defect depth for a crack provided the crack axial length is larger than the beam width. An approximate 2-dimensional theory based on an axial scan for defects of axial length smaller than beam width has been developed that improves the defect depth estimate considerably.

Numerical Analysis of the Rayleigh Wave Dispersion Due to Surface Roughness

---Waled Hassan, Honeywell Engines, Systems, and Services, 1944 E. Sky Harbor Circle N., Phoenix, AZ 85034; Mark Blodgett, Air Force Research Laboratory (AFRL/MLLP), 2230 10th Street, Suite 1, Dayton, OH 45433; Samar Bondok, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Rhodes Hall, ML 0070, Cincinnati, OH 45221

---A Rayleigh wave describes the guided wave that can exist on the surface of a semi-infinite half-space. It is very well known that on smooth, flat surfaces of homogeneous elastic materials, Rayleigh waves are both dispersion- and attenuation-free. In contrast, surface roughness causes both dispersion and attenuation during Rayleigh wave propagation. Recent interest in applications like the measurement of compressive surface residual stresses due to shot peening using surface acoustic waves have brought into the spot light the adverse effects surface roughness might have on such measurements. Surface roughness produces significant dispersion of the Rayleigh wave used in the measurements. In certain materials, especially after thermal relaxation, it is believed this dispersion can overshadow the residual stress-induced velocity change and render that effect difficult to measure. This can be attributed to the large variation in the acousto-elastic coefficients for the different materials which otherwise would have similar surface roughness. Therefore an accurate understanding of the effect of surface roughness on the velocity of Rayleigh waves is of crucial importance for this application and others in which surface roughness is a natural by-product of the manufacturing processes used to produce the part. In this effort, the dispersion of Rayleigh surface wave on a 2D-randomly-rough surface is studied numerically using Wave2000Pro, a finite difference wave propagation simulation software. First the dispersion of the wave due to the discretization of the model is investigated to establish the accuracy of the model. Wave 2000Pro is then used to analyze the dispersion of Rayleigh wave propagating on the rough surface. The results of the numerical analysis are then compared to the theoretical model of Kosachev and Shchegrov.

V(X) Ultrasonic Material Characterization Systems Employing Pairs of Line-Line and Line-Point Focused Transducers

---S. A. Titov, R. Gr. Maev, Centre for Imaging Research and Advanced Material Characterization, Dept. of Physics, University of Windsor, Canada; A. N. Bogatchenkov, Institute for Biochemical Physics of Russian Academy of Science, 4 Kosigin St. Moscow, 117977, Russian Federation

---We present a new time-resolved, wide-aperture ultrasonic material characterization system based on the scanning of the receiving transducer in the x direction along the liquid-specimen interface. By processing the recorded V(x,t) data in the spatio-temporal and spectral domains, the parameters of the leaky guided waves and the reflectance function can be obtained. In comparison with the V(z) system, the geometry of the V(x) scheme does not restrict the scanning distance and the aperture angle. As well, the angular resolution of the new technique increases when the angle of incidence decreases. The measurement error's temperature coefficient is low as a result of the constancy of the propagation distance in the immersion liquid during translation of the receiver in the x direction. Due to the good temperature stability of the measurements, the temperature coefficient of the leaky wave's velocity can be measured by the V(x) technique. Pairs of line-line and line-point focused transducers were used in the experimental setup. It was shown that the system employing the pair of line-point focused transducers is less sensitive to the error of the mechanical adjustment of the ultrasonic unit.

High-Sensitivity Air-Coupled Ultrasonic Imaging with the First-Order Symmetric Lamb Mode at Zero Group Velocity

---Stephen D. Holland and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The well known zero in the group velocity of the first-order symmetric plate wave mode has been exploited in air-coupled ultrasonic imaging to obtain significantly higher sensitivity than can be gotten in conventional air-coupled scanning. Because of the minimum in the wavenumber-versus-frequency plot at the group-velocity zero, a relatively broad range of wavenumbers will couple into this first-order symmetric mode at nearly a constant frequency, greatly enhancing the energy in the mode. Then, because the group velocity vanishes at this point, the energy does not travel away from the insonifed region in the plate. The result is a substantial increase in sensitivity. We excite the mode with a broadband air-coupled transducer that is focussed to allow a 14-degree angular range of plane-wave components. By adjusting the temporal frequency to coincide with the zero group velocity point in the S1 mode, we are able to exploit the wide spatial frequency bandwidth of the focussed probe. With this new method, we have easily imaged a single layer of Scotch tape attached to a 6.4-mm thick Plexiglas plate.---This material is based on work supported by NASA under award NAG-1-029098.

Development of a Guided Lamb Waves Array for the Monitoring of Structural Integrity

---P. Fromme, P. Wilcox[1], M. Lowe, and P. Cawley, Imperial College, Department of Mechanical Engineering, London SW7 2AZ, England; [1]University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol BS8 1TR, England

---Many structures in the oil industry consist of large plate-like components, which can suffer from severe corrosion and the development of cracks during their service life. Constant, long-time monitoring of the structural integrity is performed using permanently attached remote sensors that run autonomously, i.e., independent of external energy supply, and transmit data about the condition of the structure wirelessly. Guided Lamb waves that propagate along the structure allow the fast inspection of large areas of a structure from a single sensor location. A self-contained, permanently attached array for the inspection of plates is designed and built. The array consists of a ring of piezoelectric transducer elements for the excitation and reception of the first antisymmetric Lamb wave mode A_0. The properties and coupling of the transducers is studied and optimized to achieve a high excitation amplitude and good measurement sensitivity. The development of the compact array device for the inspection of large areas with minimum power consumption, necessary for long term operation independent of external power sources, is described. The array operation and data processing schemes are shown and first measurement results are presented.

SESSION 23
FATIGUE CRACKS, DEFORMATION, AND BUCKLING
L. Schmerr, Chairperson
BR A3

8:30 AM **A Fundamental Study on Detection of Defects in the Web Gap Region of Steel Plate Girder Bridges by the Plate Wave Technique**
---H. Shirahata, Musashi Institute of Technology, Department of Civil Engineering, 1-28-1 Tamazutsumi Setagayaku, Tokyo 158-8557, Japan; L. Greimann, T. Wipf, and B. Phares, Iowa State University, Department of Civil and Construction Engineering, Ames, IA 50011; N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:55 AM **Ultrasonic Evaluation of Fatigue Damage**
---P. Bayer, L. Singher, and A. Notea, Quality Assurance and Reliability, Technion, Haifa, Israel

9:20 AM **Fatigue Crack Closure Analysis Using Nonlinear Ultrasound**
---M. Akino, T. Mihara, and K. Yamanaka, Tohoku Univerity, Department of Materials Processing, Aoba02, Aramaki, Aoba-ku, Sendai, Miyagi, Japan

9:45 AM **Effect of Thermal Stresses Along Crack Surface on Ultrasonic Response**
---I. Virkkunen and H. Hänninen, Helsinki University of Technology, Laboratory of Engineering Materials, Espoo, Finland; M. Kemppainen, Trueflaw Ltd., Espoo, Finland; J. Pitkänen, VTT Industrial Systems, Espoo, Finland

10:10 AM ***Coffee Break***

10:30 AM **Characterization of Surface-Breaking Tight Cracks Using Laser-Ultrasonic Shadowing**
---J.-P. Monchalin[1], M. Ochiai[2], D. Lévesque[1], A. Blouin[1], R. Talbot[1], and A. Fukumoto[2], [1]Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada; [2]Power & Industrial Systems R&D Centre, Toshiba Corporation, Yokohama, Japan

10:55 AM **Advanced Flaw Manufacturing**
---M. O. Kemppainen, Trueflaw Ltd., Espoo, Finland; J. Pitkänen, VTT Industrial Systems, Espoo, Finland; I. Virkkunen and H. Hänninen, Helsinki University of Technology, Department of Mechanical Engineering, Laboratory of Engineering Materials, Espoo, Finland

11:20 AM **On the Detection of Creep Damage in a Directionally Solidified Nickel Base Superalloy Using Nonlinear Ultrasound**
---J. Kang, J. Qu, A. Saxena, and L. Jacobs, Georgia Institute of Technology, Atlanta, GA 30332-0405

11:45 AM **Buckling of Aluminum Honeycomb Core and Its Effect on Ultrasonic Velocity**
---D. K. Hsu, V. Dayal, A. Harris, and J. J. Peters, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch***

A Fundamental Study on Detection of Defects in the Web Gap Region of Steel Plate Girder Bridges by the Plate Wave Technique
---H. Shirahata, Department of Civil Engineering, Musashi Institute of Technology, 1-28-1 Tamazutsumi Setagayaku, Tokyo 158-8557 Japan; L. Greimann, T. Wipf, and B. Phares, Department of Civil and Construction Engineering, Iowa State University, Ames, Iowa 50011; N. Nakagawa, Center for NDE, Iowa State University, Ames, IA 50011

---Torsion induced fatigue cracking in the web gap area is one of the most serious problems for steel plate girder bridges. In particular, a few decade old bridges are suffering from this problem, because those bridges have poor detail for such type of fatigue cracking. It is important to detect those fatigue cracks. For the detection of the fatigue cracks, periodical inspection is necessary. Typically, visual inspection has been applied. However, there are many inspection points and that is time consuming. In this study, application of the plate wave ultrasonic test was considered. The plate wave technique has been applied for pipe inspection because of its long range propagation characteristics. This study is focusing on monitoring of detection of fatigue cracks in the web gap area. As the first step, experiments on a girder specimen were conducted. Transducers were put on the web plate. A small hole was made on the web plate. Detectability of the small hole was investigated by comparing wave forms before and after making the hole. In order to estimate the change of wave forms quantitatively, deviation from no crack case was proposed. In the experiments, the influence of a stiffener on wave forms was also investigated.

Ultrasonic Evaluation of Fatigue Damage
---Peres Bayer, Liviu Singher, and Amos Notea, Quality Assurance and Reliability, Technion, Haifa, Israel

---Fatigue of materials is a common problem that affects all moving equipment. Despite the fact that most engineers and designers are aware of fatigue, many severe breakdowns of industrial plant and machinery still occur due to fatigue. In effect, it's been estimated that fatigue causes at least 80% of the failures in modern engineering components. From an operational point of view, the detection of fatigue damage, preferably at a very early stage, is a critically important consideration in order to prevent possible catastrophic equipment failure and associated losses. This paper describes the investigation involving the use of ultrasonic waves as a potential tool for early detection of fatigue damage. The parameters investigated were the ultrasonic wave velocities (longitudinal and transverse waves) and attenuation coefficient before fatigue damage and after progressive stages of fatigue. The experiments were performed in specimens of aluminum 7075-T651. Although comparatively small uncertainties were observed, the feasibility of utilizing the velocity of ultrasonic waves as a fatigue monitor was barely substantiated within actual research conditions. However, careful measurements of the ultrasonic attenuation parameter had demonstrated its potential to provide an early assessment of damage during fatigue.

Fatigue Crack Closure Analysis Using Nonlinear Ultrasound

---Masashi Akino, Tsuyoshi Mihara, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Aoba02, Aramaki, Aoba-ku, Sendai, Miyagi, Japan

---Nonlinear ultrasound is a promising tool for evaluating closed cracks which is difficult with the linear ultrasound. Recently, subharmonics was observed and explained either by a parametric or a forced vibration. However, because the crack was not completely closed, the behavior of crack was complicated and quantitative comparison between theory and experiment has not been achieved. We prepared a closed fatigue crack in an aluminum alloy by controlling the crack opening with in-situ monitoring of the crack tip echoes. When a tone burst of 6.4 MHz longitudinal waves was obliquely incident on the closed crack, a strong subharmonics at 3.2 MHz was observed. The intensity first increased as the crack closure was reduced by applying a tensile stress, took a maximum larger than the fundamental wave and then decreased moderately as the crack was further opened. The subharmonic intensity was theoretically explained by a displacement of output crack plane, which is low-pass-filtered due to the inertia when it is driven by vibrating asperities on the input crack plane at fundamental frequency.

Effect of Thermal Stresses Along Crack Surface on Ultrasonic Response

---Iikka Virkkunen and Hannu Hänninen, Laboratory of Engineering Materials, Helsinki University of Technology, Espoo, Finland; Mika Kemppainen, Trueflaw Ltd., Espoo, Finland; Jorma Pitkänen, VTT Industrial Systems, Espoo, Finland

---Artificial flaws can be manufactured by controlled thermal fatigue loading. The produced fatigue cracks can be introduced to a wide variety of materials with high location and size accuracy. This technology gives also a unique opportunity to monitor the ultrasonic response of a thermal fatigue crack during thermal loading. This paper reports FEM studies on the effects of different thermal load cycles on the ultrasonic response with different probes. A cracked AISI 304 stainless steel sample was loaded with different thermal load cycles. The load cycles are analyzed with finite element method (FEM), and the resulting strain distributions are resolved. The FE results are combined with ultrasonic signals from several probes and with video monitoring footage from the crack opening during the loading. The effects of thermal fatigue loads along the crack surface on the ultrasonic response are discussed.

Characterization of Surface-Breaking Tight Cracks Using Laser-Ultrasonic Shadowing

---Jean-Pierre Monchalin[1], Makoto Ochiai[2], Daniel Lévesque[1], Alain Blouin[1], Richard Talbot[1], Akira Fukumoto[2], [1]Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada; [2]Power & Industrial Systems R&D Centre, Toshiba Corporation, Yokohama, Japan

---A laser-ultrasonic method based on the shadowing effect is used for sizing and locating surface-breaking tight cracks in metals. The two laser spots are separated by a fixed distance to collect ultrasound propagating at about 45^{o} with respect to the surface. The laser spots are scanned along the same line across the path of cracks on the surface of a plate-like sample. The amplitude of the longitudinal or shear wave specularly reflected from the backwall is extracted from each signal to construct an amplitude profile. In the presence of a crack, the profile shows two regions of reduced amplitude due to shadowing of the direct or reflected beam from the backwall. The sharp amplitude drop and the gentle recovery observed are well predicted by a model of crack tip diffraction. The crack depth can be simply determined by considering only the immediate vicinity of the amplitude drop from either one of the two regions. Results will be shown on a stainless steel sample having a variable depth slot as well as on a sample containing actual surface-breaking tight cracks having widths of less than 0.03 mm.

Advanced Flaw Manufacturing

---Mika O. Kemppainen, Trueflaw Ltd., Espoo, Finland; Jorma Pitkänen, VTT Industrial Systems, Espoo, Finland; Iikka Virkkunen and Hannu Hänninen, Helsinki University of Technology, Department of Mechanical Engineering Laboratory of Engineering Materials, Espoo, Finland

---Advanced artificial flaw manufacturing method has become available. The method produces true fatigue cracks, which are representative of most real, service-induced cracks. The method is applicable to any shape or size of components and results only in a desired flaw without unwanted disturbances. Beneficial is, that the characteristics (e.g., fracture surface roughness, opening, residual stresses) of the produced crack can be controlled. The method allows production of single and separate cracks and different combinations of them. This paper introduces studies of the effects of different thermal fatigue loading cycles to crack opening and residual stress state as it is seen on the surface of the sample and in the ultrasonic signal. Measurements were performed in-situ, under dynamic thermal fatigue loading of a 20 mm long surface breaking crack in an AISI 304 type steel sample. Different ultrasonic techniques and probes were used in order to obtain a comprehensive picture of the relationship between dynamical behaviour of the crack and ultrasonic response. Results of the study clearly show how different thermal fatigue loading cycles affect the crack opening behaviour and obtained ultrasonic response. Control of crack growth, final state of crack opening and residual stress state are discussed in the paper.

On the Detection of Creep Damage in a Directionally Solidified Nickel Base Superalloy Using Nonlinear Ultrasound

---Jidong Kang, Jianmin Qu, Ashok Saxena, and Larry Jacobs, Georgia Institute of Technology, Atlanta, GA 303332-0405

---A limited experimental study was conducted to investigate the feasibility of using nonlinear ultrasonic technique for assessing the remaining creep life of a directionally solidified (DS) nickel base superalloy. Specimens of this alloy were subjected to creep testing at different stress levels. Creep tests were periodically interrupted at different creep life fractions to conduct transmission ultrasonic tests to explore if a correlation exists between the higher order harmonics and the accumulated creep damage in the samples. A strong and unique correlation was found between the third order harmonic of the transmitted wave and the exhausted creep life fraction. Preliminary data also show an equally strong correlation between plastic deformation accumulated during monotonic loading and the second harmonic of the transmitted ultrasonic wave while no correlation was found between plastic strain and the third order harmonic. Thus, the nonlinear ultrasonic technique can potentially distinguish between damage due to plastic deformation and creep deformation.

Buckling of Aluminum Honeycomb Core and Its Effect on Ultrasonic Velocity

---David K. Hsu, Vinay Dayal, Aaron Harris, and John J. Peters, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Aluminum honeycomb sandwiches are ubiquitous on light-weight aerospace structures. While in service such structures often suffer impact damage and require nondestructive evaluation for its degree of damage. In addition to visual assessment of the skin deformation, computer aided tap tester (CATT) was used to map out the lateral extent of the damage and the stiffness reduction caused by the impact. Air-coupled ultrasonic test (AC-UT) was also employed to image impact damage based on the large amplitude drop of the transmitted signal. To investigate the interior morphology of the buckled honeycomb core and its effects on the ultrasonic amplitude and velocity, a systematic study was made whereby the honeycomb core was compressed to various degrees of buckling. The transmitted signal amplitude and time-of-flight were measured as a function of percent deformation. The measured time-of-flight showed a dramatic lengthening with increasing degree of buckling. The time of flight was modeled in a transient finite element analysis of a buckled honeycomb cell wall. A 5 MHz single cycle load was applied on the simplified model of the buckled wall and the response recorded at the other end of the wall. The results show qualitative agreement with the experimental data.--This work was supported by the NSF Industry/University Cooperative Research program.

SESSION 24
X-RAY MODELING AND APPLICATION
T. Jensen, Chairperson
BR A2

8:30 AM **Computer Modeling of Digital X-Ray Detector Response**
---T. C. Jensen, J. N. Gray, and J. Xu, Iowa State University, Center for NDE, 1915 School Road, Ames, IA 50011

8:55 AM **Monte Carlo Simulation of Photon Transport Coupled to CAD Object Description**
---V. Zagonov*, M. Zhukovsky, and S. Podoliako, Keldysh Institute for Applied Mathematics, Moscow, Russia; G.-R. Tillack and C. Bellon, Federal Institute for Materials Research and Testing, Berlin, Germany

9:20 AM **A Novel Radiation Transport Algorithm for Radiography Simulations**
---F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:45 AM **Defect Imaging and Image Analysis with Modern X-Ray Computed Tomography**
---J. M. Wells, JMW Associates, 102 Pine Hill Blvd., Mashpee, MA 02649

10:10 AM ***Coffee Break***

10:30 AM **Micro X-Ray Fluorescence Imaging for Silicide Diffusion Coating Inspection**
---E. R. Doering, Rose-Hulman Institute of Technology, Department of Electrical and Computer Engineering, Terre Haute, IN 47803-3999; G. J. Havrilla, Los Alamos National Laboratory, Analytical Chemistry Sciences, Los Alamos, NM

10:55 AM **Phase-Contrast X-Ray Imaging for Nondestructive Evaluation of Materials**
---J.-Y. Kim, B. Zoofan, and S. I. Rokhlin, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

11:20 AM **The Effect of Lead Intensification Screens on Film: Modeling and Experiment**
---S. Wendt, J. N. Gray, and C. Zhou, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:45 AM **A Deterministic Approach to Brachytherapy Dosimetry and a Benchmark Problem Implementation**
---C. Zhou and F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch***

Computer Modeling of Digital X-Ray Detector Response

---Terrence C. Jensen, Joseph N. Gray, and Jiadong Xu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---A variety of new types of digital x-ray detectors are being used in inspection applications. It is often desirable to compare the relative performance of different detectors for a particular problem and choose the one that will produce the best results. We have developed computer simulation models that can be used to assist in this comparison. These models are used in conjunction with the general x-ray inspection simulation code (XRSIM) that was developed previously at CNDE. In this paper we describe a general procedure for determining the parameters needed to model a generic digital detector. We then show the results of applying this procedure to model several specific detectors such as amorphous silicon, storage phosphor plates, and image intensifier/CCD camera systems.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA048 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Monte Carlo Simulation of Photon Transport Coupled to CAD Object Description

---V. Zagonov*, M. Zhukovsky, and S. Podoliako, Keldysh Institute for Applied Mathematics, Moscow, Russia; G.-R. Tillack, and C. Bellon, Federal Institute for Materials Research and Testing, Berlin, Germany

---In transmission radiography, information about an object is obtained by irradiating the object and recording the transmitted radiation. The transmitted radiation consists of a primary and a scattered component. Conventional models count only for the primary component carrying the information about the object structure. The scattered radiation is considered as a homogeneous background and described as a built-up. But for quantitative radiation technique a detailed knowledge about the contribution of the scattering component is necessary. Monte Carlo transport methods are used to simulate the distribution of scattered radiation produced within engineered components. Because most of these components are complex in geometry a coupling of a CAD-based object description with Monte Carlo transport methods is developed. We review the implemented stochastic simulation scheme and compares the results with standard Monte Carlo codes like MCNP.---*The surviving authors wish to dedicate this paper to the memory of our co-author V. Zagonov.

A Novel Radiation Transport Algorithm for Radiography Simulations

---Feyzi Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---As in many fields, simulation of various NDE processes has started to gain acceptance in the NDE community. Introduction of more physics into simulations enabled by developments in the computer technology is making simulations more realistic with time. Performing more realistic simulations by taking advantage of more capable computing platforms are possible only through new algorithms that are more sophisticated in nature. In this work, we have developed a new algorithm that is capable of representing photon and charged particle fluxes through spherical harmonic expansions in a manner similar to well known discrete ordinates method with the exception that Boltzmann operator is treated through exact integration rather than conventional Legendre expansions. This approach provides a mean to include physics for higher energy regimes where there are additional physical mechanisms for photon interactions and charged particle interactions need to be taken into consideration.---This manuscript has been authored by Iowa State University of Science and Technology under Contract No. W-7405-ENG-82 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a nonexclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

Defect Imaging and Image Analysis with Modern X-ray Computed Tomography

---Joseph M. Wells, JMW Associates, 102 Pine Hill Blvd., Mashpee, MA 02649

---The detection, location and characterization of various defects within an opaque solid volume are of considerable engineering and quality assurance interest in many technological applications. However, destructive sectioning and polishing are expensive, time consuming and irreversible processes which precludes the further utilization of the subject object. Modern X-ray computed tomography techniques provide a unique nondestructive approach which creates a powerful 3D volumetric digital interrogation of substantial size engineering objects. Defects with significant density or x-ray absorption coefficients differences are discriminated, isolated and analyzed in situ apart from the surrounding matrix material. Various image reconstruction and visualization techniques are employed and discussed using several selected examples from recent ballistic damage studies.

Micro X-Ray Fluorescence Imaging for Silicide Diffusion Coating Inspection

---Edward R. Doering, Department of Electrical and Computer Engineering, Rose-Hulman Institute of Technology, Terre Haute, IN, 47803-3999; George J. Havrilla, Analytical Chemistry Sciences, Los Alamos National Laboratory, Los Alamos, NM

---Space Shuttle orbiter thrusters fabricated from C-103 niobium alloy rely on a fused chromium disilicide diffusion coating as protection from high-temperature oxidation. The coating consists of a surface nonprotective "pest layer" and a subsurface protective intermetallic diffusion layer. Prolonged thruster activity leads to spalling (flaking or chipping) of the pest layer, resulting in 0.1-0.2" diameter coating voids. Once detected, these voids must be analyzed to determine the integrity of the intermetallic diffusion layer, since the void could also have been caused by some other damage mechanism such as micrometeorite impact. Existing detection and analysis techniques are labor intensive, prone to error, and require contact with the coating, so alternatives are necessary. Micro X-ray fluorescence (MXRF) imaging is evaluated in this study as a potential non-contact NDE method to inspect the chromium disilicide coating. MXRF imaging, a relatively new technique to map the elemental composition of a surface at high spatial resolution (i. e., 40-50 micron spot size), creates a multispectral image that can be analyzed to detect coating voids and to quantify the coating materials remaining in the diffusion layer. Analysis of multispectral images collected from sectioned thruster samples confirms that MXRF imaging is a viable detection and quantification method for the thruster coating inspection problem.

Phase-Contrast X-Ray Imaging for Nondestructive Evaluation of Materials

---Jin-Yeon Kim, Bahman Zoofan, and Stanislav I. Rokhlin, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---Practical aspects of X-ray image enhancement utilizing phase-contrast effects are considered. Diffraction field of X-rays radiated from a small finite X-ray source by an object is simulated numerically, and the effects of geometrical and material parameters on the X-ray phase-contrast image are investigated. Optimization of the experiment method to achieve phase contrast in hard X-ray regime is described for applications to nondestructive evaluation of materials. Experimental phase-contrast images of porosity obtained with a 5 micron microfocal X-ray source are compared with those from computer simulation. The phase-contrast and absorption-contrast images are compared demonstrating quantitative enhancement of image quality. The phase-contrast X-ray imaging provides enhanced contrast, improved edge definition and X-ray phase information.

The Effect of Lead Intensification Screens on Film: Modeling and Experiment

---S. Wendt, J. Gray, and C. Zhou, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---A physics-based, lead screen model has been developed. The dominant factor in producing the film density intensification is from photoelectrons ejected from a thin layer of lead near the film. The Compton electrons and the lead fluorescence x-rays contribute only a small component. We find that the optimal lead screen thickness increases from 1 mils to 3 mils depending upon the energy of the photons. This is much less than the traditional practice of a 5 mils front screen and 10 mils back screen. The model computes the intensifying effect of a lead screens placed in front or in back of a sheet of radiographic film and includes the strong energy dependent effects contributing to the intensification. The lead screen model is independent of film type, so the user can select any type of film previously characterized and any combination of lead thickness for the front and back screens. The model uses energy dependent x-ray photon absorption cross-sections to compute the production of electrons in the lead. An off line Monte Carlo calculation is used to determine energy dependent electron penetration in the lead and the film. The model calculates electron attenuation in the film emulsion, the film substrate and both front and back lead screens and determines the intensification effect as a function of the energy deposited in the film. For model validation, lead screen intensification was studied with x-ray generator settings ranging from 75 to 320 kvp using various thicknesses of aluminum and iron attenuators to filter the x-ray beam. A high precision motion control system coupled with a high purity germanium detector was used to study the energy spectra.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order # IA004 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program through the Airworthiness Assurance Center of Excellence.

A Deterministic Approach to Brachytherapy Dosimetry and a Benchmark Problem Implementation

---Chuanyu Zhou and Feyzi Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Interstitial brachytherapy employs isotopes that emit relatively low energy photons. The physics involved in that energy range are basically the same as the physics encountered in the industrial radiography and the diagnostic radiology with the exception of fluorescence radiation. Our computational algorithms developed for the industrial radiography has recently been successfully adapted to the diagnostic radiology dosimetry and brachytherapy dosimetry. In the recent stages of the project, we have included the fluorescence radiation physics and parallel computation to the standing algorithms so that cases with all types of implant seeds for multiple seed configurations can be addressed for dosimetry purposes. In addition to the algorithms enabling fluorescence radiation and parallel processing, we will also show the dosimetry results for a benchmark problem that has been designed for certification of the brachytherapy centers.---This work was supported by the NSF Industry/University Cooperative Research program.

SESSION 25
IN PROCESS NDE
P. Panetta, Chairperson
BR A4

8:30 AM **Inverse Problem Solution to Find Real-Time Temperature Distribution Inside the Spot Weld Medium Using Ultrasound Time of Flight Methods**
---A. M. Chertov and R. G. Maev, Univerity of Windsor, Centre for Imaging Research and Advanced Material Characterization, Department of Physics, Canada

8:55 AM **Non-Contact Ultrasound for Industrial Process Monitoring of Moving Objects**
---S. A. Nielsen, A. Bardenshtein, and A. M. Thommesen, FORCE Technology, Sensor & NDE Innovation, Park Allé 345, DK-2650 Brøndby, Denmark; B. Stenum, Risoe National Laboratory, Optics and Fluid Dynamics Department, Frederiksborgvej 399, DK-4000 Roskilde, Denmark

9:20 AM **Ultrasonic Spectrometers for On-line Monitoring of Colloid and Emulsion Processes**
---R. E. Challis, A. K. Homes, and A. Kalashnikov, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham, NG7 2RD, United Kingdom

9:45 AM **An All-Optical Ellipsometric System**
---L. Singher and L. Boim, Quality Assurance and Reliability, Technion, Haifa, Israel

10:10 AM ***Coffee Break***

10:30 AM **Automatic Inspection Eddy Current System for the Determination of the Aging Level of an Austenitic Stainless Steel Using a Fuzzy C-Means Algorithm**
---C. A. Souza, Jr., I. C. Silva, and J. M. A. Rebello, Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering, Rio de Janeiro, RJ, Brazil; T. L. Silveira, Federal University of Rio de Janeiro, Department of Mechanical Engineering, Rio de Janeiro, RJ, Brazil

10:55 AM **Generic Representation of Cure Monioring Data Using the Time-Temperature-Transformation (TTT) Diagram: Equivalence Between Dielectric and Ultrasonic Properties**
---M. E. Unwin and R. E. Challis, University of Notingham, School of Electrical and Electronic Engineering, University Park, Nottingham, NG7 2RD, United Kingdom

11:20 AM **Ultrasonic Assessment of Thermoset Cure: Variations in the Macromolecular Structure Due to Variations in Thickness**
---M. E. Unwin and R. E. Challis, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham, NG7 2RD, United Kingdom

11:45 AM **Void Detection in Foam with Pulsed Terahertz Frequency Electromagnetic Waves**
---W. P. Winfree and E. I. Madaras, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681-2199; D. Zimdars, J. White, and S. Williamson, Picometrix Inc., Ann Arbor, MI 48103

12:10 PM ***Lunch***

Inverse Problem Solution to Find Real-Time Temperature Distribution Inside the Spot Weld Medium Using Ultrasound Time of Flight Methods

---A. M. Chertov and R. Gr. Maev, Centre for Imaging Research and Advanced Material Characterization, Dept. of Physics, University of Windsor, Canada

---The scope of this research is to investigate specific physical mechanisms of ultrasonic beam propagation through the resistance spot weld area during the welding process. The ultimate goal of such technique is to obtain a dynamic picture of the temperature distribution during the welding process, and based on that result, to evaluate the structure distribution of the acoustical beam propagation in such three dimensional non-homogeneous mediums. In the experimental setup, a series of short acoustical pulses are being sent through the welded area during the welding process. The time needed for the signal to pass through the joint and reach the receiver changes in proportion with the degree of heating. This is caused by the change of elastic properties together with thermal expansion of the medium. As the sound velocity becomes known for the wide range of temperatures, the system could be used as a good thermal sensor. To realize this idea, numerical models of temperature fields in the weld, and the wave propagation through the weld, are obtained. These models enable us to solve the inverse problem of finding the temperature distribution in the spot weld using just one experimentally obtained value - the time of flight of the acoustical wave. The application aspects of this method will be discussed for further development of ultrasonic NDE algorithms of resistant spot weld quality inspection.

Non-Contact Ultrasound for Industrial Process Monitoring of Moving Objects

---Steen Arnfred Nielsen, Alexander Bardenshtein, and Anne Marie Thommesen, FORCE Technology, Sensor & NDE Innovation, Park Allé 345, DK-2650 Brøndby, Denmark; Bjarne Stenum, Risoe National Laboratory, Optics and Fluid Dynamics Department, Frederiksborgvej 399, DK-4000 Roskilde, Denmark

---Laser ultrasound (LU) is a promising technology for remote, non-contact inspection of material characteristics and defects. In this technique, a pulsed laser is used to generate ultrasonic modes in the material, and an optical interferometer or air coupled sensor is used to detect the ultrasonic pulse after it has propagated through the material. LU has a number of unique applications compared with traditional transducers: the high bandwidth of the laser-generated pulses enhances spatial resolution and provides more reliable defect detection compared with traditional ultrasonic techniques. In this paper, different types of discontinuities in steel specimens have been studied by means of laser-generated ultrasound. The defects are located by their reflections of the laser-generated ultrasound. Different types of defects have been studied in detail in order to optimize the configuration for LU inspection. Since LU is a non-contact technique, it allows inspection of moving objects. Studies on moving specimens have shown that this arrangement can be used on industrially rough surfaces at relatively high velocities with an improved signal-to-noise ratio (SNR). At even higher velocities, SNR decreases due to speckle noise.

Ultrasonic Spectrometers for On-line Monitoring of Colloid and Emulsion Processes

---R. E. Challis, A. K. Holmes, and A. Kalashnikov, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham, NG7 2RD, United Kingdom

---Ultrasonic spectrometry has potential to monitor colloid and emulsion processing on-line in industrial plant. A wealth of theoretical formulations are available which give reasonable if not good simulations of compression wave propagation in particulate mixtures. Bench top spectrometers are in use in many laboratories world wide, some being custom-built and some being established commercial products. However, the take-up of ultrasonic techniques to monitor chemical processes has been relatively slow due to uncertainties in the techniques for the design of whole systems. This paper describes the design of a group of industrial spectrometers which have been used on pipework on process plant. Designs are optimized in relation to the nature of the materials to be monitored, the physical constraints associated with process pipework, and the signal to noise performance of associated electronic equipment. The prospects for on-line colloid particle sizing are investigated on the basis of scattering theory, showing what may or may not be measurable within the constraints of available bandwidth. We present an electronic system for industrial use which enables at-a-distance monitoring of colloidal phenomena in industrial plant. These developments provide the basis for effective real-time on-line measurement which will pave the way to integrated process monitoring and control schemes.

An All-Optical Ellipsometric System

---Liviu Singher and Leonid Boim, Quality Assurance and Reliability, Technion, Haifa, Israel

---A new ellipsometric configuration suitable for in-situ studying of fast processes (chemical-mechanical planarization - CMP, film deposition, etc.) is presented. This tool was developed for thin film physical properties measurements by means of optical ellipsometry. The present configuration eliminates the use of mechanically rotating components during the measurement, therefore providing a high measurement speed and accuracy. CMP, one of the basic technological processes in the semiconductor industry, is presently the process of choice for integrated circuit (IC) manufacturers when polishing interlevel oxide layers on silicon wafers to achieve a certain planarity. The use of an automatic technique for in-situ monitoring of the CMP process, will enhance the productivity and reliability of both the process and equipment. A Zeeman laser based ellipsometry is proposed for the implementation of in-situ thin film properties measurement. A laboratory model was assembled and the ellipsometric parameters of industrial sample (Si film-free, SiO2 on Si, and SiO2 on Al) were measured. The comparison between the experimental results and the computed ellipsometric parameters shows good agreement up to an error of the order of 2%. In conclusion, this ellipsometric system is free of any moving parts. This allows it to be integrated with the CMP tool for in-situ automatic accurate process control.

Automatic Inspection Eddy Current System for the Determination of the Aging Level of an Austenitic Stainless Steel Using A Fuzzy C-Means Algorithm

---Carlos A. Souza Jr., Ivan C. Silva, and João M.A. Rebello, Department of Metallurgical and Materials Engineering, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil; Tito L. Silveira, Department of Mechanical Engineering, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil

---High chromium and nickel austenitic stainless steel tubes are commonly used in furnaces in the petrochemical industry. High stress level and high temperatures give origin to creep cracks which are usually detected by conventional eddy current techniques. Chromium carbide precipitation takes place and its volume fraction gradually increases with time, a process usually known as aging. Due to its ferromagnetic nature, this precipitation may change locally the microstructure homogeneity of the austenitic matrix, and disturb the eddy current signal, leading to false indications frequently misinterpreted as cracks. In the present work a method is proposed to separate tubes with different levels of aging. Eddy probe scans were performed in tubes free of cracks, exposed to different times at high temperatures, in which the carbide volume fraction was determined by conventional metallographic means. These scans give for each point along the tube surface the value of the electrical resistance and magnetic inductance. The whole assembly of points obtained from tubes with different degrees of aging is given to a Fuzzy C-Means which is a non supervised algorithm capable to separate the points in groups following the similarity of the values it contains. In a first step the algorithm separate the assembly in only two distinct group of high and low level of aging. Afterwards, tubes with intermediate levels of aging were also successfully identified.

Generic Representation of Cure Monitoring Data Using the Time-Temperature-Transformation (TTT) Diagram: Equivalence Between Dielectric and Ultrasonic Properties

---Marion E. Unwin and Richard E. Challis, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham, NG7 2RD, United Kingdom

---The assessment of the cure of thermosets is important for process and quality control in the manufacture of composite components and adhered structures, particularly in the automotive and aerospace industries. The final properties of a thermoset depend greatly on the particular cure schedule it has been subjected to. It has been shown that ultrasonic spectroscopy can be used to follow the macromolecular development of a thermoset and identify the property changes that occur due to changes in the process conditions. As an NDE technique it could easily be applied in an industrial environment, however, the interpretation of the bulk properties measured by ultrasound in terms of the molecular structure is still at an early stage. Dielectric cure monitoring techniques on the other hand, allow more detailed analysis of the solidification process. In this paper we utilize the TTT diagram as a generic format for cure monitoring data. The cure of an epoxy adhesive has been studied over a wide range of temperatures using both ultrasonic and dielectric techniques. Data from both methods have been mapped onto TTT diagrams to enable close comparison to be made between the mechanical and electrical property changes during cure. The equivalence between the mechanical and electrical phenomena observed will be discussed.

Ultrasonic Assessment of Thermoset Cure: Variations in the Macromolecular Structure Due to Variations in Thickness

---Marion E. Unwin and Richard E. Challis, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham, NG7 2RD, United Kingdom

---It is well known that the final properties of a thermoset material depend greatly on the temperature and duration of the cure process, and also on its exact chemical composition. To maintain quality and ensure safety in the many applications of thermosets, cure-monitoring and post-cure assessments of these materials are essential. It has been shown that ultrasonic spectroscopy can be used to track the cure process and to identify the changes in the final macromolecular structure that are due to changes in the process conditions. However, another important parameter has been identified on which the final cure state depends. Samples of epoxy adhesive that have been subjected to identical cure conditions show significant differences in their final cure state due to thickness. In this paper we present results showing the variations in the ultrasonic properties of several thermosets due to variations in sample thickness. Ultrasonic measurements have also been carried out to monitor the development of the macromolecular structure during cure in order to identify the origin of this thickness dependence. Comparisons have then been made with measurements of the magnitude of the exotherm and a number of possible explanations will be presented.

Void Detection in Foam with Pulsed Terahertz Frequency Electromagnetic Waves

---William P. Winfree and Eric I. Madaras, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681-2199; David Zimdars, Jeff White, and Steve Williamson, Picometrix Inc, Ann Arbor, MI

---An emerging technology that may have broad application for quantitative evaluation of critical materials and structures is electromagnetic waves at high frequencies. The short wavelengths of these terahertz pulses make them ideal for imaging flaws in dielectric materials. This paper examines the application of terahertz pulses for flaw detection in dielectric foams. Of particular interest is the detection of voids, significantly larger than the median cell size of the foam, encapsulated in the foam or at the interface between the foam and a metal backing. The technique is shown to be capable of imaging small subsurface voids through as much as 20 cm of foam. Methods for reducing the temporal responses of the terahertz pulses to improve flaw detection and yield quantitative characterizations of the size and location of the flaws are discussed.

SESSION 26 – POSTERS

EC, MAGNETIC AND THERMAL NDE MODELING, ARRAYS, POD IMAGING, X-RAYS TOMOGRAPHY, SIGNAL PROCESSING, RESIDUAL STRESS, AND NEW SENSORS

Exhibit Hall

1:30 PM

EC, Magnetic and Thermal NDE Modeling

Electric Potential Based on Coulomb's Force Behind Eddy Current Testing
---H. Hoshikawa, K. Koyama, and Y. Marumo, Hihon University, Izumicho Narashino, Chiba 275-8575, Japan

BEM-FEM Coupling and Small-Flaw Approximation for Magnetic Flux Leakage and Magnetic Particle Inspection NDE
---Y. Melikhov, S.-J. Lee, J. Lee, D. C. Jiles, M. Garton, L. Brasche, and R. Lopez, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

Metal-Loss Defect Parameterization Using Magnetic Flux Leakage Signals from Pipeline Inspection
---V. P. Lunin and V. A. Barat, Moscow Power Engineering Institute (TU), Electrical Engineering and Instrocopy Department, 14 Krasnokazamennaya, 111250 Moscow, Russia

Model-Based Investigation on the Behavior of ECT Signals According to the Changes in Geometry and Material Property of a Steam Generator Tube
---Y. H. Kim, S.-J. Song, and J.-S. Huh, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; J.-H. Han, Korea Atomic Energy Research Institute, Daejon, Korea; Y.-H. Choi, Korea Institute of Nuclear Safety, Daejon, Korea

Modeling of Magnetic Forces for Investigation of Magnetic Particles Around a Defect
---J. Lee, S.-J. Lee, Y. Melikhov, D. C. Jiles, M. Garton, R. Lopez, and L. Brasche, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

Pulsed Magnetic Flux Leakage and Eddy Current Sensor for Crack Detection and Material Characterization
---G. Y. Tian, A. Sophian, and D. Taylor, The Unversity of Huddersfield, Queensgate, Huddersfield HD1 3DH, United Kingdom

Crack Growth Characterization Using Barkhausen Noise Measurement
---H. N. Singh, P. Kotak, and K. C. Sahoo, Post Irradiation Examination Division, Bhabha Atomic Research Centre, Mumbai, 4000085, India

3D Finite Element Modeling for Simulating Remote Field Flaw Detection in Magnetic Steam Generator Tubes
---O. Mihalache, K. Yokoyama, M. Ueda, Takuya Yamashita, International Cooperation and Technology Development Center, ISI System Development Group, Japan Nuclear Cycle Development Institute, 1, Shiraki, Tsuruga-shi, Fukui-ken, Japan

Inverse Problem of Thermal NDT
---O. V. Lebedev and V. G. Avramenko, Moscow State University, Physics Department, Technical Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, Lusinovskaya Street, 62, Moscow, 116162, Russia; O. N. Budadin and E. V. Abramova, Technological Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, Moscow, Russia

Arrays, POD Imaging

Leak Detection and Location in Long-Duration Spacecraft Using Structure-Borne Noise
---R. Roberts[1], D. E. Chimenti[2], and M. Strei[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road; [2]Iowa State University, Center for NDE and Aerospace Engineering Department, Ames, IA 50011

Laser-Based Ultrasonic Tomographic Imaging of Power Metal Compacts
---H. Bian, Y. Shi, and J. L. Rose, Pennsylvania State University, Engineering Science and Mechanics, 212 Earth and Engineering Sciences Building, State College, PA 16802

Guided Wave Helical Ultrasonic Tomography of Pipes
---M. K. Hinders and K. R. Leonard, College of William & Mary, Applied Science Department, Williamsburg, VA 23187-8795

Toward Active Monitoring of Piping Using Ultrasonic Guided Wave
---J.-S. Park, Y. H. Kim, and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; J. H. Kim and H. S. Eom, Korea Atomic Energy Research Institute, Daejon, Korea; K.-H. Lim, Woosuk University, Cheonjoo, Korea

Performance Comparison of Conventional, Multi-Zone, and Phased Array Ultrasonic Inspection for 5" Diameter Ti-6Al-4V and Waspaloy Billets
---W. Hassan, Honeywell Engines, Systems, and Services, 1944 E. Sky Harbor Circle N., Phoenix, AZ 85034; A. Kinney and J. Schraan, Honeywell Engines, Systems, and Services, 111 S. 34th Street, M/S 503-118, Phoenix, AZ 85034; M, Keller, GE Aircraft Engines, Quality Technology Center, 10270 St. Rita Lane, Cincinnati, OH 45215

Compensating for Attenuation Differences in Ultrasonic Inspections of Titanium-Alloy Billets
---F. J. Margetan and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; M. Keller, GE Aircraft Engines, 10270 St. Rita Lane, Cincinnati, OH 45215; W. Hassan, Honeywell Engines, Systems, and Services, 1944 East Sky Harbor Circle N., Phoenix, AZ 85034

Ultrasound Excited by a Pulsed Thermal Source for Two Layers Sample
---J. He, X. R. Zhang, J. C. Chen, Nanjing University, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China; Y. Y. Huang, and D. C. Xian, Synchrotron Radiation Laboratory, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Development of New Robust High Power Ultrasonic Tone Burst Pulser and Receiver System
---M. McKenna, B. B. Chuck, A. Bernier, Jr., M. A. Ragosta, and G. Petersen, RITEC, Inc., 60 Alhambra Road, Suite 5, Warwick, RI 02886-1442

Development of a Fieldable Air-Coupled Ultrasonic Inspection System
---D. J. Barnard, J. J. Peters, and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Improvements in Guided Wave Inspection by Using EMATs
---G. A. Alers, EMAT Consulting, 1328 Tanglewood Drive, San Luis Obispo, CA 93401; R. B. Alers and J. J. Boyle, Sonics Sensors of EMAT Ultrasonics, Inc., San Luis Obispo, CA 93401

X-Rays Tomography

Damage Assessment with Modern X-Ray Computed Tomography – Part I Overview of Defect Imaging and Analysis with XCT
---J. M. Wells, JMW Associates, 102 Pine Hill Blvd., Mashpee, MA 02649

Damage Assessment with Modern X-Ray Computed Tomography – Part II Quantification of Damage Fraction in 3D XCT
---J. M. Wells, JMW Associates, 102 Pine Hill Blvd., Mashpee, MA 02649

Quantifying Aging Aircraft Hidden Corrosion by Using Multi-Modal NDI
---Z. Liu, D. S. Forsyth, S. Safizadeh, and A. Fahr, Institute for Aerospace Research, National Research Council Canada, Montreal Road 1191, Building M-14, Ottawa, Ontario, K1A0R6, Canada; B. A. Lepine, AECL, Inspection, Monitoring and Dynamic Branch, STN43, Chalk River Laboratories, Chalk River, Ontario, K0J 1J0, Canada

Development of Continuing Education Courses for Nondestructive Evaluation—The Use of Tutorial Simulators
---J. N. Gray, Iowa State University, Mechanical Engineering, Ames, IA 50011

Development of a High-Resolution CT System and 3D Data Visualization Tool
---J. Zhang, C. Zhou, T. Jensen, and J. N. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Signal Processing

A Novel Denoising Approach Based on Multiresolution Thresholding and Its NDT Application
---L. Li, W. Cheng, K. Tsukada, and K. Hanasaki, Kyoto University, Department of Earth Resources Engineering, Graduate School of Engineering, Kyoto, Japan

The Features Detection of the Small Rigidity Faults of Rotary Machine Elements
---N. I. Bouraou, Y. V. Sopilka, and A. G. Protasov, National Technical University of Ukraine “Kiev Politechnical Institute” (NTUU”KPI”), Department for Nondestructive Testing, Kiev, Ukraine

A Statistical Model for Eddy-Current Defect Signals from Steam Generator Tubes
---A. Dogandzic and P. Xiang, Iowa State University, Department of Electrical and Computer Engineering and Center for NDE, Ames, IA 50011

Flaw Detection in Correlated Noise
---A. Dogandzic and N. Eua-Anant, Iowa State University, Department of Electrical and Computer Engineering and Center for NDE, Ames, IA 50011

Comparative Study of Hardware and Software Methods for RF Signal Improvement
---G. Prodan, P. Petculescu, and Z. Remus, Ovidius University, Department of Physics, Mamaia Avenue, No. 124, Cod 8700, Constanta, Romania

Residual Stress

Residual Stress Assessment in Surface-Treated Metals by Laser-Ultrasonic Spectroscopy
---A. Ruiz and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221

Electromagnetic Detection of Stress Gradients at the Surfaces of Metals
---W. F. Schmidt, University of Arkansas, Mechanical Engineering Department, Fayetteville, AR 72701; O. H. Zinke, International Validators, Inc., 817 North Jackson, Fayetteville, AR 72701

Ferromagnetic Resonance Method for Residual Stress-Stain Monitoring
---B. Belyaev[1,2], Y. Bulbik[1], A. Leksikov[2], and I. Kraus[3], [1]UNESCO Chair "New Materials and Technologies" at Krasnoyarsk State Technical University, Krasnoyarsk, Russia; [2]Institute of Physics, Siberian Division, Russian Academy of Sciences, Krasnoyarsk, Russia; [3]Czech Technical University in Prague, Czech Republic

Evaluation of Stress Distribution in Magnetic Materials Using a Magnetic Imaging System
---C. C. H. Lo, J. A. Paulsen, and D. C. Jiles, Iowa State University, Center for NDE and 205 Metals Development, Ames, IA 50011

Magnetic Nondestructive Investigation of Ferromagnetic Alloys Subjected to Stress and Fatigue
---Y. Melikhov, C. C. H. Lo, and D. C. Jiles, Iowa State University, Center for NDE and 205 Metals Development, Ames, IA 50011

New Sensors

Optoacoustic Systems for Subsurface Materials Characterization
---G. N. Maguluri, L. Sui, R. A. Roy, and T. W. Murray, Boston University, Aerospace and Mechanical Engineering Department, 110 Cummington Street, Boston, MA 02215

Signal Processing Numerical Simulation for Charge Transfer Sensors
---Y. Bulbik[1,2], and I. Chemykh[2], [1]UNESCO Chair "New Materials and Technologies" at Krasnoyarsk State Technical University, Krasnoyarsk, Russia; [2]Siberian Aerospace University, Krasnoyarsk, Russia

Development of Piezoelectric Acoustic Sensors
---A. Ghoshal, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, 3B East Taylor Street, Building 1230B/Room 190, Hampton, VA 23681-2199; W. H. Prosser, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, 3B East Taylor Street, Building 1230B/Room 185, Hampton, VA 23681-2199; B. M. Copeland, NASA Langley Research Center, MS 386, 6A Langley Boulevard, Building 1232A/Room 103C, Hampton, VA 23681-2199

New Magnetostrictive Materials for Use as a Magnetic Stress Sensor for Nondestructive Evaluation
---J. A. Paulsen, A. P. Ring, C. C. H. Lo, J. E. Snyder, and D. C. Jiles, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:10 PM ***Coffee Break***

Electric Potential Based on Coulomb's Force Behind Eddy Current Testing

---Hiroshi Hoshikawa, Kiyoshi Koyama, and Yu Marumo, Nihon University, Izumicho Narashino, Chiba 275-8575, Japan

---The authors indicate in this presentation that electric potential plays a major role in inducing eddy current around discontinuities in eddy current testing. Since eddy current testing detects discontinuities by picking up the change of the eddy current circulation, it is very important to know how the eddy current circulation changes with discontinuities. However, little has been studied about what changes the eddy current. It is apparent that the induction field by the exciting coil does not cause the eddy current to circulate avoiding discontinuities because the field is basically parallel to the coil windings and does not force the eddy current to circulate in any other direction. Thus other field than the induction field is needed in inducing eddy current around discontinuities. If the test coil and test material are arranged axi-symmetrically, the ohmic potential drop by the large eddy current cancels out the induction field and there exists no electric potential. When a discontinuity in the material decreases the eddy current, electric potential builds up as the sum of the difference between the induction field and the ohmic potential drop. The building up of the electric potential is considered as follows. The electric charges are conveyed as eddy current by the induction field and stagnate around discontinuities where the eddy current gets smaller. The local electric charges have same polarity and repel each other based on Coulomb's force around the discontinuities. The presence of electric charges in conducting material means electric potential because the charges are accumulated as the work against Coulomb's force done by induction field. The posters will show the electromagnetic theory and some results of eddy current ant electric potential obtained by finite element analysis.

BEM-FEM Coupling and Small-Flaw Approximation for Magnetic Flux Leakage and Magnetic Particle Inspection NDE

---Yevgen Melikhov, Seong-Jae Lee, Junyoul Lee, David C. Jiles, Michael Garton, Lisa Brasche, and Rick Lopez, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

---Detection of near surface defects, including their position and sizes, can be achieved through magnetic flux leakage (MFL) and magnetic particle inspection (MPI). The results can be simulated using combined boundary element modeling and finite element modeling (BEM-FEM). BEM-FEM coupling solves 3D electromagnetic problems numerically and requires finite "volume" mesh construction for specific regions only, and therefore reduces significantly sizes of computational matrices comparing with pure 3D FEM. For practical applications, when the position of the crack is not known, the application of the "small-flaw" approximation is possible. That is the 3D electromagnetic problem is solved by BEM-FEM for a "free-of-defects" part and small defects are assumed to give a perturbation to the signal. Current work describes this technique in detail. The algorithm for BEM-FEM coupling (3D case, nonlinear magnetic materials) is briefly mentioned. Whereas, assumptions for using a "small-flaw" approximation and an algorithm for its application in MFL and MPI are explained in detail. The main part of the work was devoted to verification of the "small-flaw" approximation, namely, comparing it to the calculation of the defect-in-part case. Application of the "small-flaw" approximation in MPI is also compared with 2D MPI-FEM algorithm, which will also be presented at this conference.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA051 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Metal-Loss Defect Parameterization Using Magnetic Flux Leakage Signal from Pipeline Inspection

---Valery P. Lunin and Vera A. Barat, Moscow Power Engineering Institute (TU), Electrical Engineering and Instroscopy Department, 14 Krasnokazamennaya, 111250 Moscow, Russia

---Magnetic flux leakage (MFL) technique is a widely used nondestructive testing method for inspecting ferromagnetic oil/gas pipelines. Parameterization of metal-loss defects, mainly due to corrosion, is extremely important for organized maintenance of these pipelines. Analysis of MFL inspection data is a very difficult task which requires a huge amount of work by experienced operator. This is time consuming and quite expensive, therefore MFL automatic analysis system is needed to effectively aid the analysts. The quantitative automatic system was successfully developed and implemented including data preprocessing, classification and parameterization components. A number of experiments were performed on a test pipe having metal-loss defects of different shapes and sizes. Comparing the results from these experiments with model-based obtained is presented too. It was found to meet industry specifications for depth prediction with accuracy of +/- 15% pipewall thickness.

Model-Based Investigation on the Behavior of ECT Signals According to the Changes in Geometry and Material Property of a Steam Generator Tube

---Young H. Kim, Sung-Jin Song, and Jin-Soo Huh, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; Jung-Ho Han, Korea Atomic Energy Research Institute, Daejon, Korea; Young-Hwan Choi, Korea Institute of Nuclear Safety, Daejon, Korea

---Eddy current testing is periodically performed to detect defects grown in steam generator tubes during the in-service inspection of nuclear power plants. The interpretation of the test signals is known as a truly difficult task due to the influence of other factors such as the variation in geometry and material properties of steam generator tubes. To provide necessary information for the proper signal interpretation, the behavior of bobbin-coil ECT signal according to the changes in diameter, electric conductivity and magnetic permeability of a tube is investigated using a 2-dimensional finite element analysis program. This paper will describe the result of this model-based investigation.

Modeling of Magnetic Forces for Investigation of Magnetic Particles Around a Defect

---Junyoul Lee, Seong-Jae Lee, Yevgen Melikhov, David C. Jiles, Michael Garton, Rick Lopez, and Lisa Brasche, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

---Magnetic particle inspection (MPI) is a widely used nondestructive inspection method for aerospace applications, which until now has been essentially limited to experiment-based approaches. Reliable theory and modeling of magnetic particle inspection can identify factors that affect MPI characteristics and could have the potential for reductions in inspection design cost and time and for improvement of analysis of experimental data. The objective of this research is therefore to develop a software package for magnetic particle inspection simulations based on the use of the finite element method (FEM) to obtain estimated retained volumes of magnetic particles around defects with various sizes. Test materials for an MPI simulation were assumed to have isotropic ferromagnetic properties with reversible nonlinear permeability. The magnetic forces on magnetic particles at the site of a defect having different widths and depths have been simulated. We obtained the ratio between the estimated volume of retained magnetic particles around a defect and the volume of the defect by recently developed MPI-FEM algorithm. The relationship between this volume ratio and the geometry of the defect has been investigated. We observed the volume ratio increased monotonically as the defect depth increased while the ratio decreased monotonically when the defect width increased. The simulated results can be used to assist in understanding the behavior of magnetic particles under magnetic and gravitational forces around a defect.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA051 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Pulsed Magnetic Flux Leakage and Eddy Current Sensor For Crack Detection and Material Characterization

---Gui Yun Tian, Ali Sophian, and David Taylor, The University of Huddersfield, Queensgate, Huddersfield HD1 3DH, United Kingdom

---Using a pulsed eddy current sensor for crack detection and characterization in steel material inspection, a magnetization using permanent magnets is normally required. A feasibility study is conducted on the application of pulsed magnetic flux leakage (PMFL) and pulsed eddy current (PEC) inspection to crack detection and material characterisation for ferromagnetic materials. Rather than using a permanent magnet configuration, a ferrite-cored coil excited by a pulsed current is used. A Hall effect sensor is scanned the measurement region. Signals from the Hall effect sensor is processed and correlated with defects to determine corresponding PMFL signatures. Preliminary tests with specimens having naturally occurring defects indicate that the PMFL technique has excellent potential as an inspection method. This paper introduces the novel sensor design and the sensor structure. The design and construction of the sensor is introduced in the paper. The experimental results and conclusions are also reported in the end of the paper.

Crack Growth Characterization Using Barkhausen Noise Measurement

---H. N. Singh, P. Kotak, and K. C. Sahoo, Post Irradiation Examination Division, Bhabha Atomic Research Centre, Mumbai, 400085, India

---Progressive fatigue damage as a result of cyclic stress is caused by continuous change in the matrix of the materials. Evaluation of stress near the fracture surface in the critical components is of vital importance that can affect the fatigue life. The microstructural features like dislocation densities, microcrack, residual stress, etc. affect the magnetic property in the ferromagnetic materials. As a result of magnetoelastic interaction in materials with positive magnetic anisotropy (iron and most steels), compressive steels will decrease the intensity of Magnetic Barkhausen Noise (MBN) while tensile stresses increase it. MBN measurement was carried out on the Compact Tension (CT) specimen made out of advance Reactor Pressure Vessel (RPV) steel, which was subjected to crack extension by fatigue cycling at given mean load. A calibration curve for stress was generated for same RPV steel material by measuring the MBN parameter during uniaxial bending. Barkhausen Noise analysis technique was found to be effective in monitoring the progressive damage in ferromagnetic materials and show consistent trend throughout the fatigue crack growth in the material.

3D Finite Element Modeling for Simulating Remote Field Flaw Detection in Magnetic Steam Generator Tubes

---Ovidiu Mihalache, Kunihiko Yokoyama, Masashi Ueda, Takuya Yamashita, International Cooperation and Technology Development Center, ISI System Development Group,Japan Nuclear Cycle Development Institute, 1, Shiraki, Tsuruga-shi, Fukui-ken, Japan

---The remote field eddy current (RFEC) technique is a well-known method to detect corrosion in ferromagnetic tubes. The method can detect with equal sensitivity inner and outer defects in magnetic steam generator tubes of nuclear power plants. Until now the remote field eddy current technique has been studied using mainly analytical approaches or two-dimensional axisymmetric finite element modeling. In these cases the simulation results agreed very well with analytical solutions and experimental measurements. The three-dimensional finite element modeling has been successful only in case of non-magnetic tubes. In the case of magnetic tubes, however, the 3D RFEC simulations could not, until now, reflect the reality given by experiments. In this paper the authors report a successful three-dimensional simulation of the remote field effect, with application to the inspection of magnetic steam generator (SG) tubes in nuclear power plants. The precision required was obtained by using a second-order finite-element, and a very fine mesh in excitation, detection region and in the indirect coupling energy path. The 3D simulation results were compared with experimental measurements of outer defects signals in steam generator tubes. Very good agreement was obtained only in case of using a very high precision in the iterative solution.

Inverse Problem of Thermal NDT

---Oleg V. Lebedev and Vladimir G. Avramenko, Moscow State University, Physics Department, Technical Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, Lusinovskaya Street, 62, Moscow, 116162, Russia; Oleg N. Budadin and Elena V. Abramova, Technological Institute of Energetic Investigations, Diagnostic and Nondestructive Testing, Moscow, Russia

---The solution of inverse problem (IP) is depended on the solution of the direct problem in the following way: it is necessary to select parameters of the investigated objects that its calculated reaction is close as far as possible to its measured reaction. It is proved that the existence and the oneness of IP so extremum is presented. So IP of heat conductivity is reduced to the problem of minimizing the functional- root-mean-square deflection experimental and theoretical temperature time series. The searching of the minimum is based on modernizing gradient method. It is convenient to reduce the range of given system. It is achieved by the determination of the evident view of the functional from some parameters using boundary condition. Initial conditions in practice are not essentially due to its contribution in the total solution of nonstationary heat conductivity equation is reduced to zero after expiration of the characteristic time. Experimental or analytical determination of the dependence time series from thermalphysic parameters transforms the functional into the function relatively thermalphysic parameters. Usually time series are divided into time intervals of the characteristic time. The global minimum is determined on every time intervals with its own weight.

Leak Detection and Location in Long-Duration Spacecraft Using Structure-Borne Noise

---Ron Roberts and Dale Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Progress in the development of a method using leak-generated structure-borne noise to locate small air leaks in long-duration spacecraft, such as the International Space Station (ISS), is presented and demonstrated. Space debris and micrometeorites can penetrate the ISS pressure container, causing loss of air. Stopping a small leak is relatively simple, once its location is known. Because rack-mounted equipment and insulation mask the leak location, and because a leak into space vacuum produces almost no airborne ultrasonic noise in the spacecraft interior, a structure-borne noise solution is necessary. Source location using time of flight information contained in structure-borne noise signals is complicated by the multi-mode dispersive propagation characteristics of thin plate structures. Correlation-based triangulation methods do not perform well, because the underlying assumption that signals at two separate locations are time shifted replicas of one another is violated in the case of multi-mode dispersive propagation. This work is exploring the generalization of correlation-based source location to compensate for the effects of multi-mode dispersion. Array measurements are being tested which determine the propagation characteristics of the structure and isolate individual modes of propagation, while simultaneously determining source location. Experiments are examining several leak sizes in plates of different thickness. Noise signals are measured at remote locations using pinducer probes spatially scanned over receiver acquisition grids. Results demonstrating the underlying data analysis will be presented.---This material is based on work supported by NASA under award NAG-1-029-98.

Laser-Based Ultrasonic Tomographic Imaging of Power Metal Compacts

---Hongxin Bian, Yijun Shi, and Joseph L. Rose, Engineering Science and Mechanics, Pennsylvania State University, 212 Earth and Engineering Sciences Building, State College, PA 16802

---A new laser excitation system is used to obtain the cross-sectional tomographic images of density gradients of power metal compacts in the P/M industry. The work is used to improve the manufacturing process in leading to less severe density gradients in the compact, hence reducing the probability of crack formation and component failure. While the laser beam is used to excite ultrasonic energy, an air-coupled transducer is used for the reception of ultrasonic waves. An equiangular fans data collection pattern is exploited for image reconstruction of cylindrical compacts. This new system makes the data collection process non-contact, makes real-time monitoring possible, and also increases the full resolution area of the reconstructed images up to the outer edge of the compacts.

Guided Wave Helical Ultrasonic Tomography of Pipes

---Mark K. Hinders and Kevin R. Leonard, Applied Science Department, College of Wiiliam & Mary, Williamsburg, VA 23187-8795

---Ultrasonic guided waves have been used for a wide variety of ultrasonic inspection techniques. We describe here a new variation called helical ultrasound tomography (HUT) that uses helical guided ultrasonic waves along with tomographic reconstruction algorithms that have been developed by seismologists for what they call “cross borehole” tomography. In HUT, the Lamb-like guided waves travel the various helical criss-cross paths between two parallel circumferential transducer arrays instead of the planar criss-cross seismic paths between two boreholes. Although the measurement itself is fairly complicated, the output of the tomographic reconstruction is a readily interpretable map of a quantity of interest such as pipe wall thickness. We have demonstrated HUT via laboratory scans on steel pipe segments into which controlled thinnings have been introduced.

Toward Active Monitoring of Piping Using Ultrasonic Guided Wave

---Joon-Soo Park, Young H. Kim, and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; Jae Hee Kim and Heung Seop Eom, Korea Atomic Energy Research Institute, Daejon, Korea; Kwang-Hee Lim, Woosuk University, Cheonjoo, Korea

---Piping in nuclear power plants is exposed to severe environmental conditions so that it is very susceptible to failure caused by the growth of defects. Thus, it is necessary to have thorough inspection of piping in order to detect defects before failure. Unfortunately, however, inspection of piping in nuclear power plants is not easy in practice because of its long length as well as the radioactive environment. To take care of this difficulty, a research endeavor to develop techniques to monitor piping in nuclear power plants continuously and actively using ultrasonic guided wave is currently undertaken. Here, we will report the initial result of our endeavor. Specifically, investigation of the dispersive characteristics of piping and design of an ultrasonic array system for the monitoring piping will be discussed.

Performance Comparison of Conventional, Multi-Zone, and Phased Array Ultrasonic Inspection for 5" Diameter Ti-6Al-4V and Waspaloy Billets

---Waled Hassan, Honeywell Engines, Systems, and Services, 1944 E. Sky Harbor Circle N., Phoenix, AZ 85034; Andy Kinney and Joel Schraan, Honeywell Engines, Systems, and Services, 111 S. 34th Street, M/S 503-118, Phoenix, AZ 85034; Mike Keller, GE Aircraft Engines, Quality Technology Center, 10270 St. Rita Lane, Cincinnati, OH 45215

---The inspection of rotating components of aircraft engines has made important advances over the last decade. Improvements in transducers and inspection schemes have made it possible to find smaller defects under well-controlled conditions. For example, ETC Phase I and II programs included efforts in two approaches to billet inspection: (1) further development of fixed-focus, multiple transducer, zoned inspection - with the particular implementation being the Multi Zone (MZ) system developed by General Electric, and (2) initial feasibility studies of single transducer, Phased Array (PA), zoned inspection using an annular array. It is desirable to have a more quantitative comparison of the relative performance the currently available ultrasonic billet inspection techniques, namely, conventional (CON), multi zone, and phased array. In this study we present a quantitative evaluation and comparison based on SNR response extracted from C-scan images of the performance capability of these different inspection techniques on 5 in-diameter nickel and titanium alloys based engine rotor material. A 5 inch-diameter Waspaloy and Ti-6Al-4V billet reference standards having #1 and #2 FBHs at different depths have been inspected. For both materials we note that MZ and PA inspections perform, in general, significantly better than conventional inspection. In general, MZI and PAI perform at the same level with MZI performing slightly better than PAI for the Waspaloy standard. We also notice some degraded performance of the PA in the near surface zone can be attributed to the improper shape of the spherically focused center element of the probe.

Compensating for Attenuation Differences in Ultrasonic Inspections of Titanium-Alloy Billets

---F. J. Margetan and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Michael Keller, GE Aircraft Engines, 10270 St. Rita Lane, Cincinnati, OH 45215; Waled Hassan, Honeywell Engines, Systems, and Services, 1944 East Sky Harbor Circle N., Phoenix, AZ 85034

---Cylindrical billets of Titanium alloy are ultrasonically inspected prior to use in fabricating rotating jet-engine components. Although each billet has a cylindrical geometry, its ultrasonic properties are not cylindrically symmetric due to asymmetries in the process used to produce the billet from the original cast ingot. In the inspection process, a calibration standard of the same diameter containing flat-bottomed hole (FBH) reflectors is used to set the initial inspection gain (i.e., the signal amplification level). If the ultrasonic attenuation of the billet to be inspected differs significantly from that of the calibration standard, the inspection gain must be adjusted to maintain the desired defect detection sensitivity. In this paper we investigate several schemes for attenuation compensation. The gain adjustments fall into two broad categories: “global” adjustments (in dB/inch units), which are applied uniformly throughout the billet under inspection; and “local adjustments”, which vary with axial and circumferential position. The schemes make use of the patterns of reflected back-wall amplitude and backscattered grain noise seen in the calibration standard and test billet. The various compensation schemes are tested using specimens of 6”-diameter Ti-6Al-4V billet into which many FBH were drilled. The paper concludes with recommendations for improving billet inspection practices.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, and performed at Iowa State University’s Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

Ultrasound Excited by a Pulsed Thermal Source for Two Layers Sample

---J. He, X. R. Zhang, and J. C. Chen, Nanjing University, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China; Y. Y. Huang, and D. C. Xian, Chinese Academy of Sciences, Synchrotron Radiation Laboratory, Institute of High Energy Physics, Beijing, China

---We have calculated ultrasound excited by a pulsed thermal source distributed along the depth direction by dividing the distribution layer into many sublayers (sub sources), and considering the elastic properties for the sublayers are the same. Now, we consider the elastic properties for the sublayers are different. For simplicity, we suggest two-layer model for example. A pulsed ultrasonic waveform excited by a thermal source located at interface between laser irradiation layer (or film) and substrate. By using Laplce and Hankle transfers and Cagniard technique, we deduce approximate analysis expression and calculate the epicenter displacement of ultrasound. Investigation results show that: the waveform of displacement depends on the depth of the surface layer, the parameters of the two materials, such as the densities, elastic constants, etc., as well as the duration and the spot size of excitation beam. The higher the ratio of the velocities between the irradiation layer and substrate the larger the amplitude of the epicenter pulse is, and jump of the transverse pulse become flat. The shorter the thermal source the duration of ultrasound is the narrower, when the temperature increase and the sample thickness are fixed. The detail process, results, discussions and the comparison between this work and the sublayer model will be presented.

Development of New Robust High Power Ultrasonic Tone Burst Pulser and Receiver System

---Mark McKenna, Bruce B. Chuck, Arthur Bernier, Jr., Michael A. Ragosta, and Gary Petersen, RITEC, Inc., 60 Alhambra Road, Suite 5, Warwick, RI 02886-1442

---The increasing use of a variety of transducers is on-site industrial ultrasonic applications has increased the need for a more compact high power tone burst pulser coupled with a low noise receiver in a robust, environmentally secure, compact package. Typical spike pulsers are not sufficient to produce the high power outputs required for electromagnetic acoustic transducers (EMATs), magnetostrictive transducers and air-coupled piezoelectric transducers. The development of such a high power (with output powers in excess of 8KW RMS) pulser along with its companion low noise receiver will be discussed. Particular attention has been placed in the development of an environment tolerant packaging for the pulser/receiver. Some unique features include an isolated airflow for cooling where the environmental air is in contact only with heat sinks, and automatic shutdown for over-temperature and over-voltage conditions. The increased output power and increased duty cycle provides for faster data acquisition with an increased signal to noise ratio.

Development of a Fieldable Air-Coupled Ultrasonic Inspection System

---D. J. Barnard, J. J. Peters, and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This paper describes the development of a non-mechanically encoded, simple, field-worthy air-coupled ultrasonic scanning system that gives quantitative information about the size of damage and underlying structure in composite and aluminum aerospace structures. The system consists of the AIRSCAN® air-coupled ultrasonic testing system, the Flock of Birds® real-time motion tracking equipment, a lightweight composite yoke, a laptop PC and data acquisition and processing software. Through transmission C-scan images are generated manually by moving transducers attached to a yoke across the part's surface. The prototype has produced images for a variety of aircraft composite and metal honeycomb structures containing flaws, damages, and repairs. Field tests on commercial and military aircraft as well as rotor blades are planned. Test results will be shown.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D00008, Delivery Order No. IA047 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Improvements in Guided Wave Inspection by Using EMATs

---George A. Alers, EMAT Consulting, 1328 Tanglewood Drive, San Luis Obispo, CA 93401; Ron B. Alers and John J. Boyle, Sonics Sensors of EMAT Ultrasonics, Inc., San Luis Obispo. CA 93401

---Guided waves are proving to be very useful for inspecting large structures because they can cover large distances and scan large areas from a single transmitter/receiver pair of transducers. EMATs can make a valuable contribution to guided wave technology because: (1) they can be easily constructed in large sizes to operate at the long wavelengths that extend the inspection distance; (2) they can be made very mode selective so that Lamb and SH waves can be optimized for a specific inspection problem; (3) they can operate on raw surfaces in a field environment; (4) their ultrasonic beams can be scanned rapidly over an area to create a C-scan type map of flawed areas and (5) the ultrasonic beam can be focused to give enhanced sensitivity and resolution to a particular region of the structure. Examples of the application of these advantages to pipes as they enter or leave inaccessible areas will be presented and discussed.---Sponsored in part by the Pipeline Research Committee of the Gas Technology Institute.

Damage Assessment with Modern X-Ray Computed Tomography - Part I Overview of Defect Imaging and Analysis with XCT

---Joseph M. Wells, JMW Associates, 102 Pine Hill Blvd., Mashpee, MA 02649

---The detection, location and characterization of various defects within an opaque solid volume are of considerable engineering and quality assurance interest in many technological applications. However, destructive sectioning and polishing are expensive, time consuming and irreversible processes which precludes the further utilization of the subject object. Modern X-ray computed tomography techniques provide a unique nondestructive approach which creates a powerful 3D volumetric digital interrogation of substantial size engineering objects. Defects with significant density or x-ray absorption coefficient differences are discriminated, isolated and analyzed in situ and separately apart from the surrounding matrix material. Recent commercially available software packages now provide highly significant desktop PC capability in volume rendering, analysis and visualization of the interior structure details of irregular objects of engineering interest. A brief overview of current image reconstruction, visualization and both visual and quantitative defect analyses techniques is presented using selected examples. This sets the stage and prepares the audience to better appreciate the information presented in the subsequent talk -Part II, which specifically addresses the more detailed subject of the quantification of damage fraction in 3D.

Damage Assessment with Modern X-Ray Computed tomography - Part II Quantification of Damage Fraction in 3D XCT
---Joseph M. Wells, JMW Associates, 102 Pine Hill Blvd., Mashpee, MA 02649

---The capability of modern PC software to create much improved 3D tomographic images has greatly enhanced our ability to more fully visualize the complex nature of in-situ ballistic damage. Sectioning of 3D solid objects along any arbitrary 2D plane allows the observation of internal defects at any desired position. A more useful technological visualization capability is to virtually isolate the damage elements in situ and reconstruct the 3D transparent visualization thereof without including the obstructive opacity of the surrounding base material. Also, significant progress has been made recently in quantifying the amount of damage as a function of radius away from the center of the ballistic cavity on individual XCT scan planes and as a function of depth, as well as radius, through the target sample thickness along the projectile flight path. Examples of 3D plots of the unit damage function are presented for Ti-6Al-4V alloy samples impacted with a 12.7 mm APM2 projectile. The resulting 3D mathematical graphs reproduce the physical appearance of the structural damage quite well within the meso-scale limitations of the ~250 micron feature resolution level of the XCT scan data examined.

Quantifying Aging Aircraft Hidden Corrosion by Using Multi-Modal NDI
---Zheng Liu, David S. Forsyth, Saeed Safizadeh, and Abbas Fahr, Institute for Aerospace Research, National Research Council Canada, Montreal Road 1191, Building M-14, Ottawa, Ontario, K1A0R6 Canada; Brian A. Lepine, AECL, Inspection, Monitoring and Dynamic Branch, STN43, Chalk River Laboratories, Chalk River, Ontario, K0J 1J0, Canada

--- Multiple nondestructive inspection (NDI) techniques were employed to detect aging aircraft hidden corrosion. These techniques include conventional eddy current, pulsed eddy current, and ultrasonic testing. To quantify the inspection results, a function that maps the NDI measurements to the material thickness should be set up. Conventionally, a calibration curve is derived from the calibration procedure for each inspection method. To take advantage of the multiple NDI inspections, in this study, a generalized additive model was adopted to map multiple inspections to the material thickness loss. A back fitting algorithm was used to fuse the complementary information from the multiple inputs through the model. To show the efficiency of the data fusion approach, the results were compared with those from individual inspection methods. The specimen used in this study is a two-layer lap joint splice from a service-retired aircraft. The study will clarify: which individual inspection is most appropriate to characterize the top or the bottom layer corrosion and which combination of the inspections can achieve the best thickness estimation in terms of the presented approach for the two layers respectively.

Development of Continuing Education Courses for Nondestructive Evaluation—The Use of Tutorial Simulators

---Joe Gray, Iowa State University, Mechanical Engineering, Ames, IA 50011

---Nondestructive evaluation's (NDE) emergence over the last decade as an engineering function as increased the demand for continuing education courses. At the same time the increasing power and capability of engineering simulators in NDE developed at the Center for NDE at Iowa State University and other locations over the last ten years provide opportunity in education. Indeed, this is generally true in teaching engineering, namely, the expanding use by industry of complex computer models. Whether these computer models are finite element stress analysis, CAD, casting solidification models or NDE simulators, each is too complex to be incorporated into a class room environment. The use of these tools as demonstrations lacks the important interaction and student engagement that best communicates ideas. The problem is further compounded by the increasingly interdisciplinary nature of all engineering functions as practiced in industry and the need for all engineers to be more aware of the broad engineering environment that they work in. To utilize these sophisticated, engineering tools, we have developed a number tutorial simulators based on results from the complex simulators. The tutorial simulators are based on the physics in the engineering tools; however, they are trimmed to focus on a few variables or issues. The importance of these tutorial simulators is that they provide a means to bring the tools of modern engineering into the classroom without being overwhelmed by those tools complexity. They provide an important means for a student to receive the active feed back that is often lacking in illustrations, pictures or movies. We will present how we are developing these tutorial simulators and how we couple them with animations and other aids. This will be done in the context of the development of an MS degree program in NDE engineering now in development at Iowa State University.---This work was supported by the NSF Industry/University Cooperative Research program.

Development of a High-Resolution CT System and 3D Data Visualization Tool

---J. Zhang, C. Zhou, T. Jensen, and J. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The need for material characterization covers broad areas including new materials development, failure analysis, biomedical applications and process development and characterization. Length scales of 0.1 through 500 are of key importance to if processes are to be understood and a measure of control on those processes achieved. Computed tomography (CT) imaging of objects is increasingly important in that it can provide 3D information nondestructively about the internal features of interest. We present results from a recently developed CT system based on a 130 kVp microfocus tube, an amorphous Si array detector and a micro-stepped positioner. At present the highest resolutions available are voxel sizes of 4 microns with a field of view of 6 mm. The data volumes are several gigabytes and have 1400x1400x300voxels. Larger fields of view can be obtained at lower resolution. In generating these 3D data sets a number of issues need to be addressed including detector noise and artifacts, transfer of data from systems, efficient reconstruction of the large data sets, visualization of the data and finally, extraction of information from the data. Parallel processing for the CT reconstruction is implemented on a 64 node Linux cluster and provides reconstruction of a 3D volume in 30- 40 minutes A custom 3D visualization tool implements volume rendering on a PC and provides 3D viewing of the objects. Users have various functions such as histogram lookup table, mapping, region of interest clipping, normalization, and transparency to explore and interrogate the data. Examples from the CT scanning system will be presented.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #48 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

A Novel Denoising Approach Based on Multiresolution Thresholding and Its NDT Application

---Lingqi Li, Wei Cheng, Kazuhiko Tsukada, and Koichi Hanasaki, Department of Earth Resources Engineering, Graduate School of Engineering, Kyoto University, Kyoto, Japan

---Noise suppression, or denoising, is a permanent topic for engineering and applied scientists. It is particularly important in NDT field. In general, the NDT signal shows transient characteristics and the defect component varies in time. The conventional methods, such as Fourier analysis and filtering, and linear averaging can hardly reduce noise without losing the defect information. In this study, a wavelet-based multiresolution thresholding scheme is presented to enhance the signal-to-noise ration (SNR) of NDT signals. The proposed method compromises the wavelet soft (shrinkage) and hard thresholding techniques at different resolution levels. Our experimental results show its effectiveness on both noise removal and defect information preservation.

The Features Detection of the Small Rigidity Faults of Rotary Machine Elements

---Nadiya I. Bouraou, Yuriy V. Sopilka, and Anatoliy G. Protasov, Department for Nondestructive Testing,National Technical University of Ukraine "Kiev Politechnical Institute" (NTUU"KPI"), Kiev, Ukraine

---The efficient use of unidimensional amplitude discriminants as fault features are analyzed for the vibroacoustic diagnosis of small size fatigue cracks of the rotary system elements. The vibratory processes simulation and fault features detection are given. The features dependencies on generalized crack parameters are investigated at the Gaussian and non-Gaussian additive noise. The preventive Wavelet decomposition of the measured acoustical signal is used for sensitivity increasing of the above mentioned amplitude discriminants at the experimental investigation of a rotary system cracked element. The effectiveness of the two-level signal processing is shown with using acoustical signal radiated from the rotary system simulator at the stationary and non-stationary operation modes. The presented results are new and can be used for the non-destructive diagnosis and evaluation of a small fatigue crack of the rotary system element.

A Statistical Model for Eddy-Current Defect Signals from Steam Generator Tubes

---Aleksandar Dogandzic and Ping Xiang, Department of Electrical and Computer Engineering and Center for NDE, Iowa State University, Ames, IA 50011

---We propose a model for characterizing amplitude and phase probability distributions of eddy-current defect signals from steam generator tubes that can be used as an efficient feature extractor in a flaw classification scheme. The squared amplitudes and normalized phases of the defect signals are modeled as independent, identically distributed (i.i.d) random variables following gamma and beta distributions, respectively. We derive a maximum likelihood (ML) method for estimating the amplitude and phase distribution parameters from measurements corrupted by additive complex white Gaussian noise. Newton-Raphson iteration is utilized to compute the ML estimates of the unknown parameters. Finally, we apply the proposed method to analyze rotating-probe multi-frequency eddy-current data from tube inspection of a steam generator in a nuclear power plant. Initial results demonstrate the effectiveness of the proposed algorithm.
---This work was supported by the NSF Industry/University Cooperative Research program.

Flaw Detection in Correlated Noise

---Aleksandar Dogandzic and Nawanat Eua-Anant, Department of Electrical and Computer Engineering and Center for NDE, Iowa State University, Ames, IA 50011

---We present methods for detecting NDE flaw signals in correlated noise with unknown covariance. The proposed detectors are derived using the statistical theory of generalized likelihood ratio (GLR) tests and generalized multivariate analysis of variance (GMANOVA). To allow accurate estimation of the noise correlations, we incorporate "secondary" data containing only noise into the detector design. We consider parametric and non-parametric signal models and analyze the probability-of-detection performance under both scenarios. We derive probability distributions of the proposed test statistics under the null hypothesis (i.e., assuming that the signal is absent) and use the obtained results to design constant false alarm rate (CFAR) detectors. Numerical simulations demonstrate superior performance of the proposed methods compared with the detectors that neglect noise correlations. The proposed detectors will be applied to experimental NDE measurements, such as ultrasonic data containing strong backscattered grain noise.---This work was supported by the NSF Industry/University Cooperative Research program.

Comparative Study of Hardware and Software Methods for RF Signal Improvement

---G. Prodan, P. Petculescu, and Z. Remus, Ovidius University, Department of Physics, Mamaia Avenue, No. 124, Cod 8700, Constanta, Romania

---The most used method for hardware improvement of data acquisition of high frequency RF signal used by NDT, above 1 MHz in almost cases, is so called equivalent time sampling (ETS). In this paper we made a study of this method and a software algorithm of signal processing using attenuate sinus approximation. Applications of this study are given by results of material parameters determination, including velocity, attenuation, density and thickness for well known materials like steel (A1), Al, Si and Ge, at different probe frequencies : 2MHz, 4MHz, 6MHz, 8MHz , 10 MHz and 12MHz. This study includes a comparative study of statistics on RF signal for both methods, with SNR approximation and filters influences in signal evolution. Experimental data was taken using an integrated ultrasound system, from PAC with AD90 digital-to-analog converter, working at 32 MHz sampling rate and IPR100 for ultrasound pulser-receiver board. This system is integrated in 500MHz PC working under Windows ME software.

Residual Stress Assessment in Surface-Treated Metals by Laser-Ultrasonic Spectroscopy

---Alberto Ruiz and Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221

---Surface treatment methods are widely used in the aerospace industry to increase the damage tolerance of metal parts by producing a thin surface layer of compressive residual stress that prevents crack initiation and retards crack growth during service. Nondestructive evaluation of the prevailing compressive residual stress in the shallow subsurface layer is greatly complicated by the accompanying surface roughness and cold work effects. Surface acoustic wave (SAW) velocity spectroscopy is one of the best candidates for nondestructive characterization of surface-treated metals because of its ability to probe the material properties at different penetration depths via changing the inspection frequency. A high-precision laser-ultrasonic technique was developed to study the feasibility of SAW dispersion spectroscopy for residual stress assessment on surface-treated metals. A series of heat treatments were conducted to partially remove the residual stress and cold work on shot-peened aluminum 2024-T351 samples. This paper presents experimental data that indicates that the dispersion of the surface wave is affected by surface roughness, compressive residual stress, and cold work. Although surface roughness induced scattering provides a significant contribution to the observed dispersion of the SAW, our experimental data indicate that it is feasible to observe gradual changes in the SAW dispersion as the residual stress and cold work are removed by heat treatment.

Electromagnetic Detection of Stress Gradients at the Surfaces of Metals

---William F. Schmidt, University of Arkansas, Mechanical Engineering Department, Fayetteville, AR 72701; Otto H. Zinke, International Validators, Inc., 817 North Jackson, Fayetteville, AR 72701

---A general, integral expression is developed that relates measurements of the variations of the imaginary component of complex-reluctance with frequency to stress profiles near the surfaces of metals. The technique should yield residual stress profiles produced, for example, by heat-treating, metal-working, fatigue, or peening. It may even be applicable to carburizing. The technique of measurement cancels out the effects of any pre-treatment residual-stress profile (subject to the assumption of superposition). The general, integral expression is deduced from the results of measurements on a steel bar which is subjected to both axial tensile tests and bending tests.

Ferromagnetic Resonance Method for Residual Stress-Stain Monitoring

---B. Belyaev [1,2], Ya. Bulbik [1], A. Leksikov [2], and I. Kraus [3], [1]UNESCO Chair "New Materials and Technologies" at Krasnoyarsk State Technical University, Krasnoyarsk, Russia; [2]Institute of Physics, Siberian Division, Russian Academy of Sciences, Krasnoyarsk, Russia; [3]Czech Technical University in Prague, Czech Republic

---A mechanical and/or thermal treatment of metals, metal coatings deposition and other technologies leads to the surface and subsurface stress-strain origins or their redistribution. The surface state monitoring of a component during its spot check the optimal treatment technology can be selected. The stress-strain state of ferromagnetic materials influences on their local magnetic parameter changes that could be detected by the permalloy thin magnetic film (TMF) as a sensory element exposed to both the high-frequency electromagnetic and low-frequency sweeping magnetic fields applied tangentially to this sensory element. The high-frequency electromagnetic field is irradiated by a small hole on the external side of the microstrip resonator (MSR) that operates in a GHz range. The permalloy TMF having thickness of 0,1 mm and coercivity less 1 Oersted was used for this technology elaboration. Since the TMF volume is small, it almost does not disturb the external magnetic field dispersion during its monitoring on the test area with high accuracy (errors are about $\pm$ 0,01 Oe) and high locality (the hole diameter is equal to approximately 1 mm). The TMF is fixed and covers the hole so that the magnetization inversion in the sweeping magnetic field produces the microwave increased absorption due to the TMF's ferromagnetic resonance phenomenon. The MSR microwave oscillation's amplitude changes are picked by the conventional technique. The device arrangement and some experimental results are described.

Evaluation of Stress Distribution in Magnetic Materials Using a Magnetic Imaging System

---Chester C. H. Lo, Jason A. Paulsen, and David C. Jiles, Iowa State University, Center for NDE and 205 Metals Development, Iowa State University, Ames, IA 50011

---The detection of stress distributions in magnetic materials has been studied using a newly developed magnetic imaging system, which can be used to measure magnetic properties including hysteresis loop and Barkhausen effect signals while scanning the surface of a material. The system can convert the data into an image showing spatial variations in the magnetic and mechanical conditions of the test materials. In this work an s-shaped nickel sample, which was prepared by cutting two slots into a nickel plate, was used. Simulations of stress distribution using finite element modeling showed that by applying a tensile or a compressive stress along the central line of the sample, stress patterns of various degrees of complexity, such as pure shear stress or biaxial stress concentration, can be produced in different regions. It was found that under compressive applied stresses the measured images of hysteresis loop properties, such as maximum permeability and remanence, exhibited a pattern in close resemblance to the simulated stress distribution in which high levels of compressive stress were found around the end of the slot. The present result indicates that it is possible to evaluate surface stress distribution in magnetic materials by mapping magnetic properties using the magnetic imaging system.---This work was supported by the NSF Industry/University Cooperative Research Program.

Magnetic Nondestructive Investigation of Ferromagnetic Alloys Subjected to Stress and Fatigue

---Yevgen Melikhov, Chester C. H. Lo, and David C. Jiles, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Measurements of magnetic properties such as Barkhausen emission signal and hysteresis loops are promising techniques for nondestructive detection of service-induced structural changes in ferromagnetic materials resulting from mechanical causes, e.g. stress or fatigue. Nevertheless these measurements often require application of large magnetic fields to test pieces for good sensitivity. In this work we studied sensitivity of magnetic measurements to material degradation caused by stress or cyclic fatigue by increasing the amount of information collected. This includes measuring sets of symmetrical minor hysteresis loops using small applied fields without the need of magnetizing the material to saturation. Various ferromagnetic specimens, including Ni and ferromagnetic alloys Fe64Ni36, Fe55Ni45 and Fe54Ni29Co17, were subjected to tensile stress (up to the yield point) and cyclic stresses (up to the fracture point). Barkhausen signal and symmetrical minor loops were measured at various times during the tensile and fatigue tests. The experimental results were analyzed using the Preisach model formalism and Jiles-Atherton model, in order to identify parameters which better described the structural changes in the materials, and to establish inter-connections between Barkhausen emission signal, Preisach functions and mechanical and structural conditions of materials.---This work was supported by NSF and NATO under grant DGE-0108046 awarded in year 2001.

Optoacoustic Systems for Subsurface Materials Characterization

---Gopi N. Maguluri, Lei Sui, Ronald A. Roy, and Todd W. Murray, Aerospace and Mechanical Engineering Department, Boston University, 110 Cummington Street, Boston, MA 02215

---Optoacoustic imaging is a promising technique for the detection of subsurface optical inhomogeneities in optically turbid media. A pulsed laser is used to irradiate a sample volume where it is absorbed and causes rapid heating. Ultrasonic waves are launched through the thermoelastic effect and detected at the sample surface. The detected ultrasonic transients are related to the position dependent absorption coefficient allowing for imaging of the absorbed electromagnetic energy distribution. In this work, the use of optical interferometry for the detection of optoacoustic signals is explored using two detection schemes: a) a photorefractive crystal based interferometer and b) a Fabry-Perot sensor head which is coupled directly to the specimen. Optical detection of optoacoustic transients has several potential advantages over the use of contact transducers: optical systems are inherently broadband and can easily cover the useful frequency range for medical imaging, the optical source and receiver can be co-located on the specimen surface, and it is possible to fabricate optical array detectors using diffractive optics. Experimental results are presented demonstrating optical detection of optoacoustic transients in both homogeneous, absorbing tissue phantoms and optically turbid tissue phantoms. The measured optoacoustic signal profiles are compared to theoretical predictions and the absorption (homogeneous media) and effective absorption (scattering media) coefficients of the phantoms determined.

Signal Processing Numerical Simulation for Charge Transfer Sensors

---Y. Bulbik [1,2] and I. Chernykh [2], [1]UNESCO Chair “New Materials and Technologies” at Krasnoyarsk State Technical University, Krasnoyarsk, Russia; [2] Siberian Aerospace University, Krasnoyarsk, Russia

---Laminates made of the perfect, imperfect and lossy dielectrics are widely used, especially in the aerospace industry. These structures and components provide an urgent need for nondestructive evaluation (NDE) their physical properties mainly referred to the interface boundaries. Among diverse NDE tools that are available for interface boundary parameters NDE the electric field distribution sensing technology has been also developed. A relatively short duration of the test voltage pulse is applied to the high-potential electrode of the charge transfer (CT) sensor while its coplanar sensory electrodes are used to pick off the spatially-nonstationary electric flow distribution. Transient and quasi-stationary states of this flow distribution are inevitably accompanied by the electric field destabilizing effect mainly depending on the CT sensor contact conditions. This effect reduction can be reached by both the special CT sensor design and the corresponding signal processing. In the quasi-stationary mode of the CT sensor its reproducing electric flow distribution can be modeled by the charge simulation method. As for a transient mode of CT sensor operation the sensory electrode potentials have to be involved into the CT sensor signal processing numerical simulation. In this case the CT sensor signal processing simulation brings a new NDE facility due to the time-frequency mapping of the transient potentials. Some results related to the CT sensor transient charge and potential signals fusion are discussed.

Development of Piezoelectric Acoustic Sensors

---Anindya Ghoshal, National Council Research Associate, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, 3B East Taylor Street, Bldg. 1230B/Rm 190, Hampton, VA 23681-2199; William H. Prosser, Senior Scientist, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, 3B East Taylor Street, Bldg. 1230B/Rm 185, Hampton, VA 23681-2199; Benjamin M. Copeland, Materials Application and Integration Sec., NADA Langley Research Center, MS 386, 6a Langley Blvd., Bldg. 1232A/Rm 103C, Hampton, VA 23681-2199

---This paper looks at developing novel piezoelectric acoustic sensors, which are capable of sensing high frequency acoustic emissions and impact in a composite/metallic plate. The fabrication of the piezoelectric acoustic sensors made from piezoceramic ribbons would be described in details. An attempt was made to build directionality into the sensing system itself. Comparative results from these sensors with commonly available acoustic emission sensors would be presented. Novel signal processing algorithms based on bio-inspired neural systems for spatial filtering of large numbers of embedded sensor arrays in laminated composite media would also be presented. Both experimental and computational results would be compared to validate the models. It is expected that this present work would help in development of sensing techniques for highly efficient health monitoring of aerospace structural systems.

New Magnetostrictive Materials for Use as a Magnetic Stress Sensor for Nondestructive Evaluation

---Jason A. Paulsen, Andrew P. Ring, Chester C. H. Lo, John E. Snyder, and David C. Jiles, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

---Recently, there has been a search for an inexpensive and effective method for detecting stress levels for use in non-destructive evaluation of mechanical parts. In the previous studies, the use of a metal bonded cobalt ferrite material has been proven to be an excellent candidate material for magnetic stress sensor due to the magnetomechanical effect. Pure cobalt ferrite exhibits a large change in magnetization with a small change in stress levels, however it also produces some magnetomechanical hysteresis near room temperature, which creates some non-linearity. At elevated temperatures (above 60°C), this magnetomechanical hysteresis effectively disappears. A new manganese doped cobalt ferrite material that was recently developed exhibits a lower Curie temperature then the pure cobalt ferrite. This decrease in Cure temperature may decrease the magnetomechanical hysteresis at temperatures near room temperature. This will provide a new sensing material with a linear response and a large enough sensitivity to effectively act as an inexpressive stress sensor near room temperature. In this study, we will present some newly developed materials along with some of their magnetic properties that will help characterize their effectiveness as stress sensors.---This research was supported by the National Aeronautical and Space Administration (NASA) through the CNDE at Iowa State University.

SESSION 27

R. B. Thompson, Chairperson
BR A1

Discussion Session: "Future Applications of NDE Simulations"

---Over the last decade, the ability to simulate the results of NDE has made major strides. A number of tools now are available, in various stages of development, that can accurately predict the results of rather practical measurements made on parts with complex geometries and material properties. This session will provide a format for discussion of ways to best take advantage of this technical capability. Included will be considerations of how to most effectively couple to users, points in the life cycle of components when models can be most effectively used, the role of models is assessing trade-offs between various strategies for assuring reliability, and the role of models in documenting the economic benefits of NDE. Opening remarks by leaders in the field will be followed by general audience discussion of these new opportunities.

Friday, August 1, 2003

SESSION 28
ULTRASONIC ARRAYS AND APPLICATIONS
T. Gray, Chairperson
BR A1

8:30 AM **Phased Array Ultrasonic Probe Design: From Art to Science through Optimization Techniques**
---V. Lupien, 27 Eaton Street, Wakefield, MA 01880

8:55 AM **Designing of Phased-Array Transducers for Industrial Applications**
---P. Dumas, J. Poguet, and G. Fleury, Imasonic SA 15 rue Alain Savary, 25000 BESANCON, France

9:20 AM **Simulation and Application of Dynamic Inspection Modes Using Ultrasonic Phased Arrays**
---S. Mahaut, S. Chatillon, R. Raillon, and P. Calmon, DRT/LIST, Commissariat à L'Energie Atomique, CEA Saclay, Gif-Sur-Yvette, 91191, France

9:45 AM **Phased Array Beam Modeling Using a Discretely Orthogonal Gaussian Aperture Basis**
---R. A. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50014

10:10 AM ***Coffee Break***

10:30 AM **An Ultrasonic Array Wheel Probe**
---C. J. Brotherhood and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, University Walk, Bristol, BS8 1TR, United Kingdom; R. J. Freemantle, NDT Solutions Ltd., Dunston Innovation Centre, Dunston Rd., Chesterfield, S41 8NG, United Kingdom

10:55 AM **Inspection of Spot Welds Using an Ultrasonic Phased Array**
---F. Reverdy and D. Hopkins, One Cyclotron Road, Lawrence Berkeley National Laboratory, MS 46A-1123, Berkeley, CA 94720

11:20 AM **Ultrasonic Phased Array Inspection of Seeded Titanium Billet**
---J. Friedl and T. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; P. Khandelwal, Rolls-Royce Corporation, Indianapolis, IN; T. Dunhill, NDE Laboratory, Rolls-Royce plc., Bristol, United Kingdom

11:55 AM **Considerations for Using Phased Array Ultrasonics in a Fully Automated Inspection System**
---V. A. Kramb, R. B. Olding, J. R. Sebastian, W. Hoppe, D, Petricola, J. Hoeffel, D. Gasper, and D. A. Stubbs, University of Dayton Research Institute, Structural Integrity Division, 300 College Park, Dayton, OH 45469-0120

12:10 PM ***Adjourn***

Phased Array Ultrasonic Probe Design: From Art to Science through Optimization Techniques

---Vincent Lupien, 27 Eaton Street, Wakefield, MA 01880

---The design of specialized ultrasonic phased array probes is more complicated than for conventional ultrasonic probes. Parameters not found in conventional ultrasonics are the number of elements, element shape and element density. The shape of the overall probe, which in phased arrays is often nontrivial to enhance performance, is another design parameter not typically found in conventional ultrasound. The best design given a set of inspection goals is often made through an iterative process that involves as much intuition as modeling. It is often unknown in such cases whether the proposed design is truly optimal, or merely "good enough". A numerical optimization technique has been developed for designing probe shapes that finds the absolute minimum number of elements guaranteeing desired beam widths and inspection angles at specific points in the material. This tool helps eliminate the guessing in the probe design process for a certain class of problems. The success of the method suggests that similar approaches could be employed to develop a more general probe design environment.

Designing of Phased-Array Transducers for Industrial Applications

---Philippe Dumas, Jerome Poguet, and Gerard Fleury, Imasonic SA 15 rue Alain Savary, 25000 BESANCON, France

---By increasing inspection speed, and deflection capabilities of the transducers, phased-array technology has proved its interest to face new NDT challenges, and is becoming more and more popular in the main industrial fields of activities. Compare to single element transducers, phased array transducer specification requires to precise some specific parameters such as the number of elements, elements size or elementary pitch. The definition of these parameters must take into account : the kind of application, the using conditions, and to follow certain physical laws. Components used in the probe manufacturing have an effect on probe performances in term of geometric dimensions, centre frequency, pulse duration… the choice of these different components must be made in relation to specifications previously defined. This paper describes the main effects of specifications on transducer performances, and explains how to defined them. The second part speaks about the manufacturing step, showing the influence of component choice on performances. Several phased-array applications examples illustrating these considerations will be presented.

Simulation and Application of Dynamic Inspection Modes Using Ultrasonic Phased Arrays

---Steve Mahaut, Sylvain Chatillon, Raphaele Raillon, and Pierre Calmon, DRT/LIST, Commissariat à L'Energie Atomique, CEA Saclay, Gif-Sur-Yvette, 91191, France

---NDT techniques using phased arrays are more and more applied in different industrial contexts. Their main advantage is the adaptability to the testing configuration: ability to steer and to focus the beam inside the inspected component taking into account the geometry and the constitutive materials, high acquisition rates without raster scanning pattern of the probe using electronic commutation, sectorial scanning inspection to fully insonify the specimen, etc. Optimal use of phased arrays requires simulation tools accounting for the actual testing configuration. For several years, such tools are developed at the French Atomic Energy Commission. Delay laws, beam forming and echo formation (interaction of the beam with defects or specimen boundaries) models are used to design the arrays, to conceive and to evaluate the performances of methods in realistic and complex configurations. Recently, works have been made to extend the simulation skills to advanced dynamic inspection modes: electronic commutation with separate Transmission/Reception patterns, non-symmetric Transmit/Receive delay laws, sectorial scanning inspections. This paper presents some examples of simulation and application of such inspections carried out over complex specimen. These examples demonstrate the interest for simulation tools in terms of prediction, optimization and interpretation of phased arrays techniques.

Phased Array Beam Modeling Using a Discretely Orthogonal Gaussian Aperture Basis

---R. A. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50014

---Significant increases in computational efficiency have been recently realized using computational models based on gaussian beams. The gaussian beam is defined as having a gaussian cross-sectional profile at its focal plane, and is propagated in free space under the Fresnel approximation. Initially, a model for a piston radiator was presented by Wen and Breazeale using a set of gaussian beams as a basis. This work has been generalized by Margetan and others to model more arbitrary beam aperture geometries, and to consider transmission through curved interfaces. The gaussian beams used as the basis in these models do not display orthogonality, and the determination of basis coefficients is performed by an ad-hoc case-by-case optimization. This work presents a set of gaussian basis functions which display discrete orthogonality, whereby basis weighting coefficients are prescribed as simply the wavefield amplitude and phase derivatives at a discrete grid of points. Use of this basis greatly simplifies the modeling of complicated aperture geometries, such as the elements of annular sectorial phased arrays. When used in conjunction with ray theory-based Green function analysis, it is seen that the gaussian basis removes problems associated with focusing caustics in a simple fashion. This talk will introduce the basis functions, and present examples of application to phased array beam modeling for forging inspection.—This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

An Ultrasonic Array Wheel Probe

---Corin J. Brotherhood and Bruce W. Drinkwater, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom; Richard J. Freemantle, NDT Solutions ltd, Dunston Innovation Centre, Dunston Rd, Chesterfield, S41 8NG, United Kingdom

---This paper describes the development and modeling of an ultrasonic array wheel probe scanning system. The system operates at 10 MHz using a 64 element array transducer which is 50 mm in length and located in a fluid filled wheel. The wheel is coupled to the test structure dry, or with a small amount of liquid couplant. An aperture is swept along the array forming a B-Scan at each measurement position. When the wheel is rolled over the surface of the test structure a defect map (C-Scan) is generated in real-time. The tire is made from a soft, durable polymer which has very little acoustic loss. The rapid scanning is facilitated by an embedded PC which controls all of the functions of the array transmit and receive module as well as undertaking signal processing of the received waveforms. Two application studies are presented. Firstly, the inspection of sealant layers in an aluminum aircraft wing structure. Secondly, the detection of embedded defects in a thick section carbon composite sample. In both applications, the array wheel probe was found to produce C-scans of comparable quality to an immersion system with scanning times reduced by factors of 100-500.

Inspection of Spot Welds Using an Ultrasonic Phased Array

---Frederic Reverdy and Deborah Hopkins, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 46A-1123, Berkeley, CA 94720

---Decades of work in industry and research institutions aimed at development of nondestructive spot-weld inspection systems has not resulted in widespread adoption in the U.S. The most common methods for monitoring spot-weld integrity in manufacturing operations are physical teardown, during which spot welds are peeled. A size criterion is then used to determine if the remain of the peeled sample, called weld button, satisfies a minimal size. Destructive testing has several drawbacks including high costs associated with scrapped material, ergonomic injuries, and the time lag between the onset and identification of problems. In previous work, various NDE methods including x-ray, magnetic, laser-ultrasonic, ultrasonic guided waves, acoustic microscopy, resonance, and thermography have been employed to inspect spot-welded joints. None of these methods have been able to meet the stringent industry requirements for cost, ease of use, and accuracy. Ultrasonic phased arrays are an emerging technology that allows focusing, steering, and scanning of an acoustic beam without mechanical scanning. A judicious beam-forming strategy can be used to inspect spot welds and determine the size of the weld nugget, which is the criterion used in industry. The adopted beam-forming strategy will be described, as well as the signal processing technique used to evaluate welds.

Ultrasonic Phased Array Inspection of Seeded Titanium Billet

---Jon Friedl and Tim Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Pramod Khandelwal, Rolls-Royce Corporation, Indianapolis, IN; Tony Dunhill, NDE Laboratory, Rolls-Royce plc., Bristol, United Kingdom

---As part of efforts by Rolls-Royce to evaluate the use of ultrasonic phased arrays for inspection of titanium billets, a series of ultrasonic phased array inspections were performed at CNDE. The inspections were performed using a 5 MHz, 114-element, sectorial-annular array designed especially for 12 inch (305 mm) diameter titanium billet by RD-Tech and supplied to Rolls-Royce. The billet test piece is seeded with thirteen yttria (Y2O3) spheres, each 0.062 inch (1.58 mm) in diameter and located at successive depths ranging from 0.4 inches (10.2 mm) below the OD surface to just past the billet centerline. The phased array inspections employed both fixed-focus and dynamic-depth-focus (DDF) focal laws in conjunction with several depth gating schemes: a single long gate over the entire depth, short gates isolating individual reflectors, and gates as defined in the GE standard for Multizone inspections of 12-inch billets. Aperture and focal parameters were changed as a function of depth when using fixed-focus focal laws. Results include characterization of transducer performance and delay-time correction of imperfections, signal-to-noise measurements for the yttria spheres in the billet test piece, and effects of probe misalignment on flaw sensitivity.---This work was supported by the National Science Foundation Industry/University Cooperative Research Program at the Center for Nondestructive Evaluation, Iowa State University.

Considerations for Using Phased Array Ultrasonics in a Fully Automated Inspection System

---Victoria A. Kramb, Robert B. Olding, James R. Sebastian, Wally Hoppe, Dave Petricola, Jim Hoeffel, Dave Gasper, and David A. Stubbs, Structural Integrity Division, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120

---The University of Dayton Research Institute (UDRI) under contract by the US Air Force has designed and constructed a fully automated ultrasonic inspection system for the detection of embedded defects in rotating gas turbine engine components. The system performs automated inspections using the “scan plan” concept developed for the Air Force sponsored “Retirement For Cause” (RFC) automated eddy current system. Execution of the scan plan results in a fully automated inspection process producing engine component accept/reject decisions based on probability of detection (POD) information. Use of the phased-array ultrasonic instrument and probes allows for optimization of both the sensitivity and resolution for each inspection through electronic beamforming, scanning, and focusing processes. However, issues such as alignment of the array probe, calibration of individual element and overall beam response prior to the inspection have not been addressed for an automated system. This paper will discuss current progress in the development of an automated calibration procedure for various phased array apertures and specimen geometries. The results presented were obtained on the prototype inspection system, on engineered specimens containing various geometric targets and embedded defects.

SESSION 29

MATERIALS CHARACTERIZATION—MICROSTRUCTURE, STRESS

F. Margetan, Chairperson

BR A4

8:30 AM **Role of Pore Size Distribution in Ultrasonic Characterization of Microporosity in Aluminum Castings**
---B. Ghaffari, G. Mozurkewich, L. A. Godlewski, and J. W. Zindel, Ford Motor Company, Research and Advanced Engineering, MD 3083/SRL, P. O. Box 2053, Dearborn, MI 48121-2053

8:55 AM **Experimental and Theoretical Investigation of Ultrasound Propagation in Materials Containing Voids Inclusions**
---J. Takatsubo, National Institute of Advanced Industrial Science and Technology, Tsukuba-City, Ibaraki-ken, Japan

9:20 AM **Particle Size Determination of Solid Liquid Suspensions Utilizing Ultrasonic Backscattering: Theory**
---S. Ahmed and P. D. Panetta, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

9:45 AM **Particle Size Determination of Solid Liquid Suspensions Utilzing Ultrasonic Backscattering: Experiment**
---P. D. Panetta, B. Tucker, R. A. Pappas, and S. Ahmed, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

10:10 AM ***Coffee Break***

10:30 AM **Characterization of Retrogression and Reaging Heat Treatment of AA-7075-T6 Using Nonlinear Acoustics and Eddy Current**
---R. Anatulla[1], R. Ko[1], S. Sathish, and M. P. Blodgett, Metals, Ceramics, and NDE Division, Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45469-0120; [1]Structural Integrity Division, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120

10:55 AM **Investigation of Local Rayleigh Wave Velocity Dispersion Due to Surface Residual Stress**
---R. W. Martin and R. Reibel, University of Dayton, Research Institute, 300 College Park Drive, Dayton, OH 45469-0127; S. Sathish and M. P. Blodgett, Metals, Ceramics, and NDE Division, Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433

11:20 AM **On the Feasibility of Eddy Current Characterization of the Near-Surface Residual Stress Distribution in Nickel-Base Superalloys**
---M. Blodgett, Metals, Ceramics, and NDE Division, AFRL, Wright-Patterson Air Force Base, Dayton, OH 45432; P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221

11:45 AM **A Novel Inversion Algorithm for the Determination of Stress Gradients Using Ultrasonic Raleigh Wave Dispersion**
---P. Rajagopalan, Indian Institute of Technology Madras, Centre for Nondestruction Evaluation and Department of Mechanical Engineering, Chennai, TN, 600 03, India

12:10 PM ***Adjourn***

Role of Pore Size Distribution in Ultrasonic Characterization of Microporosity in Aluminum Castings

---Bita Ghaffari, George Mozurkewich, Larry A. Godlewski, and Jacob W. Zindel, Ford Motor Company, Research and Advanced Engineering, MD 3083/SRL, P.O. Box 2053, Dearborn, MI 48121-2053

---Microshrinkage porosity in cast aluminum plates was characterized utilizing the frequency dependence of ultrasonic attenuation caused by scattering from the pores. Measurements were made in pulse-echo mode in water with a spatial resolution of about 2 mm. An accurate measure of attenuation was obtained by comparing the specimen's back-surface echo with that from a pore-free reference specimen. The measured attenuation was fitted assuming various size distributions of spherical pores. The best fits were obtained for a lognormal distribution of spheres. Pore volume fraction inferred from these fits overestimates the actual volume fraction, determined from density measurements, by the same factor for all volume fractions. This factor is due to the complicated, nonspherical pore shapes and must be taken into account to obtain accurate values of porosity. The strong correlation (r2 = 0.97) between ultrasonic and density-derived volume fractions permits reliable, nondestructive laboratory measurements of porosity.

Experimental and Theoretical Investigation of Ultrasound Propagation in Materials Containing Voids Inclusions

---Junji Takatsubo, National Institute of Advanced Industrial Science and Technology,Tsukuba-City, Ibaraki-ken, Japan

---The non-destructive characterization of multiple embedded void inclusions forms an important part of the assessment of the integrity and quality of materials. In this report, we present an ultrasonic sensing method for detecting void inclusions. The idea is based upon the arrival probability of ultrasonic rays. When incident rays impinge on voids, they are diffracted around the voids to increase propagation time. We analyzed this phenomenon from a probabilistic view point, and found that the probability that ultrasonic rays will impinge on pores plays an important role in determining both sound velocity and waveform of arrival rays. On the basis of this theory, we derived the relational equations between void distributions (volume fraction and mean size) and ultrasonic characteristics (velocity and pulse width). Although this theory is very simple, it gives a reasonable explanation of the changes in both velocity and waveform. In order to examine the theory for its validity, we carried out ultrasonic tests using aluminum specimens with multiple drilled holes and ceramic specimens with artificial voids. The experimental results demonstrated the validity of this theory. We propose this method as a smart sensing technique for evaluating the integrity of materials containing multiple defects.

Particle Size Determination of Solid Liquid Suspensions Utilizing Ultrasonic Backscattering: Theory

---S. Ahmed and P. D. Panetta, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

---Rapid, on-line, non-invasive measurements of the particle size and concentration of moderate to highly concentrated slurries is required for the efficient process measurement and control for many processes. Methods based on ultrasonic attenuation can become inaccurate for non-dilute suspensions due to inadequate treatment of different mechanisms contributing to it. Further complications in using attenuation measurements arise because of 1) the necessity for careful transducer alignment and 2) high attenuation of ultrasonic beam in concentrated slurries. The backscattering measurement for characterizing solid-liquid suspension is attractive because viscous, thermal, and inertial effects have smaller contributions to backscattering than to attenuation. The effective medium approach of Spelt et al. has been applied here for the formulation of backscatter coefficient in liquid slurries. Computational results will be presented for the ultrasonic backscatter coefficients in liquid slurries over a range of concentrations.

Particle Size Determination of Solid Liquid Suspensions Utilizing Ultrasonic Backscattering: Experiment

---P. D. Panetta, B. Tucker, R. A. Pappas, and S. Ahmed, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

---Rapid, on-line, non-invasive measurements of the particle size and concentration of moderate to highly concentrated slurries is required for the efficient process measurement and control for many processes. High concentrations are often found in government applications such as waste remediation for the Department of Energy sites and in and industrial applications such as chemical and pharmaceutical manufacturing. However, existing methods based on ultrasonic attenuation can become inaccurate for non-dilute suspensions due to the complex interactions of ultrasonic waves with the constituents of the slurries. Further complications arise because of the necessity for careful transducer alignment. We are developing two measurements that help to overcome these difficulties, the ultrasonic backscattering and measurements of the diffuse field properties. The backscattering measurement is attractive because viscous, thermal, and inertial effects have small contributions to backscattering. Furthermore, the backscattering theories are simpler than attenuation theories and lend themselves to more stable inversion processes. In addition, the measurements of backscattering and diffuse fields do not require long travel distances and can be performed with a single transducer thus eliminating alignment problems. We will present ultrasonic attenuation and backscattering measurements on solid liquid suspensions at concentration up to 30 wt% with particle sizes ranging from 0.160 um to 50 um. Specific aspects of the ultrasonic measurements scale with both particle size and concentration. Where appropriate, experimental measurements will be compared with theatrical predictions.

Characterization of Retrogression and Reaging Heat Treatment of AA-7075-T6 Using Nonlinear Acoustics and Eddy Current

--Rajeshwar Anatulla[1], Ray Ko[1], Shamachary Sathish, and Mark P. Blodgett, Metals, Ceramics and NDE Division, Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45469-0120; [1]University of Dayton Research Institute, Structural Integrity Division, 300 College Park, Dayton, OH 45469-0120

---Nonlinear Acoustic Parameter and eddy current methods have been utilized to characterize heat treatment process of retrogression and reaging of aluminum 7075-T6. Samples held at a constant retrogression temperature of 195 °C for different time periods and then aged at a fixed temperature of 121 °C for 24 hours were used for measurements. The results of Nonlinear Acoustic Parameter measurement shows two distinct peaks at 30 min and at 45 min of retrogression time. Eddy current measurements on the same samples were performed using giant magneto resistance (GMR) sensor. The phase of the eddy current signal through the sample was measured as function of retrogression time. A minimum in the phase is observed in the sample retrogressed for 42 min. The changes in nonlinear acoustic parameter and the phase of the eddy current signal through the thickness of the samples are discussed on the basis of changes occurring during the heat treatment process. Application of combined methods for identifying the optimized properties in the material will be discussed.---Research sponsored by, and performed on-site at the NDE Branch, AFRL/Maerial and Manufacturing Directorate, Wright-Patterson Air Force Base, Ohio under the Contract #F33615-98-C-5217.

Investigation of Local Rayleigh Wave Velocity Dispersion Due to Surface Residual Stress

---Richard W. Martin, and Rick Reibel, University of Dayton, Research Institute, 300 College Park Drive, Dayton, OH 45469-0127; Shamachary Sathish and Mark P. Blodgett, Wright Patterson Air Force Base, Metals, Ceramics and NDE Division, Air Force Research Laboratory, Dayton, OH 45469-0120

---Residual stress induced in materials by surface modification techniques creates a stress gradient very near the top surface. The modified layer can lead to dispersion of Rayleigh surface wave (RSW) velocity. An analysis of the dispersion of RSW is expected to provide a means for nondestructive evaluation of the stress gradient. Small changes in RSW velocity, due to residual stress and the dispersion in the frequency range of 10-22 MHz, has been measured using an acoustic interferometer based on a three element focused transducer. Samples of Ti-6Al-4V subjected to surface modification techniques of importance in aerospace industry have been investigated. Results of RSW velocity and dispersion in shot peened, laser shock peened and low plasticity burnished samples are presented. The dispersion of RSW velocity caused by three different methods is compared. The potential of this method for nondestructive evaluation of the stress gradient in surface treated materials will be discussed.---Research sponsored by, and performed on-site at the NDE Branch, AFRL/Material and Manufacturing Directorate, Wright-Patterson Air Force Base, Ohio under Contract # F33615-98-C-5217.

On the Feasibility of Eddy Current Characterization of the Near-Surface Residual Stress Distribution in Nickel-Base Superalloys

---Mark Blodgett, Wright-Patterson Air Force Base, Metals, Ceramics, and NDE Division, AFRL, Dayton, OH 45432; Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221

---In light of its frequency-dependent penetration depth, the measurement of eddy current conductivity has been suggested as a possible means to allow the nondestructive evaluation of subsurface residual stresses in shot-peened specimens. This technique is based on the so-called electro-elastic effect, i.e., the stress-dependence of the electrical conductivity. Unfortunately, the relatively small (1-2%) change in electrical conductivity caused by the presence of compressive residual stresses is often distorted, or even completely overshadowed, by the accompanying conductivity loss caused by cold work and surface roughness effects. Recently, it was observed that, in contrast with most other materials, shot-peened Waspaloy and IN100 specimens exhibit an apparent increase in electrical conductivity at increasing inspection frequencies. This observation by itself indicates that in these materials the measured conductivity change is dominated by residual stress effects, since both surface roughness and increased dislocation density are known to decrease rather than increase the conductivity and the presence of crystallographic texture does not affect the electrical conductivity of these materials, which crystallize in cubic symmetry. Our preliminary experiments indicate that probably there exists a unique "window of opportunity" for eddy current NDE in nickel-base superalloys. We identified five major effects that contribute to this fortunate constellation of material properties, which will be reviewed in this presentation.

A Novel Inversion Algorithm for the Determination of Stress Gradients using Ultrasonic Raleigh Wave Dispersion

---Prabhu Rajagopalan, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, TN, India 600 036

---The measurement of Stress Gradients with Depth using an analytical ultrasonic Raleigh wave dispersion relationship inversion procedure is discussed in this paper. Ultrasonic Surface (Raleigh) waves become dispersive when propagating on non-uniformly stressed media. In the light of this, the Acoustoelastic effect on their propagation in deformed but initially isotropic materials has been investigated in the past, using an energy perturbation approach that considerably reduces the complexity in the treatment of the Acoustoelastic effect. Inversion of the perturbation relation offers an advantageous route to obtaining the stress gradients. This paper presents a new mechanism for effecting this inversion. Crucial use is made of the fact that Raleigh waves diminish rapidly beyond a depth equaling the wavelength, and the governing integral equation, a Fredholm Integral equation of the first kind, is reduced to a Volterra integral equation of the first kind. The conditions of the problem allow a further conversion into the more stable and tractable Volterra Integral equation of the second kind, which is easily solvable by conventional analytical or numerical iterative techniques. Preliminary simulation results for commonly occurring uni-axial and bi-axial stress profiles are presented.---This work was funded by the US Air-force Research Labs, Dayton, Ohio.

SESSION 30
EDDY CURRENTS
L. Udpa, Chairperson
BR A2

8:30 AM **Development of a 3D Electromagnetic Model for Eddy Current Tubing Inspection: Application to Steam Generator Testing**
---G. Pichenot, D. Premel, and T. Sollier, DRT/DECS/SISC/Electromagnetic Testing Laboratory, Commissariat a l'Energie Atomique, Gif-sur-Yvette, France; V. Maillot, ES/SAMS, Institut de Radioprotection et de Surete Nucleaire, Fontenay-aux-Roses, France

8:55 AM **Simulation of the Transient Eddy Current Response to Open Cracks**
---J. R. Bowler and F. Fu, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:20 AM **On the Apparent Loss of Eddy Current Conductivity Due to Surface Roughness**
---K. Kalyanasundaram and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221

9:45 AM **Numerical and Experimental Study of Eddy Current Crack Detection Around Fasteners in Multi-Layer Structures**
---J. S. Knopp, Nondestructive Evaluation Branch, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433-7817; R. T. Ko, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Drive, Dayton, OH 45469-0120; H. A. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706; J. C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031

10:10 AM ***Coffee Break***

10:30 AM **Eddy-Current Inspection of Cracking in Land-Based Gas Turbine Blades**
---H. Fukutomi and T. Ogata, Central Research Institute of Electric Power Industry, Materials Science Department, 2-11-1 Iwatokita, Komae, Tokyo 201-8511, Japan

10:55 AM **Processing Eddy Current Signals for the Detection of Deep Voids in Copper**
---T. Stepinski, Uppsala University, Signals and Systems, Uppsala, Sweden

11:20 AM **Massively Multiplexed Eddy Current Testing and Its Comparison with Pulsed Eddy Current Testing**
---D. J. Brown and C. M. Hils, Zetec, Inc., 1370 NW Mall Street, Issaquah, WA 98027; M. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:45 AM **Wireless Eddy Current Probe for Engine Health Monitoring**
---M. Reid, B. Graubard, R. J. Weber, and J. A. Dickerson, Iowa State University, Electrical and Computer Engineering Department, Ames, IA 50011; K. Smith and D. Raulerson, Pratt & Whitney, East Hartford, CT; L. Brasche, Iowa State University, Center for NDE, Ames, IA 50011; G. Y. Baaklini, NASA Glenn Research Center, Brook Park, OH 44142

12:10 PM ***Lunch***

Development of a 3D Electromagnetic Model for Eddy Current Tubing Inspection : Application to Steam Generator Testing

---G. Pichenot, D. Premel, and T. Sollier, DRT/DECS/SISC/Electromagnetic Testing Laboratory, Commissariat a l'Energie Atomique, Gif-sur-Yvette, France; V. Maillot, DES/SAMS, Institut de Radioprotection et de Surete Nucleaire, Fontenay-aux-Roses, France

---In nuclear plants, the inspection of heat exchanger tubes is usually carried out by using eddy current nondestructive testing. This technique, based on the analysis of changes in the impedance of one or more coils placed inside the tube, is used to detect and characterize possible flaws or anomalies in the tube. This contribution presents progress in developing a model in this context which has the capability to predict quickly the response of an eddy current bobbin coil to 3D flaws. This 3D computer code is based on a volume integral approach using the Green's dyadic formalism. 3D flaws, described as a local variation of conductivity, may vary by the shape, the size and the place in the tube's wall. This model is suitable to predict the probe response when it moves straight along the tube axis. It can also be used to quantitatively evaluate perturbation factors on the eddy current signal such as the probe wobble (off-axis response for a non-centered bobbin coil configuration). With an aim of integrating this model into the NDE multi techniques platform CIVA, it has been validated with experimental data for 2D and 3D flaws.

Simulation of the Transient Eddy Current Response to Open Cracks

---John R. Bowler and Fangwei Fu, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Calculations have been performed to determine the transient response of an eddy current probe due to an open subsurface crack in a plate. In previous work, the transient probe response due to an idea crack was calculated on the assumption that the crack had zero open yet acted as a perfect barrier to eddy currents. The computational aspects of the solution were based on an application of the boundary element method. The theoretical formulation of the problem has now been modified to take account of the fact that the crack may have a significant finite opening and the effects of the opening on the probe response have been investigated.---This material is based on work supported by NASA under award NAG-1-029-98.

On the Apparent Loss of Eddy Current Conductivity Due to Surface Roughness

---Keerthana Kalyanasundaram and Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221

---In light of its frequency-dependent penetration depth, the measurement of eddy current conductivity has been suggested as a possible means to allow the nondestructive evaluation of subsurface residual stresses in shot-peened specimens. This technique is based on the so-called electro-elastic effect, i.e., the stress-dependence of the electrical conductivity. Unfortunately, the relatively small change in electrical conductivity caused by shot peening is often distorted, or even completely overshadowed, by the apparent conductivity loss caused by the accompanying surface roughness. This geometrical artifact is due to the fact that as the frequency increases, and therefore the penetration depth decreases, the path of the eddy current must follow a more tortuous route in the material, which produces a reduction in the observed conductivity. This presentation focuses on the apparent reduction of the near-surface electrical conductivity measured by the eddy current method in the presence of surface roughness. The rough surface is modeled as a one-dimensional sinusoidal corrugation using the Rayleigh-Fourier method. The apparent conductivity is determined from the resulting change in the plane-wave reflection coefficient of the conducting half-space at normal incidence. In spite of the simplicity of the suggested analytical model, the obtained theoretical results are found to be in good qualitative agreement with recently published experimental data from shot-peened copper specimens.

Numerical and Experimental Study of Eddy Current Crack Detection Around Fasteners in Multi-layer Structures

---Jeremy S. Knopp, Nondestructive Evaluation Branch, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433-7817; Ray T. Ko, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Drive, Dayton, OH 45469-0120; Harold A. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706; John C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031

---In order to best manage the costs of the aging aircraft fleet, the United States Air Force has a need to detect corner cracks around fastener holes in multi-layer structures with the fasteners installed. Eddy current NDE has the advantage of being able to detect cracks in multi-layer structures even if air gaps are present between the layers. Previous work to address these problems using eddy current NDE has met with some success; however, several issues remain such as false call rates due to geometric factors. In this paper, a review of prior work concerning this problem is presented and a series of numerical and experimental studies investigating this problem are conducted. Using the 3D volume integral software package VIC-3D®, multi-frequency eddy current experiments are simulated to determine the influence of geometric defects on the eddy current system response. The volume integral method is a very efficient way to address the 3D features of the problems, and can be used as the basis for studying transient problems. These studies were found to provide insight into the sensitivity of eddy current inspection to variation in crack and part geometry.

Eddy-Current Inspection of Cracking in Land-Based Gas Turbine Blades

---Hiroyuki Fukutomi and Takashi Ogata, Materials Science Department, Central Research Institute of Electric Power Industry, 2-11-1 Iwatokita, Komae, Tokyo 201-8511, Japan

---There has been a growing need in the electric utility industry to assess the remaining life of blades in gas turbines. The need for life assessment technology is driven by a number of economic factors. It is quite important to nondestructively comprehend the depths of surface-breaking cracks for the life assessment and judgmental standards for extending life of blades. Eddy current testing (ECT) is very attractive because it offers both very high detectablity and high scanning speeds, however. It is not straightforward to apply a conventional ECT probe to blades having complex geometry. Flexible ECT array probes have been developed to overcome the major limitations of existing systems. The use of an array of sensors allows cracks of all lengths to be detected and will ultimately allow realtime data imaging to provide rapid inspection and easy interpretation. For this study using eddy current techniques, crack detection equipment was developed and applied to gas turbine blades for field use. By using this equipment, ECT data can be quickly taken at leading edges, and concave and convex sides of the blade mounted in a rotor after a turbine casing is removed.

Processing Eddy Current Signals for the Detection of Deep Voids in Copper

---Tadeusz Stepinski, Signals and Systems, Uppsala University, Uppsala, Sweden

---Sweden has developed the technology for long term storage of spent fuel from the nuclear power plants within. After the interim storage the fuel rods will be encapsulated in copper canisters. The canisters will be sealed by an electron beam (EB) weld and subsequently placed in a deep repository located in a bedrock. Assessment of the EB weld in the copper canisters requires means for detecting and sizing small voids located up to 4 mm under the surface. Eddy current (EC) technique for the detection and characterization of deep voids in copper is presented in the paper. Results were obtained using two specially designed multidifferential deep penetrating probes. The detection ability of the above probes was evaluated and compared using a specially designed sandwich specimen. The specimen was designed to simulate voids of different volumes (holes and slots), located in copper at different depths. It has the form of sandwich consisting of three layers: the upper layer simulating given depth, the middle layer consisting holes, and the bottom plate. To assure minimum air gaps between the plates a special system of air channels was manufactured in the upper layer and the base plate that enables pumping out air from the space between the plates using a vacuum pump. EC responses of the probes were acquired for a number of artificial voids with different depths and volumes using an automatic scanner. An automatic method for estimating phase angle of an EC pattern is proposed and verified. The method calculates the matrix of central moments and its eigenvectors for each EC pattern. It is shown that the detection of 1 mm artificial voids located at the depth of 4 mm is possible at the test frequency of approx. 700 Hz. It appeared that defect characterization is a relatively simple task consisting of two steps, estimating defect depth based on the phase angle of its response, and using EC amplitude for estimating defect cross section.

Massively Multiplexed Eddy Current Testing and Its Comparison with Pulsed Eddy Current Testing

---David J. Brown and Chris M. Hils, Zetec, Inc., 1370 NW Mall Street, Issaquah, WA 98027; Marcus Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This paper discusses the detection and presentation abilities of the Pulsed Eddy Current technique and the use of an Eddy Current instrument multiplexing 32 frequencies to simulate Pulsed Eddy Current results. Pulsed Eddy Current Testing has shown some definite advantages for the detection and characterization of discontinuities located deep within metallic structures. This is largely due to the application of an extended series of frequencies to the test piece and subsequent analysis using a time-based display. Recent advances in Eddy Current instrumentation have made available equipment with the capability of multiplexing large numbers of frequencies from which data similar to Pulsed Eddy Current may be obtained. This technique, herein referred to as Massively Multiplexed Eddy Current, has some evident advantages. It allows high-energy drive and wide dynamic range of signal acquisition at each of a large number of discrete frequencies. Individual frequencies may be independently selected over a wide frequency range.

Wireless Eddy Current Probe for Engine Health Monitoring

---Michael Reid, Ben Graubard, Robert J. Weber, and Julie A. Dickerson, Iowa State University, Electrical and Computer Engineering Department, Ames, IA, 50011; Kevin Smith and Dave Raulerson, Pratt & Whitney, East Hartford, CT; Lisa Brasche, Iowa State University, Center for NDE, Ames, IA 50011; George Y. Baaklini, NASA Glenn Research Center, Brookpark, OH

---The first prototype wireless eddy current (EC) probe for on-wing inspection was demonstrated in a F100 PW-220 engine without external cabling at the Air National Guard overhaul facility in Des Moines Iowa. Wireless NDE probes have potential safety and economic benefits leading to prevention or mitigation of safety significant propulsion system malfunctions. Two MHz EC data was transmitted using a dual-frequency, phase-modulated wireless analog communication system. Dual frequency bands were required to avoid frequency selective fading due to multi-path inside of the engine as well as frequency selective transmission stop bands resulting from microwave cavity configurations as a function of engine blade position. The signal from a sample blade placed between the 2nd and 3rd compressor stages was transmitted through the compressor and turbine stages. The receiver demodulated the radio frequency signal to recover the EC data. A PC-based data acquisition card digitized the signal at 5 MHz, 12 bits. PC software estimated the 2 MHz reference signal from the EC probe and detected notches on a sample blade. Notches down to 0.010” were detected by the system. This is comparable to the wired state-of-the-art EC technology currently used to inspect engines. The next steps are to decrease power consumption and improve system signal-to-noise ratio by implementing a digital spread-spectrum communications system on a 0.3 micron integrated circuit.---This work was performed by the Center for NDE and Electrical and Computer Engineering Department at Iowa State University and by Pratt & Whitney with funding from NASA Glenn Research Center under contract number NAS3-98005, task order number 21.

SESSION 31
SIGNAL PROCESSING
J. Michaels, Chairperson
BR A3

8:30 AM **Ultrasonic Detection of Cracks in a Complex Aircraft Structure Using a Local Correlation Method for Signals from a Moving Transducer**
---J. C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031; J. R. Mandeville, SAIC Ultra Image Int., New Londown, CT; C. V. Kropas-Hughes, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson, AFB, OH 45432

8:55 AM **Speckle Reduction and Edge Enhancement of NDE C-Scan Images Using ICA**
---C. H. Chen and X. Wang, University of Massachusetts Dartmouth, Electrical and Computer Engineering Department, 285 Old Westport Road, N. Dartmouth, MA 02747

9:20 AM **Application of Wavelet and Artificial Neural Network for NDT Flaw Classification**
---L. Q. Li, W. Cheng, K. Tsukada, and K. Hanasaki, Kyoto University, Department of Earth Resources Engineering, Graduate School of Engineering, Kyoto, Japan

9:45 AM **Compression of Noisy Ultrasonic NDT Image by Wavelet Based Local Quantization**
---W. Cheng, L. Q. Li, K. Tsukada, and K. Hanasaki, Kyoto University, Measurement and Evaluation Laboratory, Department of Earth Resources Engineering, Kyoto, Japan

10:10 AM ***Coffee Break***

10:30 AM **Wavelet Neural Network Based Data Fusion for Improved Thickness Characterization**
---P. Ramuhalli, Michigan State University, Nondestructive Evaluation Laboratory, Department of Electrical and Computer Engineering, East Lansing, MI 48824; Z. Liu, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, Canada

10:55 AM **Independent Component Analysis for Eddy Current Inspection of Steam Generator Tubing**
---B.-H. Shin, P. Ramuhalli, L. Udpa, and S. Udpa, Michigan State University, Nondestructive Evaluation Laboratory, Department of Electrical and Computer Engineering, East Lansing, MI 48824

11:20 AM **Real Time Implementation of Motion-Based Filtering in Magneto-Optic Imager**
---U. Park and G. C. Stockman, Michigan State University, Computer Science and Engineering, East Lansing, MI 48824-1027; L. Udpa, Michigan State University, Electrical and Computer Engineering, East Lansing, MI 48824-1027; W. Shih and G. L. Fitzpatrick, PRI Research & Development Corporation, 12517 131st Court Northeast, Kirkland, WA

12:10 PM ***Adjourn***

Ultrasonic Detection of Cracks in a Complex Aircraft Structure Using a Local Correlation Method for Signals from a Moving Transducer

---John C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031; John R. Mandeville, SAIC Ultra Image Int., New London, CT; Claudia V. Kropas-Hughes, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH

---A significant challenge in nondestructive evaluation is the ability to discern signals, originating from a crack and a geometric feature in a part, that are either closely spaced or superimposed in time. A case study is the ultrasonic inspection of C-130 beam cap holes, where a skewed riser, installed fasteners, and limited transducer accessibility result in fastener hole signals occurring at similar times-of-flight as near and far crack signals. To address this data classification problem, a novel feature extraction methodology is proposed where a series of signals from a moving transducer are first accurately aligned to the primary part signal feature and subsequently analyzed within multiple time windows for shifting signals associated with the crack. The local correlation method functions to detect the relative shift of signals in time for adjacent transducer locations due to echo dynamics from crack and part geometries that differ in shape and location. Feature extraction is then performed by applying an acceptance criteria for relative time shift and signal magnitude. Experimental and simulated studies were used to evaluate this methodology for the C-130 beam cap hole problem. Benefits of this method were demonstrated for both far and near crack detection problems under in-field conditions.

Speckle Reduction and Edge Enhancement of NDE C-Scan Images Using ICA

---C. H. Chen and Xianju Wang, University of Massachusetts Dartmouth, Electrical and Computer Engineering Department, 285 Old Westport Road, N. Dartmouth, MA 02747

---A novel speckle removal method for ultrasonic NDE images is proposed. Our method is based on Independent Component Analysis (ICA). Firstly, we use FastICA algorithm to estimate the basis images. Then a mixing transform of the original image is employed. In terms of the characteristic of NDE images, we assume that “speckle noise” and “true signal” come from different signal sources, or signal spaces, and use a classifier to classify these basis images. Based on the classification result, we design our nonlinear filter for each independent component and obtain restored image after a demixing transformation. Finally, we compare our method with median filtering and Wiener filtering. The experimental results demonstrate that the proposed method achieves a better performance improvement.

Application of Wavelet and Artificial Neural Network for NDT Flaw Classification

---Lingqi Li, Wei Cheng, Kazuhiko Tsukada, and Koichi Hanasaki, Department of Earth Resources Engineering, Graduate School of Engineering, Kyoto University, Kyoto, Japan

---Flaw classification is one of the most important NDT subjects. Such an inverse problem is usually solved using some advanced mathematical algorithms, such as finite element method (FEM), and bounded element method (BEM). However in NDT field, these numerical techniques suffer from a large amount of computational burden, difficulty to build a clear mathematical model, and unreliablity when the input NDT information is incomplete or inaccurate due to noise. In this research, artificial neural networks (ANN) combined with multiresolutional wavelet method is studied and investigated to deal with the NDT defect classification problem. The motivation arises from both the characteristics of ANN wherein it can treat this nonlinear relationship by its self-training ability with a training set and has low computational complexity, and the feasibility of wavelet to extract the feature sets buried in the noised NDT data. The NDT signals in our research are 2-D ultrasonic flaw images which are picked up from experimental specimen. Multi-layer perception (MLP) is extensively employed. Wavelet transform is performed to extract the feature sets at different resolutions based upon the flaw shape and orientation, and the back propagation (BP) algorithm is used to train MLP. The experiment results demonstrate that our method performs better to classify the ultrasonic flaw corrupted by large scale of noise, and that it also provides better accuracy than other methods based on Fourier descriptor (FD) and principle component analysis (PCA).

Compression of Noisy Ultrasonic NDT Image by Wavelet Based Local Quantization

---Wei Cheng, Ling Q Li, Kazuhiko Tsukada, and Koichi Hanasaki, Measurement and Evaluation Laboratory, Department of Earth Resources Engineering, Graduate School of Engineering, Kyoto University, Kyoto, Japan

---Compression on NDT image will bring about over-smoothness in the decompressed image due to the blur inevitably introduced in the compression procedure. Moreover, it will turn worse when the original image is noise-corrupted which is always the case in ultrasonic NDT. This image will turn to be even harder or useless in flaw detecting. To solve this problem, a compression method based on Discrete Wavelet Transform (DWT) that can also suppress the noise without introducing much compression blur, is presented in this work. Unlike the commonly used wavelet compression methods that apply entropy quantization to all the discrete wavelet coefficients (DWCs), there is a pre-processing to them before the quantization. A simple way named DWCs classification, exploiting the multi-resolution and interscale correlation property of DWT, is introduced first to classify DWCs as dominated by noise, signal or both. The compression method named local quantization is carried out at this stage. In this procedure, different quantization strategies are applied to the DWCs according to their classification and the local image variance of where they are. Based on the Human Visual System (HVS) property, it allocates the bit rate more efficiently to the DWCs thus achieve a higher compression rate. Meanwhile, in the decompressed image, it shows the effects of noise suppressed and flaw characters preserved.

Wavelet Neural Network Based Data Fusion For Improved Thickness Characterization

---Pradeep Ramuhalli, Nondestructive Evaluation Laboratory, Dept. of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824; Zheng Liu, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, Canada

---Corrosion in ageing aircraft lap joints is a serious problem for the aviation industry. While there are many methods to detect the presence of hidden corrosion, there is a lack of approaches that provide accurate quantification of the amount of corrosion (or equivalently, the thickness loss of the specimen). This is particularly so when the corrosion is in the second layer. Traditional approaches use a single inspection mechanism to test the sample, and use calibration methods to determine the thickness. This paper proposes the use of wavelet neural network based data fusion approaches for combining the information provided by multiple inspection techniques. Wavelet neural networks provide an approximation to the function mapping a given input to the corresponding output. The mapping is learnt by means of repeated presentations of data in a training data set. The neural network uses wavelet basis functions to form the approximation, using a smaller number of basis functions when compared to other neural network approaches such as the radial basis function and MLP neural networks. The proposed algorithm is applied to fusing data obtained from multifrequency eddy current testing and pulsed eddy current testing of ageing aircraft lap joints. In the experiments, lap joints from a service-retired airplane were inspected by conventional multi-frequency eddy current technique and pulsed eddy current technique. Thickness estimates for 1st layer are provided using traditional approaches, as well as with the wavelet neural network based data fusion approach. Moreover, the 2nd layer thickness is estimated with the proposed method. Initial results indicate that the proposed data fusion approach provides better thickness estimates than traditional approaches. The efficiency of the proposed approach can be seen from the experimental results.

Independent Component Analysis for Eddy Current Inspection of Steam Generator Tubing

---Byung-Hyuk Shin, Pradeep Ramuhalli, Lalita Udpa, and Satish Udpa, Nondestructive Evaluation Laboratory, Dept. of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---Multi-frequency eddy current testing (MFECT) is commonly used in the nondestructive evaluation (NDE) of steam generator tubing. In steam generator inspection, indications from defects are often buried in noise or signals from external support structures. In MFECT, linear mixing techniques are used for suppression of signals from supports, where the mix parameters are determined using simulated support signals at different frequencies. The disadvantage of linear mixing techniques is that the algorithm fails if the signals from supports are not similar to the signals used to generate the parameters. This paper proposes the use of independent component analysis (ICA) as an alternative for suppressing support signals while enhancing defect signals. Independent Component Analysis (ICA) is a statistical technique for separating a set of unknown sources from a set of observed signals. The measured data is assumed to be generated by some combination (linear or non-linear) of the sources. The sources are combined using a mixing matrix. The objective of ICA is to invert the unknown mixing system and reconstruct the source signals. In this application, three sources are assumed, namely, defect, support plate and noise. The set of observed signals is the eddy current data at multiple excitation frequencies. An affine transform is first used to transform all signals to a reference frequency signal. ICA is then applied to the transformed ECT data to estimate the signals from each of these sources. The proposed algorithm is applied to both simulated data generated using the finite element method as well as experimental data. Initial results indicate that ICA is capable of filtering out both the measurement noise and support plate indications, thus improving the defect signal-to-noise ratio (SNR).

Real Time Implementation of Motion-Based Filtering in Magneto-Optic Imager

---Unsang Park and George C. Stockman, Computer Science and Engineering, Michigan State University, East Lansing, MI, 48824-1027; Lalita Udpa, Electrical and Computer Engineering, Michigan State University, East Lansing, MI,48824-1027; William Shih and Gerald L. Fitzpatrick, PRI Research & Development Corporation, 12517 131st Court Northeast, Kirkland, WA

---The Magnetio-Optic Imager (MOI) is a relatively new Nondestructive Inspection Technique. The MOI produces analog images of the magnetic field associated with the eddy current on the surface and subsurface structures. However, the magnetic domain wall structure of the sensor adds a serpentine noise pattern to the MOI images, that degrades the inspection capability of the MOI. Among the various image-processing algorithms to reduce the noise patterns, our Motion-based Filtering algorithm represents an effective technique for removing the noise patterns and increasing the MOI inspection ability. The Motion-based Filtering algorithm separates structures and defects from the background noise by a multiple inter frame subtraction method. However, the Motion-based Filtering algorithm has been tested only on the post-inspection images and it needs to be implemented to run in real time. This paper presents the architecture and algorithm of Motion-based Filtering to meet the real time processing constraints. A detailed architecture and algorithm will be presented with the test results.

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